Nr. 16 - 2019

REPORT

NATURE-BASED SOLUTIONS

Landslides Safety Measures

Bjørn Kalsnes and Vittoria Capobianco

KLIMA 2050

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Klima 2050 Report No 16
Nature-based Solutions. Landslides Safety Measures
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Keywords: Landslide mitigation, nature-based-solutions, innovation, societal involvement
ISBN: 978-82-536-1638-4
Publisher: SINTEF Community, Høgskoleringen 7 b, PO Box 4760 Sluppen, N-7465 Trondheim
www.klima2050.no
Illustration front cover and page 3: Unsplash

Preface

This report presents an overview of Nature-Based Solutions (NBS) and their main applications to address climate-related challenges (temperature, floods, sea level rise, landslides, droughts) with a special emphasis on innovative physical measures for landslides mitigation

Klima 2050 - Risk reduction through climate adaptation of buildings and infrastructure is a Centre for Research-based Innovation (SFI) financed by the Research Council of Norway and the consortium partners. The SFI status enables long-term research in close collaboration with private and public sector, as well as other research partners aiming to strengthen Norway's innovation ability and competitiveness within climate adaptation. The composition of the consortium is vital in order to being able to reduce the societal risks associated with climate change.

The Centre will strengthen companies' innovation capacity through a focus on long-term research. It is also a clear objective to facilitate close cooperation between R&D-performing companies and prominent research groups. Emphasis will be placed on development of moisture-resilient buildings, stormwater management, blue-green solutions, measures for prevention of water-triggered landslides, socio-economic incentives and decision-making processes. Both extreme weather and gradual changes in the climate will be addressed.

The host institution for SFI Klima 2050 is SINTEF, and the Centre is directed in cooperation with NTNU. The other research partners are BI Norwegian Business School, Norwegian Geotechnical Institute (NGI), and Norwegian Meteorological Institute (MET Norway).

The business partners represent important parts of Norwegian building industry; consultants, entrepreneurs and producers of construction materials and technology: Skanska Norway, Multiconsult AS, Mesterhus/Unikus, Norgeshus AS, Leca AS, Skjæveland Gruppen, Isola AS and Powel AS. The Centre also includes important public builders and property developers: Statsbygg, Statens vegvesen, Jernbanedirektoratet and Avinor AS. Key actors are also Trondheim kommune, The Norwegian Water Resources and Energy Directorate (NVE) and Finance Norway.

Trondheim, august 2019

Berit Time
Centre Director
SINTEF Community

Summary

This report presents an overview of Nature-Based Solutions (NBS) and their main applications to address climate-related challenges (temperature, floods, sea level rise, landslides, droughts) with a special emphasis on innovative physical measures for landslides mitigation.

Nature-Based Solutions (NBS) is a collective term for solutions that are based on natural processes and ecosystems to solve different types of societal challenges. Of particular interest are mitigation and adaptation strategies to address climate-related challenges.

The aim of this report is to provide a brief introduction to NBS for addressing mitigation of natural hazards linked to extreme weather events. In particular, the report is focused on innovative solutions suitable for landslides protection in accordance with Work Package 3 (WP3) in Klima 2050, but it also includes elements relevant for flood and stormwater protection (WP2 in Klima 2050). The innovation potential relates to both technical solutions appropriate for private and public partners of Klima 2050, and to new solutions related to management, governance, training and communication, which may be most relevant to public partners.

In addition to discussing the use of NBS and describing examples of NBS to be used for climate related natural hazards, the report provides reference to key actors, important studies, and the potential for innovation, in Norway as well as internationally.

Norsk sammendrag

Naturbaserte løsninger (NBS) er et samlebegrep for å beskrive løsninger som er basert på naturlige prosesser og økosystemer for å løse ulike typer samfunnsutfordringer. Strategier for risikoreduksjon og tilpasning for å håndtere klimarelaterte utfordringer er av spesiell interesse.

Formålet med denne rapporten er å gi en kort introduksjon til NBS for håndtering av naturfarer knyttet til ekstreme værforhold. Spesielt er rapporten fokusert på innovative løsninger som er egnet for skredsikring i samsvar med arbeidspakke WP3 i Klima 2050, men rapporten inneholder også elementer som er relevante for flom- og overvannsbeskyttelse (WP2 i Klima 2050). Innovasjonspotensialet gjelder både tekniske løsninger som passer for private og offentlige partnere i Klima 2050, og til nye løsninger relatert til forvaltning, ledelse, opplæring og kommunikasjon, som kan være svært relevante for offentlige partnere.

I tillegg til å diskutere bruken av NBS og beskrive eksempler på NBS som skal brukes til klimarelaterte naturfarer, refererer rapporten til sentrale aktører, viktige studier og potensialet for innovasjon, både i Norge og internasjonalt.

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1 Introduction

1.1 Background

Nature-Based Solutions (NBS) is a collective term for solutions that are based on natural processes and ecosystems to solve different types of societal challenges. Of particular interest are mitigation and adaptation strategies to address climate-related challenges.

In Norway, one of the main effects of climate change will be more intense precipitation (Hansen-Bauer, 2015). This will lead to an increased probability for water-triggered landslides as well as floods with high destructive potential for exposed infrastructure.

In order to reduce the societal risk associated with climate change and enhanced precipitation, NBS can represent a sustainable, efficient and cost-effective approach. NBS have been increasingly applied to design new resilient landscapes and cities with beneficial outcomes for the environment, the society and human well-being.

A first milestone in the establishment of NBS was the World Bank's report *Biodiversity, Climate Change and Adaptation: Nature-Based Solutions from the World Bank Portfolio* (World Bank, 2008). In recent years, NBS has received increased attention, not least as a result of the European Commission (EC) investing considerable resources in building up European competitive advantage in this field. EC is today a leading capacity in the work of promoting NBS. EC has identified NBS as a priority area for research and innovation programmes and is actively engaged and investing in NBS-related projects to become a leader in developing new resilient sustainability-driven landscapes throughout Europe and the world.

1.2 Aims and objectives of the report

The aim of this report is to provide a brief introduction to the concept of Nature-Based Solutions for addressing climate-related challenges. In particular, this report is focused on innovative solutions suitable for landslides protection in accordance with Work Package 3 (WP3) in Klima 2050, as well as flood and stormwater protection that represent another relevant issue related to Klima 2050 project (WP2).

There is a high potential for innovation both on technical solutions appropriate for private and public partners of Klima 2050, and on solutions related to governance, management, training and communication, which may be most relevant to public partners. Klima 2050 is a center for research-driven innovation, and the use of Nature-Based Solutions represents the perfect field in which research goes hand in hand with innovation.

Nature-based solutions is a relatively new topic in international research, but it is receiving increasing attention. A main issue in that respect is related to how the solutions currently used on a small scale, can be upscaled to larger areas. The EC H2020 project PHUSICOS, which started in May 2018 - coordinated by NGI, is aimed at demonstrating that nature-based flood protection and landslide mitigation measures can be implemented in large rural areas exposed to natural hazards. The implementation of these solutions at specific demonstration sites will be supported by an innovative stakeholders participation through a Living Lab approach for the selection, design and assessment of the NBS, together with a governance innovation framework exploring financial instruments to enhance the effectiveness of the design and implementation of NBS. One of these demonstration sites in rural areas is the Gudbrandsdalen valley in Oppland, where NBS can represent a cost-effective and sustainable solution for flood and landslide protection. Since the PHUSICOS project is strictly linked to this topic, it can be an interesting arena for partners of Klima 2050 in developing new innovative solutions against natural hazards.

1.3 Definition of NBS

There are many different definitions of NBS. Many of them have been used in communication targeting policy makers, rather than scientists and technicians. Some of the definitions are listed in Table 1.

Table 1 **Definition of Nature-Based Solutions provided in the last few years**

Source	Definition	Reference
IUCN	Actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits.	Cohen-Shacham et al. (2016)
EC	Nature-Based Solutions are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes.	European Commission (2015)
EKLIPSE	Nature-Based Solutions (NBS) are solutions to societal challenges that are inspired and supported by nature.	Raymond et al. (2017)
Miljø-direktoratet (Norwegian Environment Agency)	Nature-Based Solutions are: • solutions that use or restore existing habitats and ecosystems; • solutions that are based on the use of nature	Menon Economics (2017)

Source	Definition	Reference
	(semi-natural solutions); • solutions that are most often categorized under blue-green infrastructure, and which can to a greater extent involve "nature-conserving" solutions, such as construction of stormwater dams, ditches, etc.	
OpenNESS	Operationally one can explore the scope of a 'nature-based solution' by unpacking the different elements in the concept, namely: **Nature:** as it relates to biodiversity at large, i.e. individual elements of biodiversity (gene pools, species, habitats, ecosystems), the functions that maintain them, and/or ecosystem services. **Nature-based:** as it refers to ecosystem management, including sustainable use and harvest, ecological restoration, biodiversity conservation and bio-engineering. **Solutions:** as it refers to interventions directed to a specific societal problem or issue that lead to beneficial outcomes. Inclusion of the idea of a 'solution' in the concept explicitly recognizes that people agree that there must be **a problem that needs to be solved**.	Potscin et al. (2016)
Natural Hazards Nature-based Solutions	Nature-based solutions basically cover the full scope of using ecosystems to address hazards, making use of natural processes and ecosystem services for functional	The World Bank – GFDRR – Deltares (https://naturebasedsolutions.org/)

Source	Definition	Reference
	purposes, such as decreasing flood risk, erosion, and landslide risk. Nature-based solutions can be completely "green" (i.e. consisting of only ecosystem elements), or "hybrid" (i.e. a combination of ecosystem elements and hard engineering approaches).	

