# DELIVERABLE 1.5

## Visualisation of cause-effect relations and potential systemic effects – front-running regions

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# Visualisation of cause-effect relations and potential systemic effects – front-running regions

## Project description

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|---|---|
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# Abbreviations

| | |
|---|---|
| EU | European Union |
| Land4Climate | Utilization of private land for mainstreaming nature-based solution in the systemic transformation towards a climate-resilient Europe |
| NbS | Nature-based solutions |
| WP | Work Package |
| CIC | Climate impact chains |
| FRR | Front running region |
| RR | Replicating region |

# Executive Summary

This report presents the cause-effect relations of climate hazards such as Drought, Heat, Flooding and Heavy Rain through climate impact chains (CIC). Additionally, nature-based solutions (NbS) are addressed, and examples of NbS interventions that can be implemented within the framework of the Land4Climate project are introduced. The objective of the report is to offer an overview of the cause-effect relations of climate hazards on multiple sectors and to illustrate the systemic effects of nature-based solutions on mitigating the impacts of climate hazards.

After a brief introduction, the report outlines the concept of CIC and presents the individual CIC for the climate hazards Drought, Heat, Flooding, Heavy Rain and Storm Surge highlighting their influence on various sectors. This is followed by a brief introduction to the concept of NbS, including a description of the characteristics that they should exhibit within the project context. Subsequently, various NbS measures are introduced, which can be implemented on private land within the five sectors: built environment, agriculture, forest, coast, and rivers. Concluding the deliverable is a summary of key findings and insights.

# Keywords

Climate impact chains, Cause-effect relations, nature-based solutions

# 1. Introduction

With increasing climate risks due to the more frequent occurrence of climate-related hazards, it is becoming increasingly important not only to mitigate climate change impacts, but also to adapt to them. When adapting to climate change, it is important to understand how a climate-related impact influences different sectors of society (Estoque et al 2022). Possible climate change adaptation measures include nature-based solutions that not only mitigate the effects of climate hazards, but also bring multiple co-benefits for the economy, society and the environment. The purpose of this report is on the one hand to visualise the effects of climate hazards on different sectors as well as to present the impacts, example NbS can have to reduce the effects of these climate hazards.

The Land4Climate project aims to increase the climate resilience of landscapes and urban settlements in the continental biographic area and beyond through the implementation of NbS on private land. In the six front running regions (FRR) in Germany, Austria, the Czech Republic, Romania, Slovakia and Italy, which were shortly introduced in Del 1.1, four relevant climate hazards were identified (Drought, Heat, Flooding and Heavy Rain). CIC can be used to build an understanding of the impacts of climate hazards on different sectors of society. These impacts can then be linked to the benefits of NbS in order to select a suitable adaptation measure, to increase the FRR resilience to climate change.

The Land4Climate project aims not only to implement NbS on private land within the FRR but also to enable upscaling to contribute to the mission of the EU to a more climate resilient Europe and therefore adapt to climate change. This deliverable is not only for the partners within the project but also to inspire other regions and stakeholders to develop ideas on how to find suitable NbS to implement on private land.

The deliverable begins with a short description of the fundamentals of CIC followed by the visualisation of the CIC of the climate hazards Drought, Heat, Flooding, Heavy Rain and Storm Surge in different sectors of society. The next chapter starts with describing the concept of NbS. After the short description different examples of NbS are presented within short fact sheets, including a description of the measure, the effects of the climate hazards that they mitigate and also further co-benefits they provide. The deliverable ends with a short conclusion of the findings of the report.

# 2. Climate Impact Chains

## 2.1 Principles

Within the Land4Climate project, cause-effect relationships and systemic effects are comprehensively understood: The terminology involves examining the connections between climate hazards and their impacts on various sectors, as well as understanding the fundamental principles of NbS and identifying the points within the Climate Impact Chains (CIC) where they can be applied. Accordingly, this deliverable begins by establishing CIC for the climate hazards relevant to the project.

CIC are an analytical framework based on cause-effect chains that visualise all key factors and processes that lead to specific climate risks. The factors and processes are categorised under the risk components of hazard, exposure and vulnerability, while cascading effects are considered as intermediate effects. In their structure, CIC always focus on the risk resulting from a specific hazard (e.g. high temperatures leading to heat), while exposure defines the sector affected by this risk (e.g. human health, agriculture). The intermediate impacts usually concern biophysical elements (i.e. they are primarily related to the hazard component) that eventually lead to the final human-related risk. The vulnerability factors reflect the non-climatic dimensions that either increase or decrease the risk for the exposed sector (Fritzsche et al. 2014) (Zebisch et al. 2017).

CIC have the advantage of being able to map the climate risk and its contributing factors in their entirety. They are therefore well suited to identify potentially appropriate adaptation measures. In the context of Land4Climate, CIC form the starting point both for the conceptualisation of the climate risk assessment (see DEL 1.1) and for the identification of suitable nature-based solutions. The focus is on those impact structures that can be spatially localised and can therefore serve as evidence basis for localizing and justifying climate risk hotspots and suitable areas for interventions in the participating front-running regions. For simplification, the chains are visualised separately for each climate hazard as well as the related vulnerable (and potentially) exposed sectors:

- Drought – agriculture
- Drought – forestry
- Heat – agriculture
- Heat – human health
- Heat – industry and commerce
- Heat – transport infrastructure
- Heat – energy industry
- Heavy rain and flooding – human health
- Heavy rain and flooding – agriculture
- Heavy rain and flooding – energy industry
- Heavy rain and flooding – transport infrastructure
- Heavy rain and flooding – industry and commerce
- Storm surges – coastal and marine protection

The following CIC are based on impact chains that were derived from of the German Federal Environment Agency (UBA, 2016) and have been adapted to the framework of the Land4Climate project. Additionally, interviews were conducted with the FRR, during which the relevant climate hazards in the regions were identified. The CIC can be utilized by the FRR as well as the Replicating region (RR) within the project to identify relevant influencing factors on various climate risks and to analyse the consequences of these risks on the sectors in their region. The CIC are also useful for communicating the impacts of climate hazards within a region. Furthermore, they serve as a basis for identifying appropriate NbS measures for the areas, targeting specific vulnerabilities or hazards depicted in the CIC.

## 2.2 Effect of drought on agriculture and forestry

The following two visualised CIC show the impacts the climate hazard Drought can have on the sectors agriculture and forestry. The top section of each subsequent CIC delineates the climate hazard. The middle section outlines the intermediate effects that can arise, while the final section illustrates the climate risks resulting from the climatic hazard and its associated consequences. The vulnerabilities that influence the effects of the climate hazard are highlighted in the black-framed box within each CIC.