Nesshöver et al. (2017) points out quite correctly that the definitions today are rather vague, which can lead to the dissemination of NBS being unnecessarily difficult. On the other hand, there is also a risk of over-simplification, and a vague definition may therefore be appropriate. It can be claimed that what a NBS is, depends entirely on the specific problem that one is dealing with.

1.4 Fields of application

A key result of the EU BiodivERsA project was the identification of three types of NBS interventions (Balian et al., 2014):

1. **Type 1**: Better use of existing ecosystems by minimizing the impact on the systems themselves;
2. **Type 2**: Modification of existing ecosystems to better deliver selected ecosystem services;
3. **Type 3**: Creating new ecosystems (eg by ecological engineering, green roofs etc.).

They pointed to a few selected areas (without being specific) where the use of NBS can be appropriate: *Natural hazard risk management, climate change mitigation, climate change adaptation, food production, water production, land, forest and land management.*

In its systematic review of a more practical use of NBS, Sutherland et al. (2014) classified the following fields of application: *Air quality, climate regulation, water regulation, erosion, water purification, disease regulation, pest control, pollination, natural hazards*.

Menon Economics (2017) made a study for the Norwegian Environment Agency related to climate adaptation in relation to the following fields: *Flood, stormwater, sea level rise and storm surge, landslide, precipitation, temperature and drought*.

In other words, NBS can have a wide scope of application, with some specific areas being very central to Klima 2050 (natural hazards, climate change, land management).

1.5 Benefits of using NBS

The use of NBS has several advantages beyond their primary goals, such as preventing natural hazards. IUCN (2017) points out the breadth of benefits the use of NBS can include: a) Increasing biodiversity; b) Long-term stability; c) Ecological management both "upstream and downstream"; d) Direct societal benefits; e) Local governance.

The report on NBS for climate adaptation provided by Norwegian Environment Agency (Menon Economics, 2017) states:" *Nature-based solutions often have more functions in addition to contribute to climate adaptation for the relevant climate challenge. They provide what we call additional benefit or positive additional effects, while traditional solutions often have only one function. The benefits can be environmental (for example, contributing to the recreation or conservation of biodiversity), social (for example, green lungs in urban areas) and / or economic (for example, by opening streams and other blue-green solutions can affect property prices in the area).* " Therefore, as a starting point for innovation, it can be useful to mention some direct or indirect positive consequences of facilitating nature-based solutions to the contexts that are of much interest for Klima 2050:

Physical consequences:

- Reduced probability for damage due to landslides and floods;
- Help in maintaining, even enhancing, the quality of ecosystems in the immediate vicinity of the measure through time;
- Increase recreation areas for local residents and thus increase their quality of life;

Societal and political consequences:

- Contribute to increased participation in local democracy;
- Improved municipalities or other public entities, ability to carry out major projects with great local interest and participation;
- Increase the societal awareness of sustainable solutions for a better future;
- Better communication between problem owner and user;

Economic consequences:

- Be economically advantageous, not least considering the future needs of maintenance;
- Stimulate innovative development;
- Contribute to participation by local business and local entrepreneurs;

2 Actors

Nowadays, many actors are dealing with NBS in different areas. A few key actors known by partners in Klima 2050 are mentioned below, grouped respectively in international organizations, international research, practitioners, international journals, and actors in Norway. Their related websites can be used to collect knowledge of specific innovative solutions, as well as to "get inspiration" from their own work in the development of nature-based solutions in Klima 2050.

2.1 International organizations

- **World Bank** (http://www.worldbank.org/)**.** A first milestone in NBS was the World Bank's report: *Biodiversity, Climate Change and Adaptation: Nature-Based Solutions from the World Bank Portfolio* (World Bank, 2008). The World Bank also issues guidelines for specific use of NBS, for example related to protection of coastal areas (World Bank, 2016).
- **International Union for Conservation of Nature, IUCN** (https://www.iucn.org/). IUCN was founded in 1948 and is headquartered in Gland, Switzerland. Members are states, government agencies, international non-governmental organizations / private institutions and national NGOs / private institutions. Norwegian institutions and organizations that were members in 2015 were the Ministry of Climate and Environment, the Norwegian Environment Agency, the University of Life Sciences and WWF Norway. Since 2013, NBS has been a prioritized program area for IUCN, focusing on the following themes: ecological restoration; ecological engineering; restoration of forest landscape; green infrastructure; natural infrastructure; ecosystem based management; ecosystem based adaptation; ecosystem-based restriction; ecosystem-based disaster risk reduction; climate adaptation services. The report made by Cohen-Shacham et al. (2016) entitled *Nature-based Solutions to address global societal challenges* also provides some practical case studies related to NBS interventions on the main themes mentioned above. At present IUCN is working on a Global Standard for NBS, to be issued in 2020.

2.2 International Research

- **EU – European Union**. NBS is a priority area for the EU. They have stated that they want the EU to become a world leader in the development of industrial and technological solutions "inspired, used, copied from or assisted by nature". The EU already has several programs related to NBS, such as the BiodivERsA program (http://www.biodiversa.org/), OpenNESS (http://openness-project.eu/) and EKLIPSE (http://www.eklipse-mechanism.eu/). Under the Horizon 2020 Research and Innovation programme, NBS has been declared a priority area for investment projects. Recent examples of EU programs are SCC-02-2016-2017 demonstration projects with NBS for climate and water quality in cities (2016) and NBS for inclusive urban renewal (2017); with the purpose of increasing the resilience of urban areas in the light of climate change effects, such as extreme temperature, pollution, wind, and drought. Furthermore, within the SC5-8-2017 demonstration projects on NBS for hydro-meteorological risk reduction in rural areas, NGI, as coordinator, was awarded the project 'PHUSICOS' (meaning 'according to nature' in Greek) (https://phusicos.eu/). Other projects awarded from the same call include

OPERANDUM (https://site.unibo.it/operandum/en) and RECONECT (http://www.reconect.eu/). A related EC project worth mentioning is NAIAD (http://naiad2020.eu/).

- **Alter-Net**. ALTER-Net (http://www.alter-net.info/) is a network of institutes from 18 European countries. ALTER-Net integrates research capacity across Europe by assessing changes in biodiversity, analysing the impact of these changes on ecosystem services, and informing decision makers and the public on a European scale. Originally funded by the EU Framework VI program to stimulate cross-border cooperation, ALTER-Net now operates independently and contributes to a continuous integration of Europe's research diversity dealing with biodiversity and the use of NBS.
- **AMAP**. AMAP (http://amap.cirad.fr/en/index.php) is a research center with participants from several French research units who physically reside at the University of Montpellier. They conduct basic research on plants and ecosystems. A grouping at this center (Community) led by Alexia Stokes works specifically with the influence of vegetation on slope stability.
- **CBBG, Arizona State University**. The Center for Bio-Mediated and Bio-Inspired Geotechnics (https://cbbg.engineering.asu.edu/) focuses on ecologically friendly, cost-effective solutions, inspired by nature, for the development and rehabilitation of robust and sustainable infrastructure systems. It serves as a connection for two trends in engineering: biological-based design and sustainability. They develop knowledge and systems in four areas: hazard limitation, environmental protection and restoration, construction of infrastructure, and transversal projects.
- **ThinkNature** (https://www.think-nature.eu/). ThinkNature project is under EC Horizon 2020 Research and Innovation programme and is executed by a consortium of 17 partners originating from 8 countries across Europe, led by the Technical University of Crete. The objective is to develop a platform that supports the understanding and the promotion of Nature-Based Solutions (NBS) with the main following goals: a continuous dialogue and interaction on nature-based solutions; a broad multi-stakeholder platform; steer dialogue through forums and debates; identify, communicate and promote successful nature based solutions; identify potential regulatory, economic and technical barriers; foster collaboration at multiple levels. This platform acts as an umbrella to create a synergy for all projects on Nature-Based Solutions funded by the EU H2020 program: Eklipse, Inspiration, NAIAD, Nature4Cities, Naturvation, Biodiversa, URBAN Green-UP, Unalab, GrowGreen, Connecting Nature, OPERANDUM, RECONECT and PHUSICOS.

2.3 Practitioners

- **Oppla** (https://www.oppla.eu/) aims to be a virtual hub where the latest thinking on ecosystem services and nature-based solutions is gathered from all over Europe. The web portal is open to everyone and will provide access to a wide range of resources. Oppla also organizes seminars where researchers, users and companies with innovative solutions can meet. Oppla has its own website for NBS products. Some of these are summarized below. Oppla distributes weekly newsletters by e-mail to those registered.
- **CIRIA**. CIRIA (https://www.ciria.org//) is an example of more practical research and development within NBS, which can also be an example of what

the supplier industry can offer. CIRIA is a British research center which (also) provides specific guidelines and technical details for the use of various NBS.

- **Natural Hazards – Nature-based Solutions** (https://www.naturebasedsolutions.org/). The Natural Hazards – Nature-based Solutions platform is a hub for projects, investments, guidance and studies making use of nature to reduce the risks associated with natural hazards. The objective is to host and facilitate the exchange of knowledge, experiences and lessons learned from a range of stakeholders, to provide guidance on the planning and implementation of nature-based solutions, and to champion these solutions in the arenas of policy-making and investment for disaster risk reduction. The guidance was developed and agreed upon by a group of leading international institutions who are engaged in designing, planning, financing and/or implementing nature-based solutions around the world. The platform was developed by the World Bank, the Global Facility for Disaster Reduction and Recovery (GFDRR), and Deltares.
- **Nature-Based Solutions Initiative** (http://www.naturebasedsolutionsinitiative.org/). This is a programme of research policy advice and education aimed at increasing the implementation of NBS through the application of science. Founded by the Oxford Martin School, NERC (Natural Environment Research Council of UK) and Oxford University in collaboration with core partners IUCN, IIED (International Institute for Environment and Development) and ICCCAD (International Centre for Climate Change and Development), the platform is aimed to gather all scientific information on NBS for climate change adaptation and make it more accessible to decision makers. The programme has recently launched an interactive bibliography for nature-based solutions to explore publications on different use of NBS for climate change adaptation, climate change mitigation, disaster risk reduction, ecosystem health, food and water security and human well-being and development.

2.4 International journals

In recent years many new international journals have been founded by experts and researchers with the objective of sharing new ideas or sustainable and innovative solutions for both policy makers and technicians for urban resilience and human well-being. A list of some of these journals are given below, with a short description of aims and purposes and some examples of recently published papers.

- **Solutions**. This is a non-profit online publication devoted to showcasing bold and innovative ideas for solving the world's integrated ecological, social, and economic problems. The journal brings the cutting edge ideas of academics and professionals in the field to an audience of policy makers, business leaders, and engaged members of the public. A selection of papers related to NBS includes:
  - Talberth, J. (2013). Green versus gray: Nature's solutions to infrastructure demands. *Solutions*, *4* (1).
  - Andersson, J., Arheimer, B., & Hjerdt, N. (2016). Combine and Share Essential Knowledge for Sustainable Water Management. *Solutions*, *7* (3), 30-32.
  - Johnson K. A., Piazza B. P., Fore J. D., Motew M., Yacobson E. (2018). Prioritizing Floodplains to Restore the Health of the Mississippi River Basin. *Solutions, 9 (3)*

  - Capon S. J., Palmer G. J. (2018). Turning over a new leaf: the role of novel riparian ecosystems in catchment management. *Solutions*, 9 (3)
  - McCormick D., O'Brien M. (2017). Flood Plain Wall. *Solutions*, 8 (2).
- **Environmetal Research** publishes original reports describing studies of the adverse effects of environmental agents on humans and animals. Among the fields directly related to the journal are; Air, soil, water pollutants and health; Global warming/climate change; Risk analysis, risk assessment and risk management; Public health; Water, wastewater management, and sewage. A selection of papers related to NBS includes:
  - Lafortezza, R., Chen, J., van den Bosch, C. K., & Randrup, T. B. (2018). Nature-based solutions for resilient landscapes and cities. *Environmental research*, *165*, 431-441.
  - van den Bosch, M., & Sang, Å. O. (2017). Urban natural environments as nature-based solutions for improved public health–A systematic review of reviews. *Environmental research*, *158*, 373-384.
  - Zölch, T., Henze, L., Keilholz, P., & Pauleit, S. (2017). Regulating urban surface runoff through nature-based solutions–An assessment at the micro-scale. *Environmental research*, *157*, 135-144.
  - Panno, A., Carrus, G., Lafortezza, R., Mariani, L., & Sanesi, G. (2017). Nature-based solutions to promote human resilience and wellbeing in cities during increasingly hot summers. *Environmental research*, *159*, 249-256.
- **Ecological Engineering**. The journal is meant for ecologists who, because of their research interests or occupation, are involved in designing, monitoring, or restoring ecosystems, and can serve as a bridge between ecologists and engineers. Specific topics covered in the journal include: Habitat reconstruction; Eco-technology; Synthetic ecology; Bioengineering; Restoration ecology; Ecology conservation; Ecosystem rehabilitation; Stream and river restoration; Reclamation ecology; Non-renewable resource conservation. A selection of papers related to NBS includes:
  - Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., ... & Hylin, A. (2017). Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management. *Ecological Engineering*, *108*, 489-497.
  - Van der Nat, A., Vellinga, P., Leemans, R., & van Slobbe, E. (2016). Ranking coastal flood protection designs from engineered to nature-based. *Ecological Engineering*, *87*, 80-90.
- **Sustainability** is an open access journal of environmental, cultural, economic, and social sustainability of humans. It provides an advanced forum for studies related to sustainability and sustainable development. A selection of papers related to NBS includes:
  - Pérez-Maqueo, O., Martínez, M. L., Sánchez-Barradas, F. C., & Kolb, M. (2018). Assessing Nature-Based Coastal Protection against Disasters Derived from Extreme Hydrometeorological Events in Mexico. *Sustainability (2071-1050)*, *10*(5).
  - Sutton-Grier, A. E., Gittman, R. K., Arkema, K. K., Bennett, R. O., Benoit, J., Blitch, S., ... & Hughes, A. R. (2018). Investing in natural and nature-based infrastructure: building better along our coasts. *Sustainability*, *10*(2), 523.

- Xing, Y., Jones, P., & Donnison, I. (2017). Characterisation of nature-based solutions for the built environment. *Sustainability*, *9*(1), 149.
- Santiago Fink, H. (2016). Human-nature for climate action: Nature-based solutions for urban sustainability. *Sustainability*, *8*(3), 254.

2.5 Actors in Norway (beyond KLIMA2050 partners)

- **Norwegian Environment Agency (Miljødirektoratet)**. (https://www.miljodirektoratet.no/). From the Norwegian public sector, it is primarily the Norwegian Environment Agency that has been active in NBS. In 2017, they announced a strategy for the use of NBS for climate adaptation, with the following questions: i) What is meant by nature-based solutions? ii) What climate challenges can nature-based solutions be effective in solving, and what measures can be used in connection with these different challenges? iii) How are the measures considered in terms of level of knowledge, efficiency, costs, limitations of use, etc.? iv) How are nature-based solutions compared with other technical solutions with regard to goal achievement related to the different climate challenges, and what positive and negative additional effects do these different solutions have for society? v) What examples are found on the use of nature-based solutions for climate adaptations in Norway related to different climate challenges? vi) What analyses, including cost-benefit analyses, exist that assess and describe planned or implemented measures using natural-based solutions in Norway? (and possibly foreign analyses if there are few Norwegian analyses). The assignment was carried out by Menon Economics in collaboration with NINA (below) and the consultancy Sweco. The report was completed in autumn 2017 (Menon Economics, 2017). Results from the report are summarized other places in this note. The Research Council of Norway has at present no research programs directly in the direction of NBS, although some of the existing programs may invite research within NBS (Byforsk, JPIClimate, Miljøforsk, Klimaforsk).

- **Norwegian Institute for Natural Research, NINA**. NINA (http://www.nina.no/) is an independent foundation that makes research on nature and nature–society interaction. NINA has 240 employees, with headquarter in Trondheim and departments in Tromsø, Bergen, Lillehammer and Oslo. They have useful expertise for NBS in the field of restoration, vegetation and pollution ecology, effects of nature interventions, impact assessments, environmental monitoring and biological diversity, and showcase projects on assisting energy companies and other builders to take care of nature when building.

- **Miljøkommune.no**. This website has been developed by the Norwegian Environment Agency for those who work with environmental issues in Norwegian municipalities. They have a separate page on the use of nature-based solutions in climate adaptation work in Norwegian municipalities (https://www.miljokommune.no/Temaoversikt/planlegging1/Miljohensyn-i-arealplanlegging/Klima/Klimatilpasning/). The webpage states that a number of measures of this type, which are able to counteract the effects of climate change, have to be introduced into land use planning. Border zones, streams and various nature-based solutions can help prevent damage and disadvantages related to the effects of the climate change

- **Norwegian county administrations**. Several Norwegian counties focus on the use of nature-based solutions in security measures, perhaps especially on the use of forests and vegetation as landslides protection measures. Oppland- (participant in PHUSICOS) and Hordaland county administrations can be mentioned as good examples.

- **NIBIO.** The Norwegian Institute for Bioeconomy (NIBIO) is likely the research organization in Norway, next to NINA, which has traditionally worked most in the fields that NBS targets (ecological management, ecosystem services). NIBIO was established on July 1, 2015 as a merger of Bioforsk, the Norwegian Institute for Agricultural Economics Research (NILF) and the Norwegian Institute for Forest and Landscape.

3 Use

3.1 Challenges

NBS has many fields of application in relation to different types of challenges and the NBS interventions strictly depend on the type of challenges that they are intended to address. The identification of the challenges is therefore a key point for many projects.