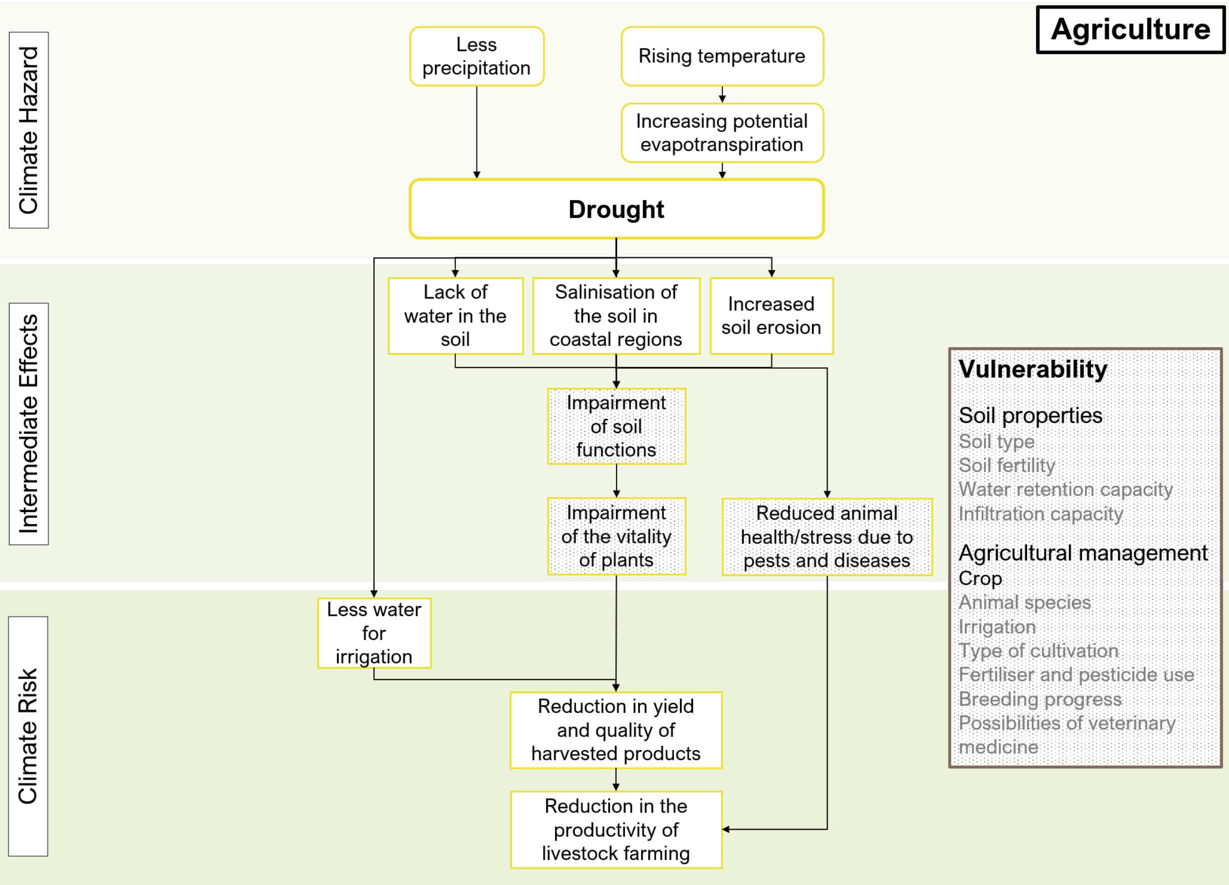



Figure 1: CIC for Drought on agriculture

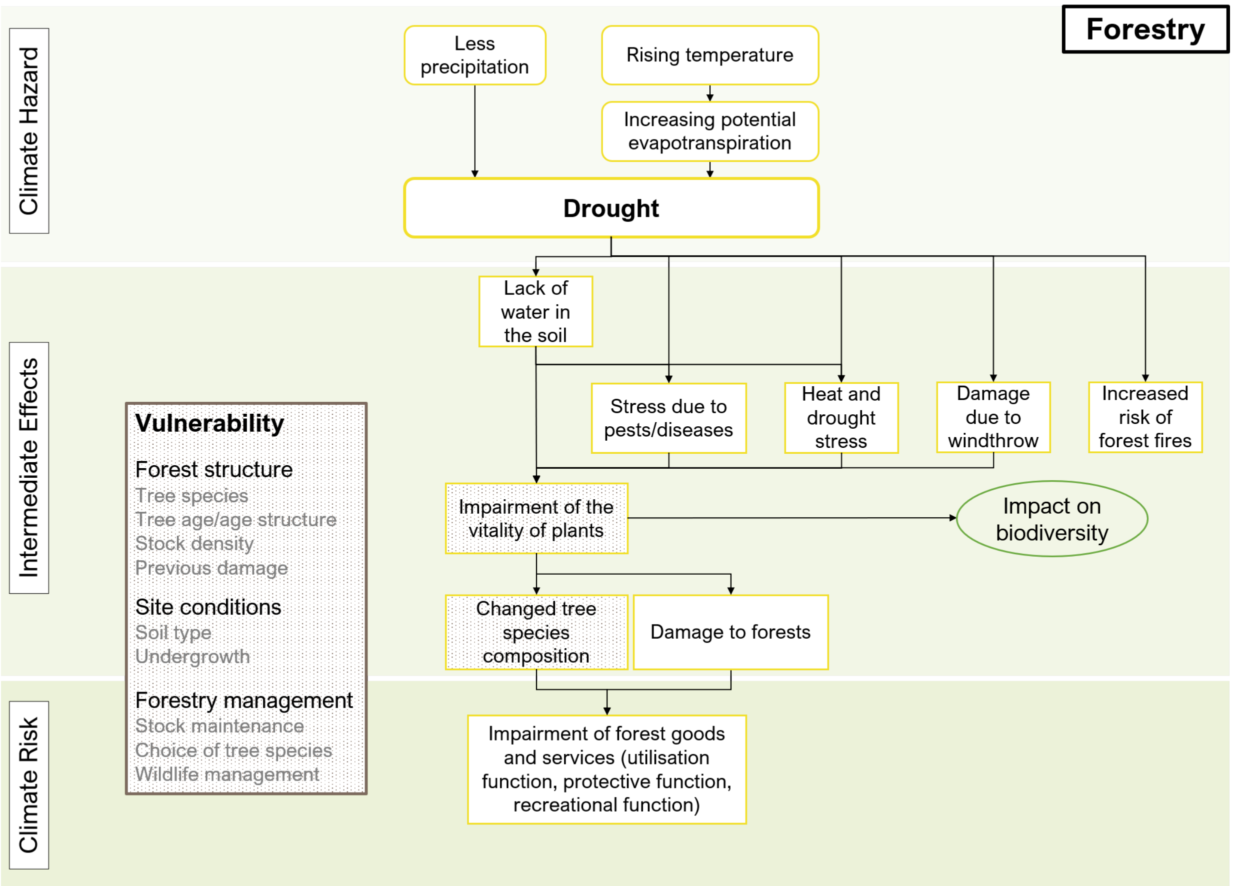



Figure 2: CIC for Drought on forestry

## 2.3 Effect of Heat on different sectors

The following CICs show the impacts the climate hazard Heat can have on the sectors: agriculture, human health, industry and commerce, energy industry and transport infrastructure. The top section of the following CIC delineates the climate hazard. The middle section of each CIC outlines the intermediate effects that can arise, while the final section illustrates the climate risks resulting from the climatic hazard and its associated consequences. The vulnerabilities influencing the effects of the climate hazard are shown in the black framed box within the CIC.