A EU project, EKLIPSE, selected 10 specific challenges related to the use of NBS (Raymond et al., 2017): 1) Climate resilience; 2) Water management; 3) Coastal resilience; 4) Green Space management; 5) Air quality; 6) Urban regeneration; 7) Participatory planning and governance; 8) Social justice and social cohesion; 9) Public health and well-being; 10) Potential for economic opportunities and green jobs.
The list contains a mixture of specific problem areas, administrative and social challenges as well as economic opportunities.

A study related to the use of NBS is summarized by Sutherland et al. (2014), in which a systematic assessment of a total of 296 specific NBS measures was carried out, with a view to a number of topics such as air quality, climate, stormwater, erosion, water purification, waste management, infection, diseases, pollination and natural damage to various ecosystems such as forest, wetlands, fresh water, beach zones, sea, agriculture and city. Most measures were proposed for the topics of erosion (56), natural hazards (47) and agricultural infection (45). Most measures for ecosystems were linked to agriculture (124), beach zones (53) and forests (45). Based on this study, it is possible to conclude that NBS can be used for a variety of problems and ecosystems. However, there are no conclusions related to the costs, the efficiency or the risk involved in implementing these NBSs. On the other hand, the study identified basic conceptual challenges that lie in the implementation of NBS and thus divided the decision-making process into six issues: 1) What environmental values are destroyed and over what scale? 2) Prioritization of problems and identification and understanding of hazards 3) Scanning of potential solutions (actions) to cope with hazards and restoring priority values 4) Collection and review of facts, 5) Management action 6) Monitoring efficiency.

Aarestad et al. (2015) pointed out that physical climate adaptation measures carried out in order to increase safety for people and societal values, often will be in conflict with natural values, as the measures can lead to degradation of nature and changes in ecosystem functions such as access to water and food. The measures that most likely affect nature are constructions in waterways made to limit flood damage, and Aarestad et al. (2015) claim that such measures may, in some cases, be counterproductive. Furthermore, they claim that flood protection measures in some cases can increase negative effects of floods in areas downstream of the river bed. Similarly, such measures will probably also affect the water-purifying capacity of the natural habitat. According to Aarestad et al., (2015) it is not necessarily the flood that is most detrimental to the ecosystems along the watercourses, but the flood-suppressing measures that change the dynamic nature of the river banks.

3.2 Examples of NBS and indicators

3.2.1 Physical NBS

Table 2 provides a number of main types of NBS that are in practical use today, within what is considered relevant for the Klima 2050's activities (primarily WP2 and WP3). The summary is based on the report from Menon Economics (2017) for the Norwegian Environment Agency (for Norwegian conditions), an article by Sutherland et al. (2014), and from the EU H2020 project Raymond et al., (2017). A list of more detailed proposals for NBS from the various sources is given in Appendix A.

Table 2 Relevant NBS main types

NBS related to	Hazards
Water, waterways, rivers and streams	Flood, erosion
Forest	Flood, stormwater, landslides/avalances, erosion
Vegetation, grass covering	Flood, erosion
Other vegetation	Flood, stormwater, erosion, landslides, sea level rise, drought, climate
Wetlands, floodplains, riverbanks	Flood, erosion
Edge vegetation	Flood, stormwater, erosion
Geotexiles	Flood, landslides, erosion
Rainwater collection/management	Stormwater, drought
Green roofs and walls	Stormwater, temperature, climate
Waterbodies and permeable covers	Stormwater
Drainage	Stormwater, landslide
Forest and vegetation near to the sea and coast	Sea level rise, storm surge and tsunami
Soil walls/dikes/dunes	Sea level rise, storm surge and tsunami
Hybrid (beach park) and natural habitat solutions	Sea level rise, storm surge and tsunami
Soil mass movement	Landslides
Drougth tolerant and fresh vegetation	Drought
Forest/land management/ use of fire	Wildfire
Re-naturalization of grey infrastructures	Temperature, climate, air pollution
Building green areas	Temperature, climate, air pollution
Open water surface	Temperature, climate, air pollution
Building green areas, establish climate-resistant vegetation	Temperature, climate, air pollution

3.2.2 Online data platforms of NBS

Among the on-going and completed projects related to NBS, open source data platforms gathering all the several implemented solutions within the Disaster Risk Reduction contexts are available. They represent an inventory of NBS addressing climate-change and the associated hydro-meteorological hazards at different scales and social contexts (rural or urban).

The PHUSICOS project developed its own data platform based on eigth identified existing data platforms by only focusing the attention on the NBS related to extreme hydro-meteorological events in rural and mountainous landscapes. Seven solutions aimed to address the landslide-related risk were identified, see Table 3. The data platform will be updated periodically.

Table 3 Implemented landslide-related NBS in PHUSICOS inventory

Case study name	Description	PHUSICOS link
Tree Planting Counters Landslides and Erosion in Kazbegi	Rock-filled gabions and trees to reduce landslide and erosion hazard in the natural reserve	http://phusicos.brgm-rec.fr/en/fiche-solution/516
Forest to protect the road from rockfall : the Fuorn Pass road, Engadin Region, Switzerland	Forest protection has been demonstrated to be sufficient against rock fall, without need of grey protection measures (rockfall nets)	http://phusicos.brgm-rec.fr/en/fiche-solution/495
Forest protection in the region Pinzgau (Austria)	Forest protection against natural hazards in alpine settings	http://phusicos.brgm-rec.fr/en/fiche-solution/509
Ecosystem-based erosion control in Azerbaijan	Afforestation, orchard management and other erosion control measures were adopted on degraded pastures to reduce surface erosion	http://phusicos.brgm-rec.fr/en/fiche-solution/512
Integrative Forest Management, Tadjikistan	Sustainable forest management to reduce natural hazards in degraded areas, with active roles from individuals on the land use	http://phusicos.brgm-rec.fr/en/fiche-solution/513
Assessing the interaction between mountain forests and snow avalanches at Nevados de Chillán, Chile and its implications for ecosystem-based disaster risk reduction	Conservation of regional native forest as Eco-DRR protection measure against snow avalanches, rockfalls and shallow landslides	http://phusicos.brgm-rec.fr/en/fiche-solution/510
Lovstien Nature Trail, Bergen, Norway	Nature trail with high tolerance against runoff and landslide	http://phusicos.brgm-rec.fr/en/fiche-solution/507

On Oppla's website there is also a presentation of climate-related NBS products such as demonstrations, guidelines, factsheets (https://oppla.eu/marketplace) useful for implementation and management of NBS in different fields of application. A brief presentation of the main climate-related products is given in Table 4.

Table 4 Relevant climate-related NBS products available on Oppla website

Product	Hazard type	Brief description	Link
Sustainable Water Management - Treatment Wetlands Design	Flood, Stormwater, Climate	Nature-based solutions like constructed/treatment wetlands, can play an essential role for the water pollution control at urban scale and for reducing the flooding risk while providing positive effects on biodiversity, social acceptance and economics.	https://oppla.eu/product/2029
Green Values	Climate	Guidelines to identify, measure and articulate the multifunctional benefits of urban green infrastructure (UGI) projects in order to support the development of cohesive business cases and to inspire project initiators to refine their projects to yield wider benefits.	https://oppla.eu/product/17504
Living Walls	Climate	Guidelines for implementing multi benefit vertical green infrastructure with living plant constructions (suitable for difficult urban locations, short time frames).	https://oppla.eu/product/17506
Green Infrastructure, a wealth for cities - URBES (Urban Biodiversity and Ecosystem Services) Factsheet #6	Climate	This URBES factsheet outlines the key components of Green Infrastructure and explores the linkages between the EU Green Infrastructure Strategy and the urban context. Using examples from Barcelona, it presents how cities can use Green Infrastructure to tackle environmental, social and economic challenges, while also becoming more resilient to climate change, improving quality of life, saving money, and strengthening the local economy	https://oppla.eu/product/2087
Urban agriculture - URBES Facthseet #7	Climate	This factsheet will explain the importance of urban agriculture: the ecosystem services that urban agriculture provides for human wellbeing, food security and urban resilience; and the need for integrated planning across sectors to ensure that the ecosystem services that urban agriculture provides can proliferate	https://oppla.eu/product/203

Product	Hazard type	Brief description	Link
OpenNESS Synthesis paper: Green infrastructure	Climate	Considering the overall goals of the OpenNESS project and its variety of case studies, it is important to have a clear idea about how the concept of green infrastructure can be operationalised in practice, despite its inherent conceptual complexity and ambiguity. The concept of Green Infrastructure (GI) is gaining political momentum and has been rapidly introduced in both planning theory and policy, especially in US and Europe. Yet, it does not have a single widely recognised or accepted definition	https://oppla.eu/product/2049
Green Infrastructure Valuation Toolkit	Climate	A toolkit for valuing the benefits of green infrastructure, consisting of a spreadsheet calculator and a user guide. Monetary and non-monetary values are calculated, generally using a benefits transfer approach. Can be used either to value a planned intervention, or existing green infrastructure.	https://oppla.eu/product/1973
LANDPREF - Interactive tool to assess and visualise land use preferences	Climate	LANDPREF is a novel tool to assess desired land use visions. It enables the adjustment of a virtual landscape according to personal preferences of competing land uses, and is an interactive tool for the survey-based assessment of land use preferences. It allows the respondents to interactively combine competing land use options at different intensity levels to an overall desired land use. The combination of land use options is restricted based on current state of the knowledge and practice guidelines and requires respondents to make explicit trade-offs. LANDPREF has originally been designed for the Pentland Hills case study and has since been adapted and applied in other surveys.	https://oppla.eu/product/2099