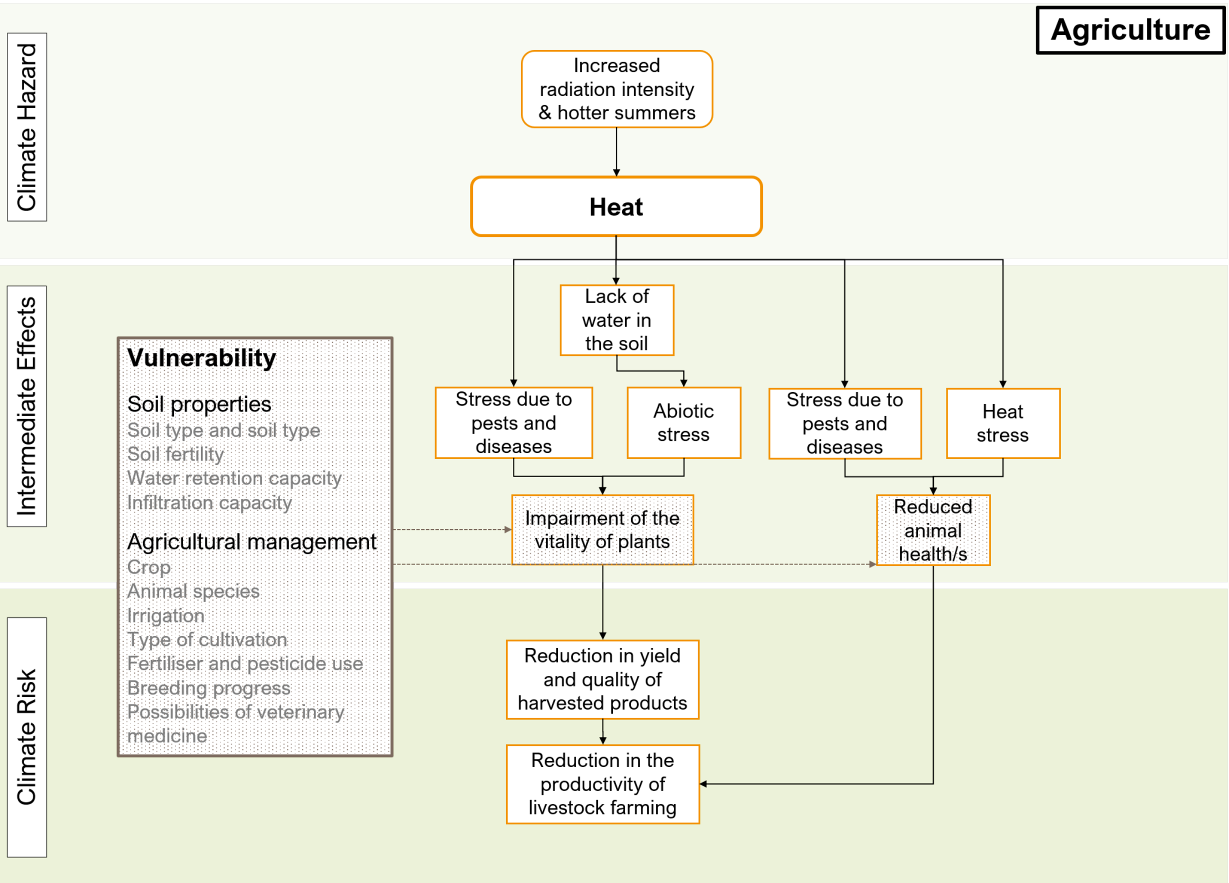



Figure 3: CIC for Heat on agriculture

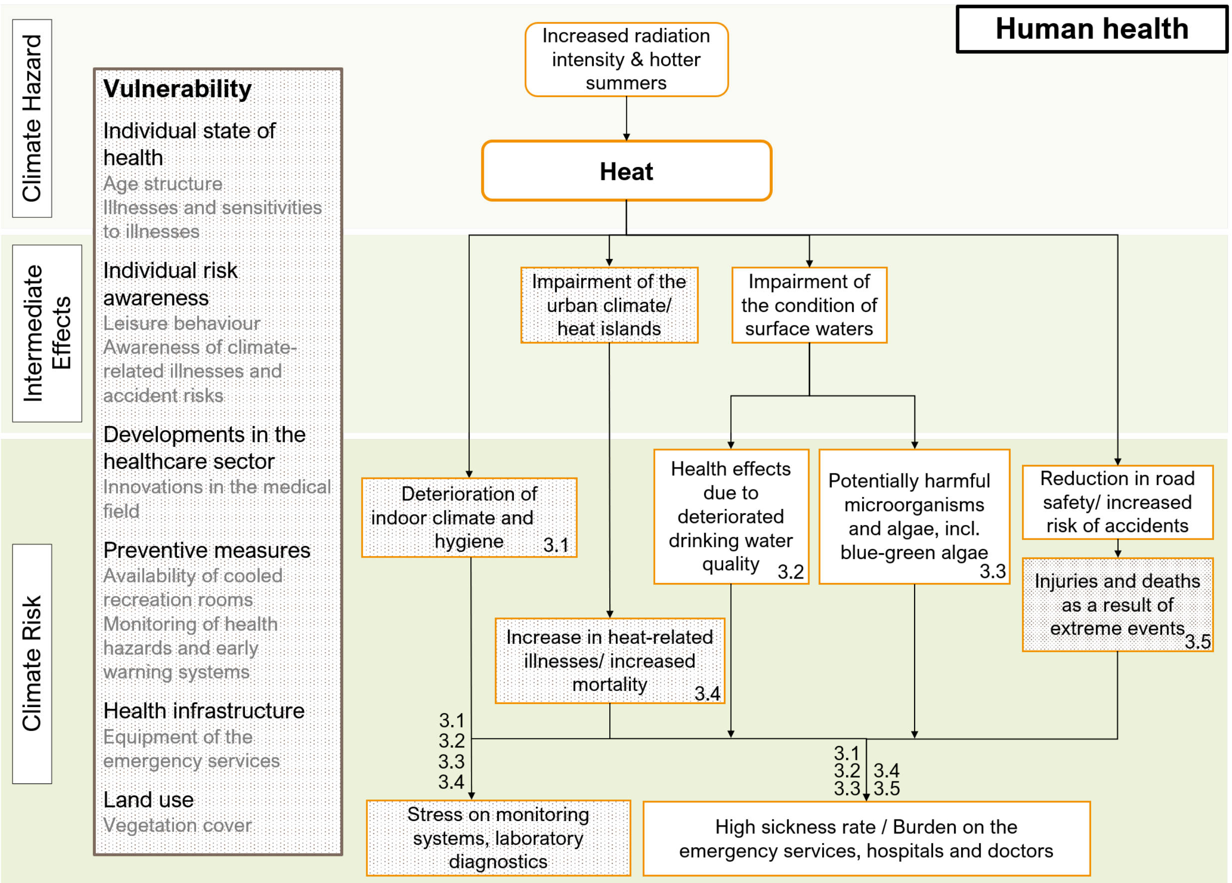



Figure 4: CIC for Heat on human health

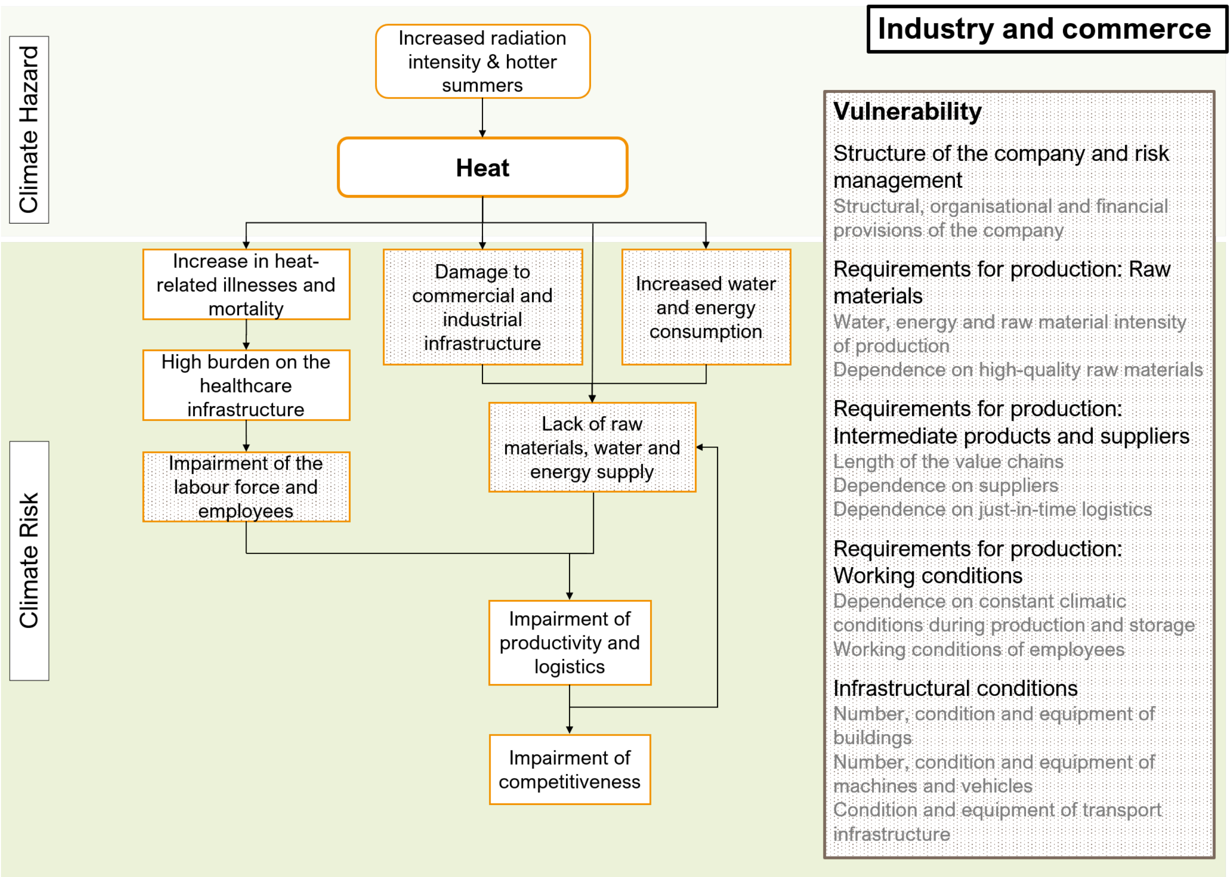



Figure 5: CIC for Heat on industry and commerce

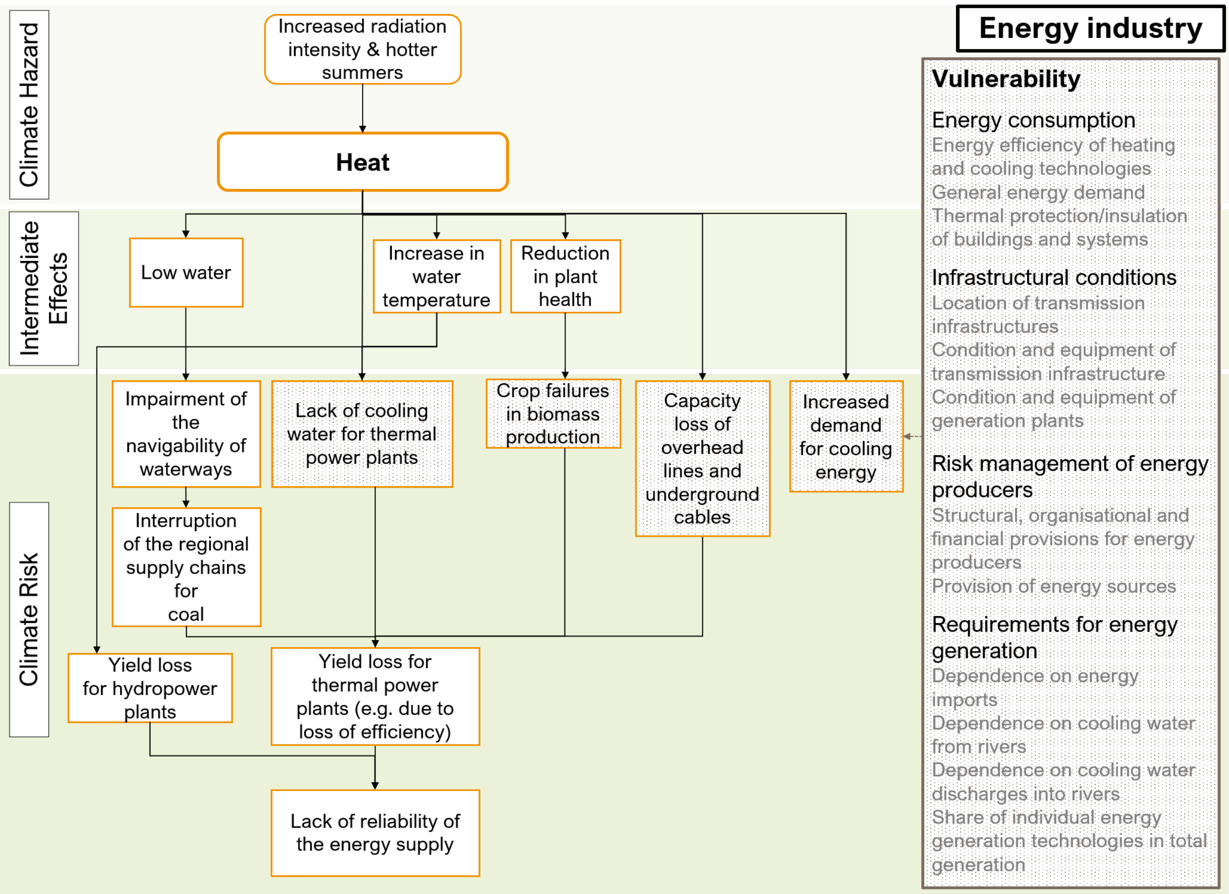



Figure 6: CIC for Heat on the energy industry

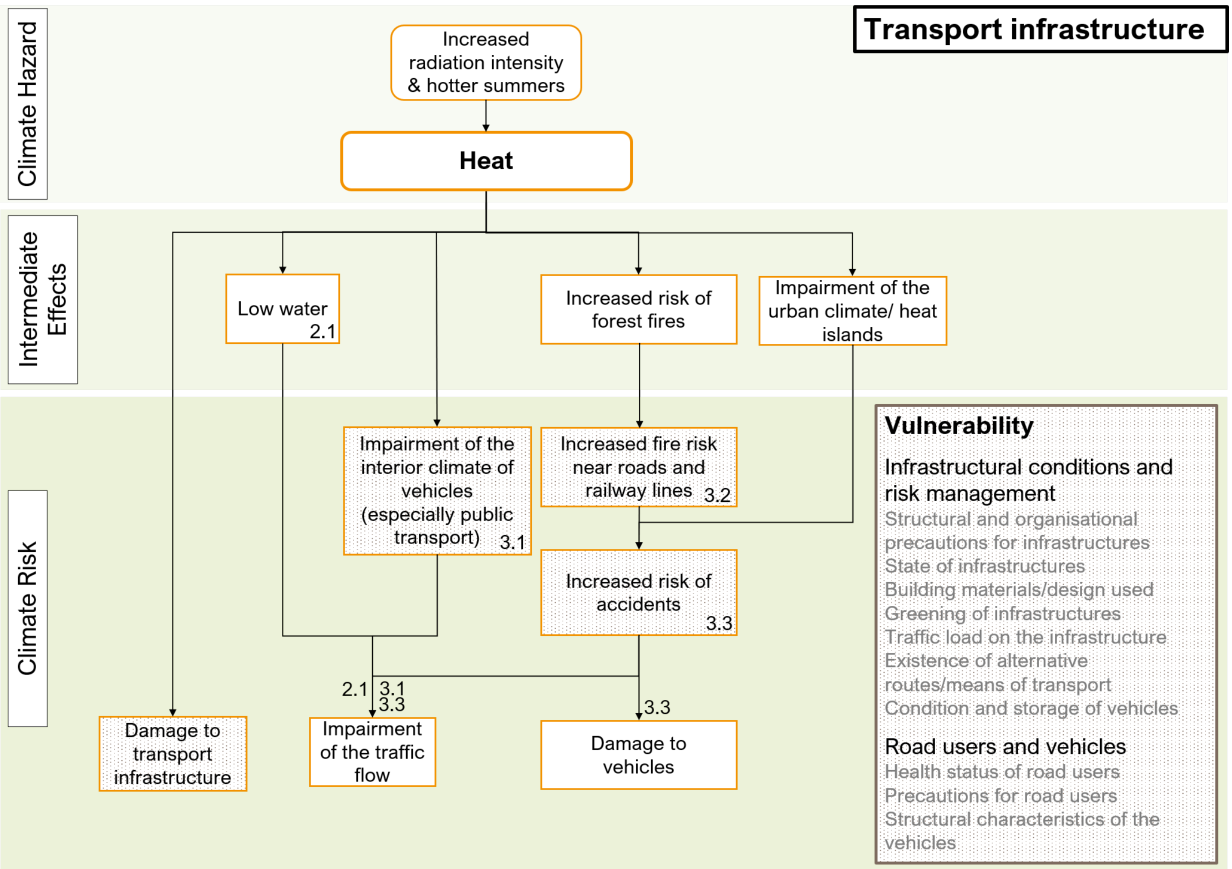



Figure 7: CIC for Heat on the transport infrastructure

## 2.4 Effect of heavy rain and flooding on different sectors

The following CICs show the impacts of the climate hazards River flooding and Heavy rain on the sectors: human health, agriculture, energy industry, transport infrastructure and industry and commerce. The top section of each subsequent CIC delineates the climate hazard. The middle section outlines the intermediate effects that can arise, while the final section illustrates the climate risks resulting from the climatic hazard and its associated consequences. The vulnerabilities that influence the effects of the climate hazard are highlighted in the black-framed box within each CIC.

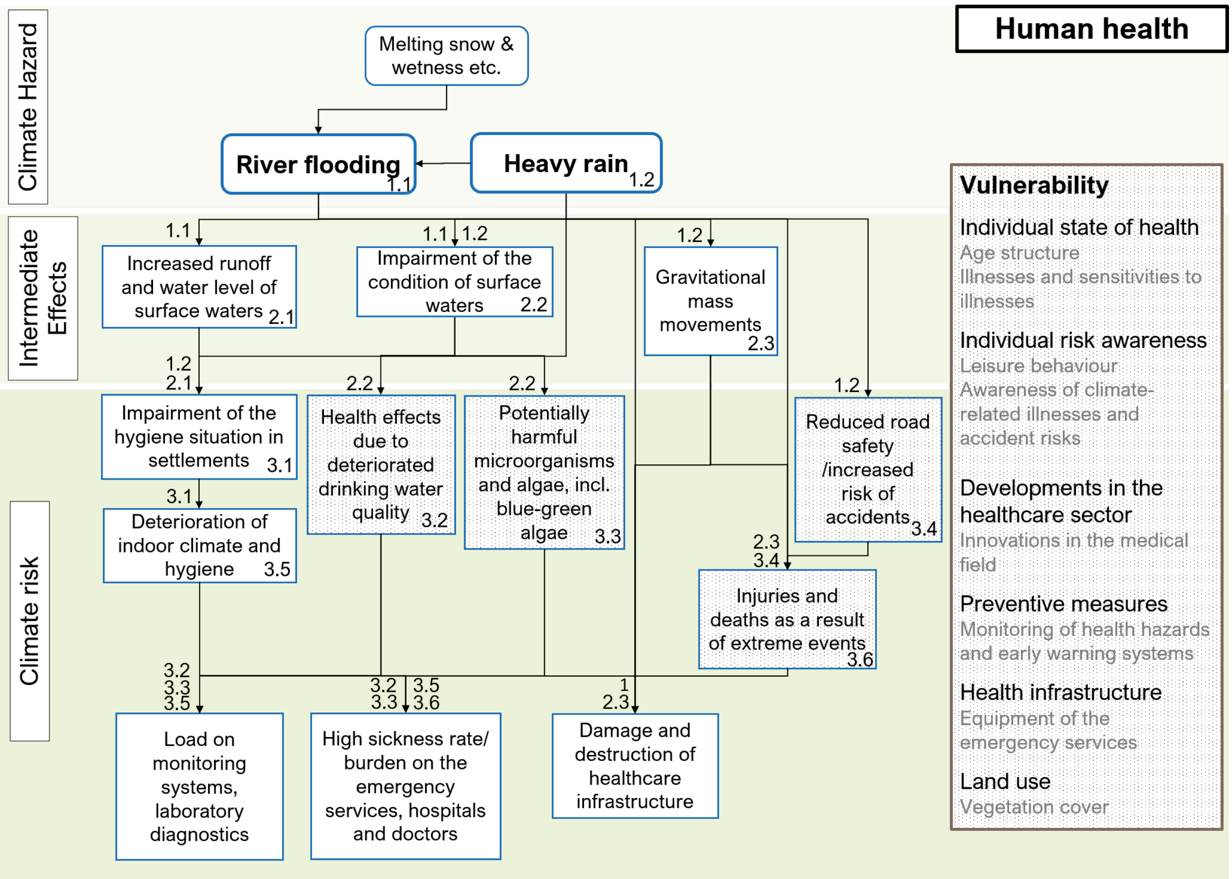



Figure 8: CIC for Heavy Rainfall and River Flooding on human health

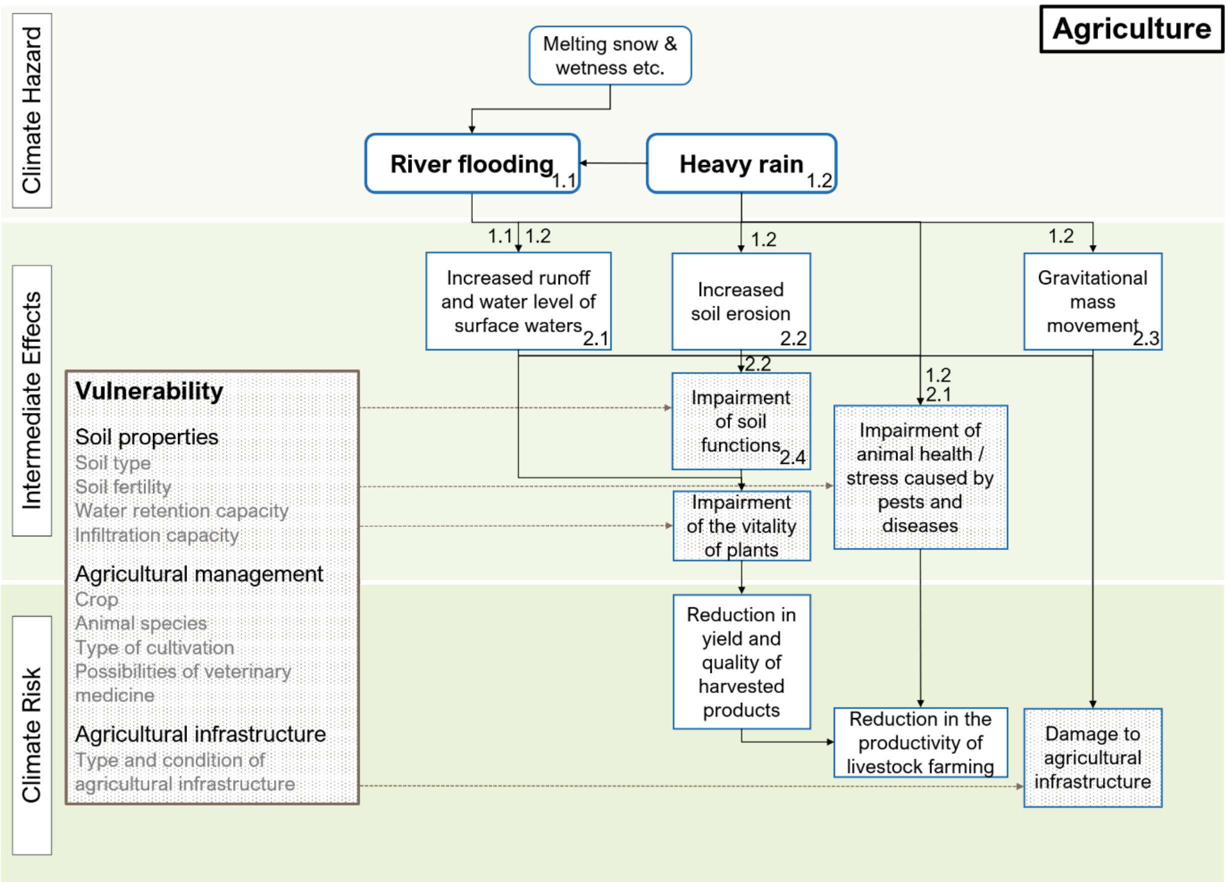



Figure 9: CIC for Heavy Rain and River Flooding on agriculture

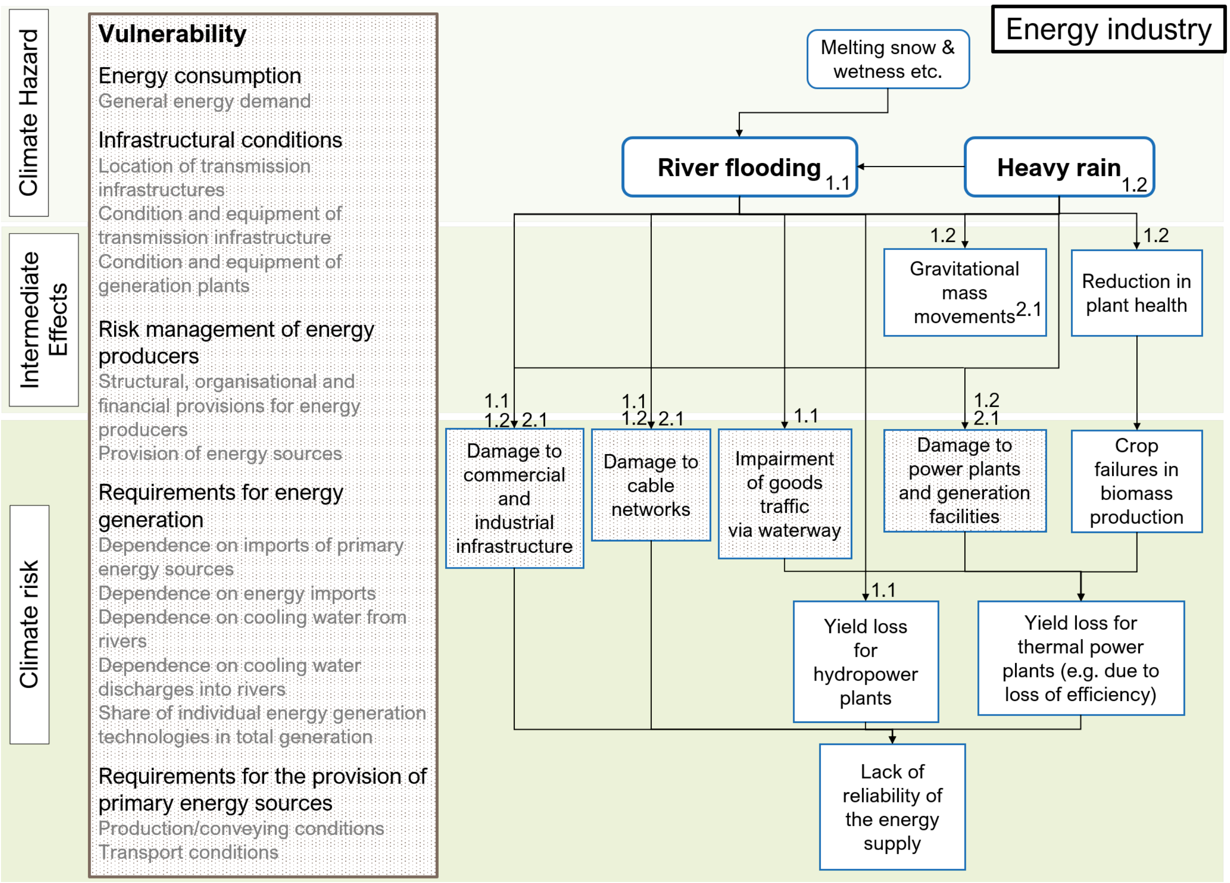



Figure 10: CIC for Heavy Rainfall and River Flooding on the energy industry

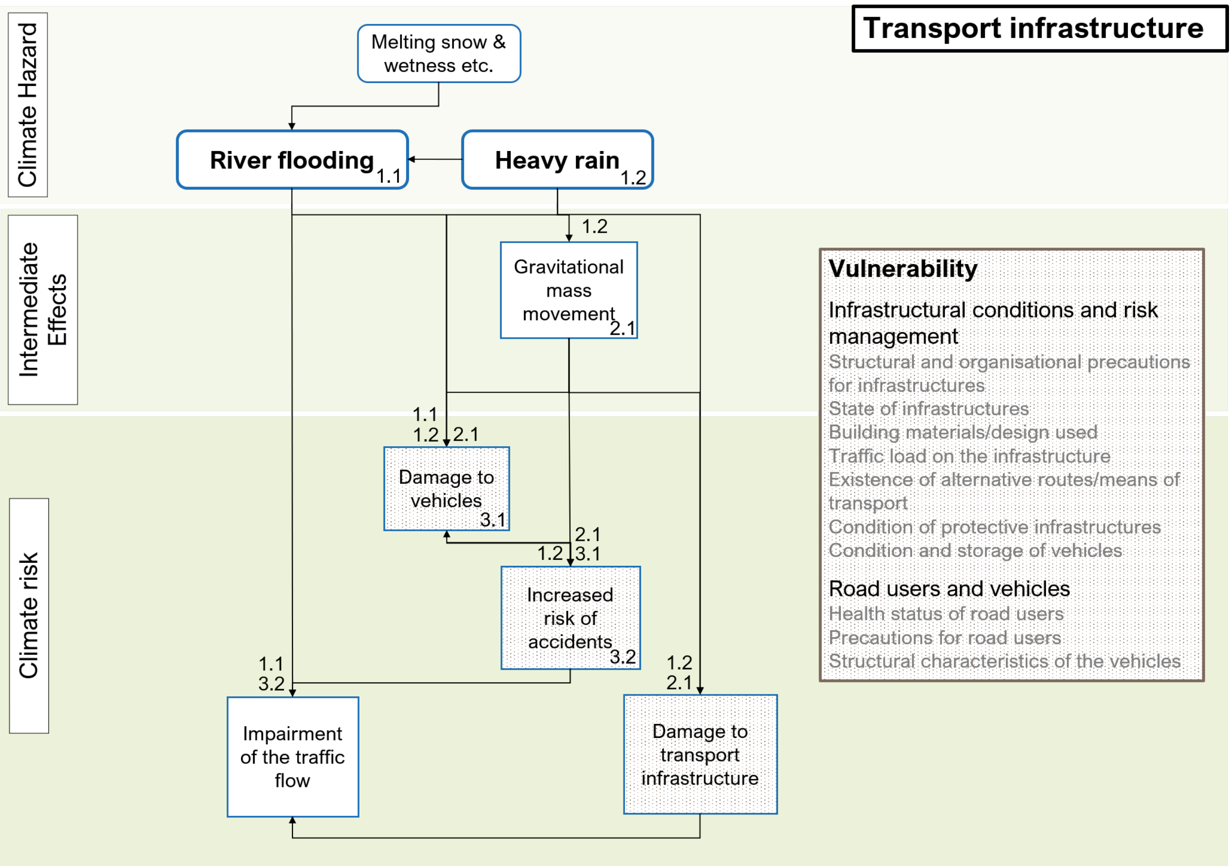