Moreover, the Oppla platform comprises a database of several case studies of NBS applications around the world, dealing mostly with extreme rainfall, stormwater and flood hazards. A selection is listed below:

- GIZ ValuES - Combining flood protection and habitat restoration, USA (https://www.oppla.eu/casestudy/17595)
- Nature-Based Stormwater Management (https://www.oppla.eu/casestudy/17562)
- CONFLUENCE Project: Creating a Periurban Park in Prague
- Bilbao - NBS for dealing with extreme temperature and rainfall events (https://www.oppla.eu/bilbao-nbs-dealing-extreme-temperature-and-rainfall-events)
- Brague DEMO: Flash flood and wildfire hazards in a Mediterranean catchment (https://www.oppla.eu/casestudy/18475)

3.2.3 Indicators

One way of evaluating the effect of NBS is the use of indicators. In the EKLIPSE project, the use of indicators has been specifically investigated (Raymond et al., 2017). For each challenge area, the report presents a small number of representative examples of indicators that are considered important for assessing key impacts of specific NBS measures. It also identifies a number of methods for assessing each indicator. These indicators can be economical (direct saving, reduced need for energy, jobs, etc.), environment-related (nutrients, energy needs, carbon emissions, biodiversity etc.), social/psychological (local awareness, access to green areas, security, local democracy etc.).

The identification, the use and the evaluation of indicators for NBS performance assessment represent a core part of the ongoing EC H2020 project PHUSICOS, coordinated by NGI. The main subject for PHUSICOS is the reduction of risk from extreme weather events, such as floods landslides and drought, in rural mountain landscapes. The indicators are aimed at estimating the benefits of NBS (or hybrid solutions) during the whole process (from baseline to the long-term scenario) in relation to the 5 principal ambits: Risk reduction, Technical feasibility, Environment and ecosystem, Society and Local Economy (Figure 1).

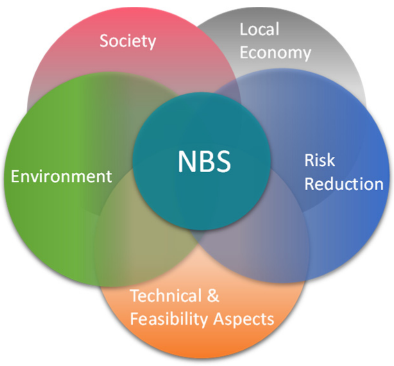

Figure 1. The PHUSICOS project's scheme of main ambits that can be affected by NBSs.

One of the objectives of this part of PHUSICOS is the standardization of the approach for NBS evaluation, independently on the type of risk and the type of rural areas they are dealing with. The PHUSICOS **Framework Tool for Nature Based Solutions (NBSs) Assessment** is the starting point for the assessment of different risk mitigation measures that can be adapted to the local context.

NBS performance assessment will be carried out for the demonstration sites selected respectively in Italy, Spain-France (Pyrenees) and Norway (Oppland region). These areas are representative of different risk types (Italy: drought, flood; Pyrenees: flood, landslides; Oppland, Gudbrandsdalen valley: Flood, landslides) and different contexts around Europe.

3.3 Hybrid solutions

NBS is often referred to as green, blue or blue-green solutions, as opposed to traditional engineering solutions that are often referred to as grey solutions. Green / blue solutions usually consist of materials that are degradable or consist of organic materials (typically vegetation). Grey solutions often consist of materials that are not degradable. In many cases, however, NBS will not be sufficient as safety measures. In these cases, a combination of NBS and traditional solutions, so-called grey-green solutions or hybrid solutions, can be a suitable alternative. Much of today's research on NBS is aimed at identifying in which contexts NBS will function adequately, and in which contexts traditional solutions must also be included in order to achieve adequate safety. An example is provided by the flood protection measure implemented in the Upper Vistula river basin in the Sandomierz area of southern Poland. First green measurements consisted in a re-naturalization of reservoirs and wetland restoration implemented in 15 locations along the Upper Vistula River and aimed to increase the controlled water retention capacity of the area. Then the green measures were combined with grey solutions: expansion, reconstruction and modernization of river embankments (enlargement and rise of the embankment for protecting the urban area) and construction of water pump stations and water discharge channels to discharge excess water (EEA 2017).

Hybrid solutions for landslide protection can also involve grey solutions mostly coupled with a vegetation cover (hydroseeding, live transplanting, live stakes) for the reduction of negative impacts of inert materials on the ecosystem.

4 NBS for landslide protection

4.1 Soil Bioengineering

The use of living plant materials to build structures that provide slope support is at the core of Soil Bioengineering practice. Natural approaches for the reduction of potential for slope failure and erosion have been used as engineered practices since early 1980s (Gray & Leiser, 1982), even if the use of natural solutions for managing rivers and riverbanks with regards to floods and erosion has been introduced in Europe since the second half of 1800 (Evette et al. 2009).

Typical bioengineering solutions include the use of living materials such as plant/grass seeding, live transplanting, and other approaches such as wattle fences and brush layers.

4.1.1 Bioengineering for Landslide mitigation

Bioengineering practice can be considered as the pioneer of NBS for landslide protection since it provides environmental-friendly and cost-effective solutions in accordance with the principles of NBS actions "inspired by, supported by or copied from nature".

The effectiveness of Soil Bioengineering interventions has been mostly evidenced for surface erosion control and the stabilization of shallow landslides. Surface erosion is defined as the detachment, transport and deposition of soil particles by an erosive process (Gray and Sotir 1996; Boardman and Poesen 2006). The majority of erosive processes along a soil surface are generated by rainfall, which in some cases can trigger failures along the slope evolving into shallow landslides. Within bioengineering applications, the use of vegetation as tree/shrub species or mixtures of herbaceus species has been the most common practice. In particular trees or shrubs are preferred to herbaceus species for slope stabilization even in steep slopes, because of the dual effect of roots in reinforcing soil, acting like nails into the slopes, and in reducing water content by evapotranspiration processes. On the other hand, the use of grass is preferred against surface erosion because they can develop a good turf and dense root system that substantially prevent soil erosion (Lyons et al., 2000). Combined measures of living and not living approaches have been widely used to stabilize existing landslide areas to minimize the probability of future landslides and surficial erosion of loose soil. **Live fascines** are long bundles of live woody vegetation buried in shallow trenches that have been combined with seeding or **live staking** for the stabilization of a debris flow scar (Thomas & Kropp, 1992). In other cases the landslide area has been stabilized with **vegetated cribwalls** combined with **vegetated slope grids** and covered with vegetation to protect the steep slopes from additional soil erosion (Florineth et al., 2012).

4.1.2 Bioengineering for Flood mitigation

The areas along streams/torrents/rivers are among the most affected by floods from prolonged rainfalls. Furthermore, unvegetated riverbanks are more prone to failure due to heavy rainfall than from inundation due to high discharge and rapid change of water level. An example of bioengineering techniques for improving ecological restoration and reduce flood risk are those implemented along the river channels in the vicinity of

Shanghai airport: 1) **brush layers** comprises horizontal rows of cuttings buried in the surface of the bank zone and covers all riverbanks above the average normal water level; 2) **live fascines** consists in a long bundles of cut branches bound together in a cylindrical structure which is planted in shallow contour trenches on the bank zone, 3) **live staking** involves the insertion and tamping of live, vegetative cuttings into the ground, 4) **vegetated geo-grids** and 5) **vegetated gabions** were used in some segments of rivers with higher flow rate (Li et al., 2006). Others bioengineering measures used in Atlanta since the early 90s are: **brush mattresses** consisting in layers of living branches laid in a crisscross pattern on a riverbank to cover the entire soil surface and protect the bank until new vegetation is established, or **rip rap** protection (Simon and Steineman 2000).

4.2 The LaRiMiT tool (Landslide Risk Mitigation Toolbox) – NBS categories

One of the most challenging issues for practitioners when they come to address landslide mitigation, is the selection of the more technically suitable and cost-effective mitigation measure among the many structural and no-structural measures available. A first selection of the possible mitigation measures should be done considering the landslide characteristics (i.e. type of movement, material involved, rate of movement, groundwater conditions etc.). Secondly, possible socio-economical or environmental constrains should be taken into account. To address this challenge, a web tool, LaRiMiT (www.larimit.com), has been developed in Klima 2050 (based on original ideas created by NGI within the EC FP7 Safeland project (www.safeland.no)).

The operational process behind the toolbox and its functional structure is provided by Uzielli et al., (2017). The procedure for the end-user (practicioner) mainly consists of the following steps: 1) the user provides as input the landslide and site-specific features; 2) the toolbox processes the input data through a ranking algorithm based on expert scores and selects the most technically viable measures (already resident on the toolbox server in the form of a database) for that specific landslide; 3) the user can choose to give a weight to some constrains (environmental, economical, time-related) relevant for the selection of the more suitable mitigation measure among those technically viable; 4) finally the ranking algorithm provides the list of the candidate mitigation measures which are technically most viable and most efficient for risk reduction, taking into consideration the constraints made by the user.

The database contains 80 mitigation measures divided in 11 categories depending on the physical process that they are intended to address. Among these 11 categories, the first 2 are new NBS related categories: ***1. NBS for surface protection and erosion control - Living Approach***, ***2. NBS for surface protection and erosion control – Living/Not living Approach***, while other NBS measures belong to already existing categories related to other physical processes. The new NBS Categories and the total 24 NBS mitigation measures added to the LaRiMiT toolbox are provided in table 5. Furthermore, some combined NBS-engineered solutions are listed and are labeled as Hybrid. More detailed descriptions of the various measures are described in www.larimit.com.

Table 5. NBS mitigation measures included in LaRiMiT

Category - Physical process	NBS measure
NBS for surface protection and erosion control - Living Approach	Hydroseeding
	Turfing
	Tree bushes direct/pit planting (live transplanting)
	Live/intert fascines and straw wattles
	Bush mattresses
	Bush layering
	Live Stakes (live poles)
	Live smiles
NBS for surface protection and erosion control - Combined Living/Not living Approach	Geotextiles (Rolled Erosion Control Products)
	Drainage Blankets
	Beach replenishment/nourishment
	Rip-rap
	Rock dentition
Modifying the slope geometry - mass distribution	Terracing
Modifying the surface water regime - surface drainage	Vegetation - hydrological effects
	Live pole drains
	Live/rock check dams
Modifying the mechanical characteristics of the unstable mass	Vegetation - mechanical effects
Transfer of loads to more competent strata	Soil nail and root technology (SNART) - Hybrid
Retaining structures to improve the slope stability	Vegetated gabions (Hybrid)
	Live crib walls
	Vegetated slope gratings
Passive control works for dissipating the energy of a landslide	Afforestation
	Live gully breaks

The LaRiMiT toolbox is constantly being developed within the Klima2050 project, aimed at both improving the innovation potential and the user friendliness of the web-tool. The innovation potential is related to the extension of the existing database by adding all possible NBS for landslide mitigation based on an extended literature review on applications, case studies and data platforms.

5 Studies on NBS landslide protection

5.1 NVE/NGI report (2015)

Use of forests and vegetation is one of the few prevailing opportunities within NBS to reduce landslide risk (see list in Appendix A). NGI has participated in a study funded by the NVE to investigate the effect of forest on landslide risk (NVE, 2015). The study concluded that stability of slopes is generally a function of the soil cover's grain size distribution, pore pressure (positive or negative pressure) and anchoring of the roots. In fact, the presence of vegetation into the soil affects the water balance between air and soil in the soil-atmosphere interaction process. Moreover, the erosion potential of slopes, gutters and streams is crucial to the actual efficiency of flood defences. Therefore, vegetation on slopes, in gutters and near streams is important for the likelihood of erosion, slippage and landslides. For local stability, root properties and water content in soil and especially in the root zone play a significant role. The upper soil layer is affected by roots and freeze / thaw processes, and this leads to looser soil structure and higher water conductivity than what pure geotechnical laboratory results of soil samples show. Water flow usually follows cracks, canals and roots. In mixed forests, for example, roots develop better root systems by following the roots of others, and usually a mixed forest will be the forest type that gives the greatest infiltration capacity. Observed events on clear-cuts can be a combination of surface effects and tractor roads, but the effect is often visualized at or along roads because these often lead water undesirably.

Some of the specific conclusions in the report are as follows:

- Deep roots increase stability and reduce the risk of shallow landslides;
- The surface layer (grass and herbs) binds soil particles;
- Roots increase the infiltration capacity of the soil so that surface runoff is reduced (very important in soils with high clay content);
- The water content of the soil is reduced by the plants' uptake;
- Roots affect the water content and suction condition also in the lower root horizon;
- The interception, i.e. the part of the precipitation that does not reach the ground, is larger as the forest become denser. The interception is over 50% in dense forests and about 30% in more open areas with shrubs and grass;
- Any obstruction or roughness in the waterway reduces the flow rate of surface runoff.

5.2 NBS on stream bank stability in Norwegian agricultural areas – Article by Krzeminska et al. (2019)

Another key issue related to the use of vegetation as NBS for landslide/flood/erosion protection is the type of vegetation used. This recent experimental study investigates the effect of different types of vegetation, typical of Norwegian agricultural areas (grass, shrubs and trees), on the hydro-mechanical behaviour of clay soils at seasonal time scales. The area tested is a stream bank, which can be systematically affected by landslides (bank failure) following floods or after prolonged rainfalls. Hydraulic variables (water level and volumetric water content), undrained shear strength, soil porosity and the bank profile variation have been systematically measured and recorded for more than one year.

The main findings were:

- The water content in soil is strictly related to the root depth: at highest depths the lower water content was in the forested river bank because of the longer root network compared to that of shrubs and grass;
- The undrained shear strength depends on the type of roots, the position of the main root network and the season of the year: highest values of undrained shear strength have been found during "dry" season (spring, summer) and along the forested stream bank in correspondence of the main root network;
- the instability mostly increases with the slope inclination, so a good choice of the vegetation to be used depends also on the stream bank inclination.

Based on this field data analysis together with river bank stability modelling, Krzeminska et al (2019) concluded that, since the positive effect of vegetation on slope stability is given mostly by the root reinforcement, trees should be used for steeper slopes, while the use of grasses can be a sufficient treatment for gently slopes.

5.3 Article by Stokes et al. (2014)

An article from the biological community (Stokes et al., 2014) provides a good overview of issues related to the use of vegetation to stabilize slopes. The article refers to basic and applied research in areas such as soil formation and biogeochemistry, hydrology and microbial ecology to argue that vegetation can be used as slope stabilizing measure. The article points out that the plant roots change its local environment in a number of ways, from changing the earth's biophysical, chemical and mechanical properties, to stimulating microbial diversity. Through understanding these basic processes, relevant solutions can be developed to carry out both successful ecological restoration and soil protection, and to reinforce the ground. Vegetation can therefore be an ecological alternative to traditional engineering solutions in order to protect against shallow landslides and soil erosion. The vegetation contributes to water infiltration, soil surface protection, strength and fertility, as well as improvement of biological activity in the soil. But it is also emphasized that vegetation has the potential to destabilize slopes, for example in connection with strong winds, and mostly with the weight of trees which can add to the destabilizing forces of a slope stability profile.

The article refers to ten key issues where further studies are needed in connection with the use of vegetation for slope protection:

1. Evaluate how small-scale soil fixation can have large-scale consequences;
2. Understand the effects of vegetation on slope hydrology;
3. Understand the role of vegetation in reducing debris flows activities;
4. Understand the impact of trees on the stability of dikes (levees);
5. Modelling the mechanical stability of vegetated slopes;
6. Identifying the most appropriate plant types;
7. Using inert engineering structures and live plant material and their efficiency over time;
8. Improving bioengineering in harsh environments;
9. Assessing how vegetation on slopes provides ecosystem services;
10. Improving the widespread adoption of eco- and bio-engineering.

5.4 The PHUSICOS project

The EC H2020 innovation action PHUSICOS (www.phusicos.eu) started in May 2018, and will last for 4 years. There is a total of 15 partners from 7 countries, with NGI as coordinator. The project became one of the selected for the SC5-08 "Large-scale demonstrators on nature-based solution for hydro-meteorological risk reduction (Innovation action)". PHUSICOS aims at implementing NBSs at three demonstration sites (Serchio-Basin area in Italy, Pyrenees in France / Spain and Gudbrandsdalen in Norway). These three demonstration sites are representative of hydro-meteorological hazards, vegetation, topography and infrastructure in rural and mountainous regions of Europe. The purpose is to test how NBS can be a cost effective solution exportable also in other regions.

The use of NBS will be tested in the Gudbrandsdalen valley. The demonstration site may represent an excellent opportunity also for for Klima 2050 partners to test innovative solutions in Norway related to both landslide protection and flood control.

6 Future needs

Increasing attention is being paid to the use of NBS in climate adaptation work, in the public as well as in the private sector. The website www.Miljøkommune.no lists major plans for the initiation of NBS in municipal administrations. In the long term, we can also expect that there will be requirements for the use of naturally-adapted solutions for mitigation measures. Instead of using traditional "gray" solutions, NBS which include, for example, the use of ramparts, ponds and other larger structures may be used. This development is due both to an increased awareness of the services nature contributes (ecosystem services), and a desire to work "with nature" rather than against it both to safeguard ecosystems in a pressed situation and to strengthen human connection to nature.

The EU has major plans for the use of NBS. Their goal is clearly to become a world leader in the use of NBS. This is not only due to environmental / social considerations, but also in a business perspective. EC believes that NBS will be an important industry in the long term. They are therefore investing considerable resources on research within NBS, and many networks have been established (partly under the auspices of the EC) which aim to convey the development of NBS for practical purposes.