Figure 11: CIC for Heavy Rainfall and River Flooding on the transport infrastructure

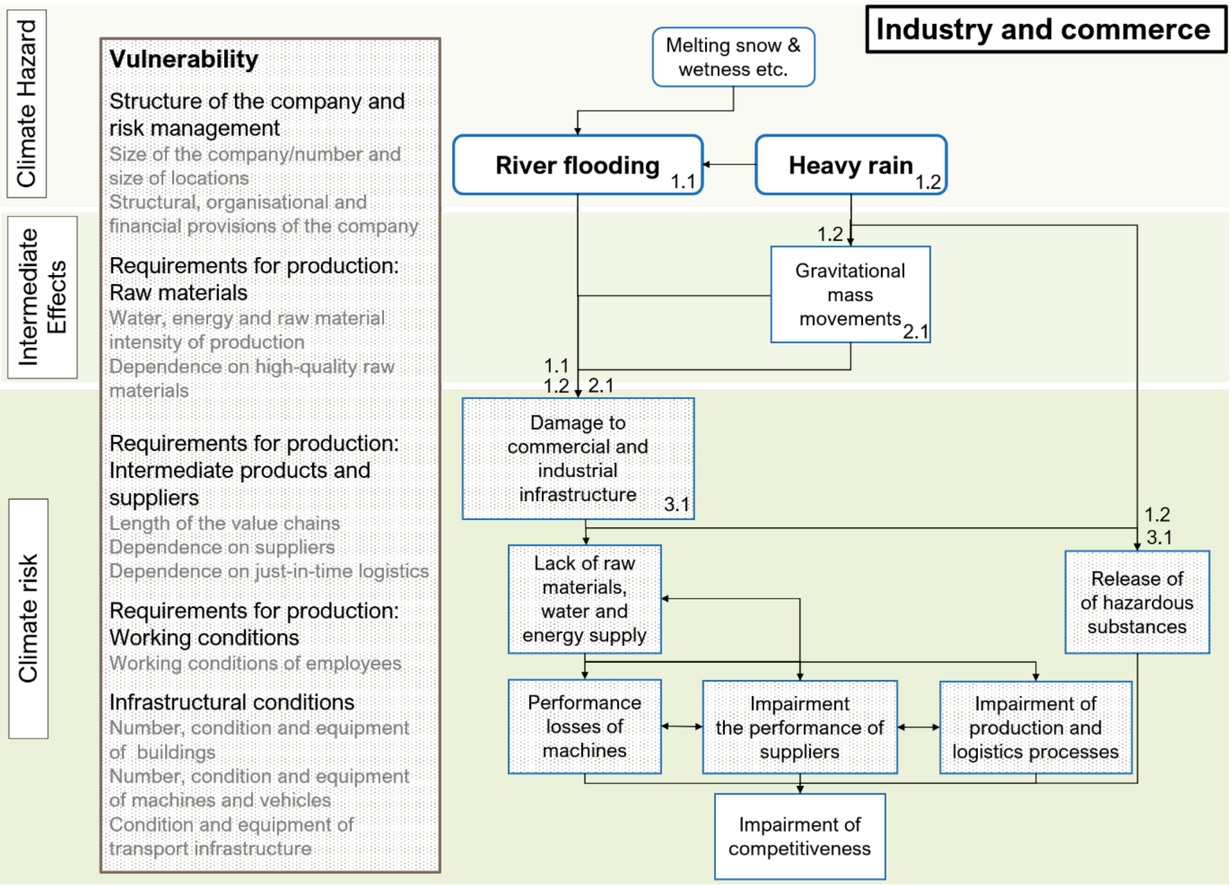



Figure 12: CIC for Heavy Rainfall and River Flooding on the transport infrastructure

## 2.5 Effect of storm surge on coastal and marine protection

In the following figure, the CIC of the climate hazard Storm Surge is depicted, showing the impact of this climate hazard on coastal and marine protection. The top section of the following CIC delineates the climate hazard. The middle section of each CIC outlines the intermediate effects that can arise, while the final section illustrates the climate risks resulting from the climatic hazard and its associated consequences. The vulnerabilities influencing the effects of the climate hazard are shown in the black framed box within the CIC.