7 Innovation potential

There are many forms of innovation related to NBS. This relates not only to the technical solutions, but also to governance, management, training and communication. In this way, the development of innovative nature-based solutions should therefore be relevant to the majority of Klima 2050's partners.

7.1 Physical safeguards

Table 2 lists the most relevant types of nature-based solutions. For landslide and erosion protection, for example, the use of forests and other vegetation, and the use of geotextiles, are the main NBSs suggested. Appendix A provides a more detailed list of NBSs categorized after the type of action they request (i.e. action on waterways, rivers and streams, action on forests etc.) for different types of hazards. This list has been prepared on the basis of a few research projects that have studied this in more detail. Much research is still needed in the field, with the aim of developing new innovative solutions that are both effective, economical and ecologically sound, while being socially accepted and locally rooted. The PHUSICOS project will hopefully add significantly to this.

Key elements that contribute to physical landslide protection measures being effective are:

- Binds the soil and increases resistance to erosion and other instabilities
- Takes up water and reduces the amount of water that the soil has to absorb.

7.2 Administrative safeguards

The implementation of NBS can be related to administrative actions. The administrative measures that have been found by EKLIPSE (2017) to be most important in relation to societal challenges can range over urban planning strategies towards green spaces or increasing knowledge and awareness on NBS in the urban environment for stakeholders and policy makers. Appendix B provides an overview of the administrative measures that can be implemented using NBS.

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Appendix A – Physical NBS

Table A1 NBS measures for Flood and erosion mitigation

Actions on:	Measures	Hazard type	Reference
waterways, rivers and streams	Keep open water and waterways	Flood	Menon Economics (2017)
	Restore lakes and waterways	Flood	Menon Economics (2017)
	Reopen closed streams / rivers	Flood	Menon Economics (2017)
	Moving and establishing artificial streams	Flood	Menon Economics (2017)
	Reconnect rivers with floodplains to enhance natural water storage	Flood	Sutherland et al. (2014)
	Re-meander rivers	Flood, erosion	Sutherland et al. (2014)
	Install small dams in surface drains to reduce hydraulic connectivity and improve habitat structure to slow overland flow	Flood, erosion	Sutherland et al. (2014)
	Reduce canalisation and create channel diversity to reduce speed of flood transmission	Flood	Sutherland et al. (2014)
Forest	Preservation of forests	Flood	Menon Economics (2017)
	Planting of forest	Flood	Menon Economics (2017)
	Sustainable forest management	Flood	Menon Economics (2017)
	Protect the area and condition of existing forest areas from clearing and degradation	Flood	Sutherland et al. (2014)
	Retain forest cover on steep slopes	Flood, erosion, avalanches	Sutherland et al. (2014)

Actions on:	Measures	Hazard type	Reference
	Reforest degraded land and encourage benign abandonment of low productivity or disused land	Flood, erosion	Sutherland et al. (2014)
Surrounding area/ floodplain	Create areas for temporary flooding along rivers (floodplains) by moving flood protection infrastructures.	Flood	EKLIPSE (2017)
	Restore floodplain forest or other semi-natural features, such as wet grassland, to increase hydraulic roughness and so slow conveyance and enhance storage of floodplains	Flood	Sutherland et al. (2014)
Wetland	Conservation and sustainable management of natural wetland (incl. Marshland and floodplain)	Flood	Menon Economics (2017), Sutherland et al. (2014)
	Use wetlands to create emergency flood capacity	Flood	Sutherland et al. (2014)
	Restore/create/increase wetlands in river-basins.	Flood	EKLIPSE (2017), Menon Economics (2017)
Vegetation, Restoration	Re-establish edge vegetation	Flood	Menon Economics (2017)
	Preserve lace vegetation	Flood	Menon Economics (2017)
	Increase the structural diversity upstream	Flood	Menon Economics (2017)
	Establish permeable twig dams	Flood	Menon Economics (2017)
	Reduce channeling by restoring meanings	Flood	Menon Economics (2017)
	Balance the use of evergreen and deciduous trees to enhance seasonal water regulation	Flood	Sutherland et al. (2014)
	Restore riparian vegetation to assist in reconnecting rivers with floodplains and to provide greater instream ecosystem complexity	Flood	Sutherland et al. (2014)

Actions on:	Measures	Hazard type	Reference
	Practise controlled removal of peatland vegetation or use appropriate grazing to reduce the risk of wild-fire	Flood, wildfire	Sutherland et al. (2014)
	Encourage re-vegetation of riverbanks	Flood,erosion	Sutherland et al. (2014)
	Retain vegetation on margins of water courses	Flood, erosion	Sutherland et al. (2014)
Geotexiles	Use geo-textiles to arrest peat erosion	Flood, erosion, landslide	Sutherland et al. (2014)
Others	Increase up-stream structural diversity (such as through the re-introduction of beavers, or restoring boulders and large woody debris in upland rivers) to increase flood interception potential	Flood, erosion	Sutherland et al. (2014)

Table A2. NBS measures for Stormwater mitigation

Actions on:	Measures	Hazard type	Reference
Vegetation/infiltration	Vegetation-clad river and brooks	Stormwater	Menon Economics (2017)
	Green ceilings	Stormwater	Menon Economics (2017)
	Green walls	Stormwater	Menon Economics (2017)
	Rain garden	Stormwater	Menon Economics (2017)
	Create or keep infiltrable surfaces	Stormwater	Menon Economics (2017)
	Trees and other vegetation / green structure	Stormwater	Menon Economics (2017)
	Creation of new vegetated surface waterbodies (ponds, drains, lakes, bio-retention cells).	Stormwater	EKLIPSE (2017)

Actions on:	Measures	Hazard type	Reference
Rainwater collection/management	Rainwater Pit	Stormwater	Menon Economics (2017)
	Rainwater collection	Stormwater	Menon Economics (2017)
	Disconnecting gutters from the drainage system	Stormwater	Menon Economics (2017)
	Swales	Stormwater	Menon Economics (2017)
	Infiltration pool	Stormwater	Menon Economics (2017)
Waterbodies and permeable covers	Permeable cover	Stormwater	Menon Economics (2017)
	Re-opening / preserving streams, rivers and water mirrors	Stormwater	Menon Economics (2017)
	Stormwater foam	Stormwater	Menon Economics (2017)
	Designed wetlands	Stormwater	Menon Economics (2017)
	Filter pool	Stormwater	Menon Economics (2017)
	Open dry delay pool	Stormwater	Menon Economics (2017)
	Dry drain	Stormwater	Menon Economics (2017)
	Creation of artificial waterbodies for short term temporal water storage.	Stormwater	EKLIPSE (2017)
	Creation of new subsurface waterbodies for water storage.	Stormwater	EKLIPSE (2017)
Other	Reduced use of curbstones	Stormwater	Menon Economics (2017)

Table A3. NBS measures for sea level rise and storm surge mitigation

Actions on:	Measures	Hazard type	Reference
Forests and vegetation near to the sea and coast	Restore and preserve forest near the sea and coast (salt-influenced beach and swamp forest)	Sea level rise and storm surge	Menon Economics (2017)
	Restore and preserve sea-beach vegetation (beach meadows and beach lumps)	Sea level rise and storm surge	Menon Economics (2017)
Soil walls/dikes/dunes	Establish soil or clay dike	Sea level rise and storm surge	Menon Economics (2017)
	Utilizing existing sand dunes (restoration and active maintenance)	Sea level rise and storm surge	Menon Economics (2017)
Hybrid (beach park) and natural habitat solutions	Establishing beach park solutions (hybrid solution)	Sea level rise and storm surge	Menon Economics (2017)
	Conservation of habitats in the shoreline	Sea level rise and storm surge	Menon Economics (2017)
	Conservation of natural habitats on the seabed below the spring zone	Sea level rise and storm surge	Menon Economics (2017)
	Promote various NBS in coastal areas that can maintain or restore valuable coastal ecosystems and coastal biodiversity.	Sea level rise and storm surge	EKLIPSE (2017)
	Use NBS against coastal storms and sea level rises and protect the population from these risks in combination with engineered structures.	Sea level rise and storm surge	EKLIPSE (2017)

Table A4. NBS measures for landslides, snow avalanches, and erosion mitigation

Actions on:	Measures	Hazard type	Reference
Forests and vegetation	Conservation of vegetation	Landslides, avalanches	Menon Economics (2017)
	Conservation and sustainable management of forests in steep terrain	Landslides, avalanches	Menon Economics (2017)
	Forests against avalanches, rockslides and avalanches	Landslides, avalanches	Menon Economics (2017)
	Sustainable forestry for climate adaptation	Landslides, avalanches	Menon Economics (2017)

Actions on:	Measures	Hazard type	Reference
	Encourage enrichment planting in degraded and regenerating forests	Landslides, avalanches	Sutherland et al. (2014)
	Retain forest cover on steep slopes	Landslides, flood, erosion	Sutherland et al. (2014)
	Practise controlled removal of peatland vegetation or use appropriate grazing to reduce the risk of wild-fire	Landslides, flood, erosion	Sutherland et al. (2014)
	Reforest degraded land and encourage benign abandonment of low productivity or disused land	Landslides, flood, erosion	Sutherland et al. (2014)
Soil mass movement	Use of bulk material for the build-up of dams and dikes	Landslides, avalanches	Menon Economics (2017)
Geotexiles	Use geo-textiles to arrest peat erosion	Flood, erosion, landslide	Sutherland et al. (2014)
Drainage	Drainage	Erosion, Rainfall	Menon Economics (2017)

Table A5. NBS measures for rainfall mitigation

Actions on:	Measures	Hazard type	Reference
Vegetation, grass covering	Edge Vegetation	Rainfall	Menon Economics (2017)
	No or exposed soil work	Rainfall	Menon Economics (2017)
	Catch growth, possibly in addition to wintering in stubble	Rainfall	Menon Economics (2017)
	Grass covered waterways and grassy buffer zone	Rainfall	Menon Economics (2017)
	Other grass-covered areas	Rainfall	Menon Economics (2017)
	Encourage re-vegetation of riverbanks	Rainfall, erosion	Sutherland et al. (2014)
	Use cultivars with deeper rooting systems to maximise rainfall use	Rainfall	Sutherland et al. (2014)
	Renaturing urban waterbodies (opening channels, de-culverting,	Rainfall	EKLIPSE (2017)

Actions on:	Measures	Hazard type	Reference
	increase vegetation, greening waterfronts).		
	Use of vegetation in urban areas (e.g. street trees, grassland, green roofs and facades, infiltration gardens and urban forests).	Rainfall	EKLIPSE (2017)
external buildings/vegetation	Building green roofs.	Rainfall/temperature/climate/air pollution	EKLIPSE (2017)
Soil	Check dams	Rainfall	Menon Economics (2017)
	Better soil structure for reduced runoff	Rainfall	Menon Economics (2017)
	Sediment pools along roads	Rainfall	Menon Economics (2017)
Drainage	Drainage	Rainfall	Menon, 2017

Table A6. NBS measures for drought mitigation

Actions on:	Measures	Hazard type	Reference
Drought tolerant and fresh vegetation	Controlled burning of heathlands and other flammable habitats to replace old heather and other old vegetation with new, fresh plants.	Drought	Menon Economics (2017)
	Use of drying tolerant species and protection of their genetic diversity	Drought	Menon Economics (2017)
Water management	Rainwater collection	Drought	Menon Economics (2017)

Table A7. NBS measures for wildfire mitigation

Actions on:	Measures	Hazard type	Reference
Forest/land management/ use of fire	Impose strict limitations or bans on the use of fire to manage agricultural land adjoining forested areas	Wildfire	Sutherland et al. (2014)
	Limit or carefully manage salvage logging to prevent dangerous build-up of fuel loads	Wildfire	Sutherland et al. (2014)
	Limit use of fire in agriculture on or near peat soils	Wildfire	Sutherland et al. (2014)

Table A8. NBS measures for temperature, climate, and air pollution mitigation in urban areas

Actions on:	Measures	Hazard type	Reference
Re-naturalization of grey infrastructures	Green roofs	Temperature, Climate, Air pollution	Menon Economics (2017)
	Green walls	Temperature, Climate, Air pollution	Menon Economics (2017)
	Re-naturalization of grey infrastructure	Temperature, Climate, Air pollution	Menon Economics (2017)
	Increasing green walls and roofs to cool down the city through outdoor energy management using shading and the latent heat of evapotranspiration of plants and soils.	Temperature, Climate, Air pollution	EKLIPSE (2017)
Building green areas, establish climate-resistant vegetation	Building green roofs.	Rainfall, Temperature, Climate, Air pollution	EKLIPSE (2017)
	Establish green corridors	Temperature, Climate, Air pollution	Menon Economics (2017)
	Establish or preserve parks	Temperature, Climate, Air pollution	Menon Economics (2017)
	Planting trees in the cities	Temperature, Climate, Air pollution	Menon Economics (2017), EKLIPSE (2017)
	Increasing the area of (or avoiding the loss of) green space, particularly wetlands and tree cover, for both direct and indirect carbon storage.	Temperature, Climate, Air pollution	EKLIPSE (2017)
	Maximizing the net sequestration of carbon through species selection and management practices i.e. improving mitigation as well as choosing species that are adapted to future conditions.	Temperature, Climate, Air pollution	EKLIPSE (2017)
	Maintaining existing green infrastructure.	Temperature, Climate, Air pollution	EKLIPSE (2017)
	Increasing the area of (or avoiding the loss of)	Temperature, Climate, Air pollution	EKLIPSE (2017)

Actions on:	Measures	Hazard type	Reference
	vegetation and particularly tree cover.		
Open water surfaces	Establish or maintain open water surfaces	Temperature, Climate	Menon Economics (2017)

Appendix B – Administrative measures

Table B1. Administrative measures for NBS

Measures	Hazard type	Reference
Inventories, hierarchizing and representation of green and blue spaces.	Green space management	EKLIPSE (2017)
Set clear and measurable quality and quantity requirements for existing and new NBS.	Green space management	EKLIPSE (2017)
Make use of innovative, interdisciplinary planning methods for green space co-design and co-implementation, including development of innovative social models for long-term positive management (e.g. Citizen Engagement for Health).	Green space management	EKLIPSE (2017)
Create, enlarge, fit out, connect and improve green and blue infrastructure by implementing NBS projects.	Green space management	EKLIPSE (2017)
Conserve, improve and maintain existing NBS areas in respect to biodiversity.	Green space management	EKLIPSE (2017)
Support energy efficiency in building design and layout, building form, infiltration and ventilation, insulation, heating and lighting.	Urban regeneration	EKLIPSE (2017)
Design for: richness in urban environments, such as the promotion of street life, natural surveillance, visual richness, public art, and street furniture; diversity in use, such as mix of people, mix of uses, appropriate densities and visual diversity; ease of movement, including through-movement, priority given to public transport, priority given to innovative parking, meeting needs of people with sensory impairments.	Urban regeneration	EKLIPSE (2017)
Provide the urban brand with a narrative and a value aimed at changing the perception of potential users or visitors, whether they are citizens,	Urban regeneration	EKLIPSE (2017)

Measures	Hazard type	Reference
international tourists or investors.		
Design knowledge co-production processes to bring openness, transparency in governance processes, and legitimacy of knowledge from citizens/civil society, practitioners and policy stakeholders.	Participatory planning and govenrance	EKLIPSE (2017)
Create different institutional spaces for cross-sectoral dialogue and interactions of different stakeholders for strengthening/fostering adaptive co-management and knowledge sharing about urban ecosystems.		EKLIPSE (2017)
Enable cross-sectoral partnerships for NBS design, implementation and maintenance.	Participatory planning and govenrance	EKLIPSE (2017)
Support processes that enrich or regenerate ecological memory for restoring urban ecosystems with NBS.	Participatory planning and govenrance	EKLIPSE (2017)
Promote and work towards creative designs of NBS in cities that are adaptive over time.	Participatory planning and govenrance	EKLIPSE (2017)
Support community-based projects on greening and restoring urban green spaces that also ensure accessibility to these spaces and stewardship.	Participatory planning and govenrance	EKLIPSE (2017)
Distribute various types of NBS across urban areas to ensure a range of ecosystem services and experiential qualities of place are available to people from different socio-economic backgrounds.	Social justice and social cohesion	EKLIPSE (2017)
Support experiential learning and capacity building programs on NBS in ways that meet the varying requirements, rights and duties of local residents.	Social justice and social cohesion	EKLIPSE (2017)

Measures	**Hazard type**	**Reference**
Actively engage excluded social groups in the design, delivery and monitoring of NBS, as well as in the rules to support the governance of NBS.	Social justice and social cohesion	EKLIPSE (2017)
Build the capacity of typically excluded groups to participate in NBS decision-making processes. Capacity building can include efforts directed to improving basic literacy and numeracy, physical security, employment, information and recognition as a citizen (Rutt and Gulsrud, 2016).	Social justice and social cohesion	EKLIPSE (2017)
Distribute various types of urban green spaces as NBS across urban areas.	Public health and well-being	EKLIPSE (2017)
Provide adequate urban planning and design mechanisms to ensure sufficient green space provision for positive health effects.	Public health and well-being	EKLIPSE (2017)
Design of urban green spaces, such as parks and playgrounds, should take in account the needs of children and the elderly while taking measures to minimize the risk of injuries.	Public health and well-being	EKLIPSE (2017)
Provide proper urban green space design, maintenance and recommendations to minimize trade-offs (allergenic pollen, transmission of vector-borne diseases).	Public health and well-being	EKLIPSE (2017)
Encourage methods to transfer the benefits of common goods provided by NBS to the initiators of NBS, e.g. through tax reductions or subsidies.	Potential for economic opportunities and green jobs	EKLIPSE (2017)
Support vocational training programs to enhance skills in the design and delivery of NBS measures.	Potential for economic opportunities and green jobs	EKLIPSE (2017)
Increase knowledge and awareness on NBS in the urban environment for stakeholders and policy makers.	Potential for economic opportunities and green jobs	EKLIPSE (2017)
Develop online NBS impact calculation tools.	Potential for economic opportunities and green jobs	EKLIPSE (2017)
Restore or plant green spaces or other NBS.	Potential for economic opportunities and green jobs	EKLIPSE (2017)

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