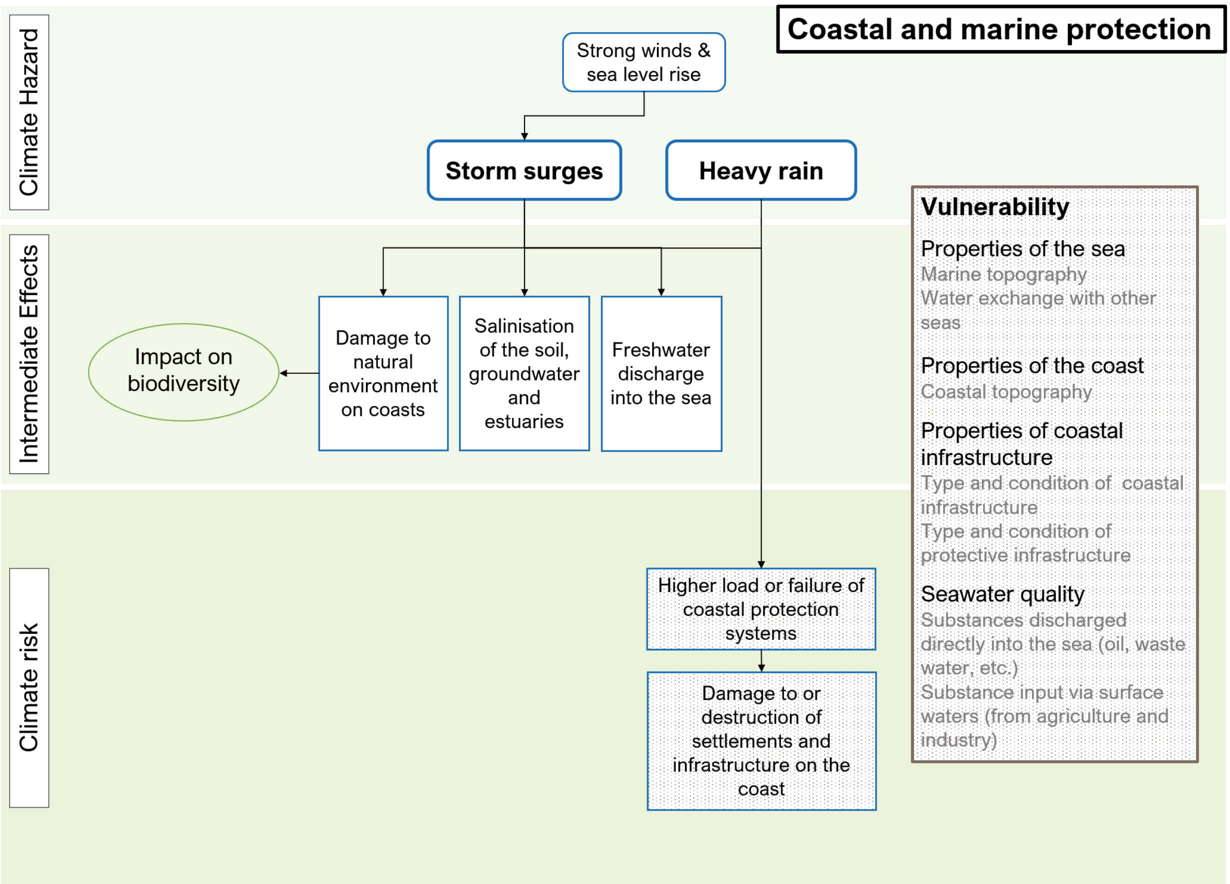



Figure 13: CIC for Storm Surges and Heavy Rainfall on coastal and marine protection

# 3. Nature-based solutions

The previously outlined effects of climate hazards on the various sectors highlight the need to develop suitable adaptation measures. In recent years, there has been a shift towards the implementation of nature-based solutions (NbS). The concept of NbS generally encompasses all kinds of strategies and approaches that utilise nature or natural processes to address societal challenges, such as climate change, or enhance sustainability. However, there is still a lack of clear differentiation regarding what exactly qualifies as NbS (Nesshöver et al. 2017).Two commonly cited definitions come from the European Commission and the International Union for Conservation of Nature:

NbS are „solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systematic interventions (European Commission and European Research Executive Agency 2022)."

NbS as "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)."

Based on these definitions, a number of criteria can be derived for NbS that distinguish them from conventional grey or technical solutions and are also applicable for NbS in the context of Land4Climate:

- NbS build on natural ecosystem processes and do not require intense engineered or technological interventions
- NbS protect or support biodiversity as well as ecosystem functions and thereby, enhance the adaptive capacity and resilience of ecosystems
- NbS are multifunctional and provide multiple co-benefits for both people and the environment, such as biodiversity conservation, water quality improvement, or recreational opportunities
- NbS are more cost-effective to implement and maintain than conventional grey infrastructure
- NbS need to be adapted to the local conditions

Depending on the NbS to be implemented they can act on various components (Hazard, Vulnerability and Exposure) of the risk concept (see section 2). The vulnerability component can be decreased by enhancing the resilience of the ecosystem and the communities. Lastly the exposure can be reduced by influencing the land use and planning strategies (European Environment Agency 2021).

When implementing NbS, it is important to consider the topic of scale, especially temporal scale and spatial scale. An essential consideration in the implementation of NbS is to minimize their negative effects while maximizing their positive impacts. This is particularly important when considering temporal scale, as the temporal aspects of NbS are complex and frequently extend beyond conventional planning periods. NbS often require a longer timeframe to demonstrate their full effectiveness.  When implementing NbS, there is often time pressure to adapt as fast as possible to reduce the risks of climate hazards (Odongo et al. 2022; Debele et al. 2023). Furthermore, the effectiveness of NbS in mitigating climate hazards and addressing climate change adaptation is highly dependent on spatial scale. Outcomes can vary based on the size and conditions of the implementation area.

NbS measures are classified as follows:

- microscale (local), where single NbS are investigated under site-specific conditions;
- mesoscale, involving groups of NbS measures at a catchment or neighborhood scale;

- and macroscale (regional), where a combination of NbS measures is upscaled to a larger region or city (Haghighatafshar et al., 2018; Debele et al., 2023).

## 3.1 List of NbS examples

Numerous projects, have already addressed the topic of NbS, with several extensive catalogues available, particularly in urban areas such as the EU project URBANGREENUP (URBAN GreenUP Consortium Partners 2017) or UniLab (Eisenberg et al. 2022) as well as the NbS Catalogue by the World Bank (World Bank 2021). NbS have also been addressed in various projects in non-urban areas, such as rural and natural landscapes, as well as mountain landscapes. These include, for example, the EU projects OPERANDUM (www.operandum-project.eu), PHUSICOS (https://www.phusicos.eu/) and RECONECT (http://www.reconect.eu/). These projects did investigate NbS in the context of their contribution in reducing the risk of hydro-meteorological hazards. Not only EU projects, but also global research initiatives and regional projects have already covered the topic of NBS.

However, despite the number of projects featuring NbS, there is no universal categorization of NbS. This deliverable does not aim to present a general overview of all nature-based solutions worldwide, but rather a selection of NbS that can be implemented on private land and are within the scope of the Land4Climate project. In the following, different NbS practices will be presented, that are commonly known and used within different sectors.

The sectors of application were selected based on the investigated sectors within the climate impact chains (section 2).

Those are:

1. Built Environment
2. Agriculture
3. Forest
4. River
5. Coast

The following NbS measures were selected based on the conditions and ideas of the FRR and the benefits the NbS could provide for the regions while reducing the climate impacts which are problematic within the regions. The selection of NbS is based on interviews with the FRR and workshops conducted during a consortium meeting in Ustí nad Labem, Czechia. Additionally, a literature review and searches on various NbS platforms, such as GeoIKP (https://geoikp.operandum-project.eu/), WOCAT (https://qcat.wocat.net/en/wocat/), Climate-ADAPT (https://climate-adapt.eea.europa.eu/), and Oppla (https://oppla.eu/), were performed to compile the following selection of NbS. These platforms provide numerous practical examples of NbS implemented worldwide. The focus was on identifying NbS that could be implemented on private land within the scope of the Land4Climate project. The objectives of this deliverable are to present potential NbS that can mitigate the impacts of the climate hazards identified in the project in a practical and clear manner for the FRR and RR. This selection can serve as a basis for the no-regret list of NbS, which is to be developed in close cooperation with the FRR project partners. “No regret” means in the context of the project, that the positive results should be maximized and the negative minimized. The co-designing and co-selection of NbS is important in further project steps to increase the acceptance of NbS in the implementation areas, especially when it comes to private land.

The following table gives an overview over all NbS presented within this deliverable and the main climate hazards (Drought, Heat, Flooding, Heavy Rain and additionally Storm Surge) that are addressed.

**Table 1: Overview of example NbS and the adressed climate hazards**

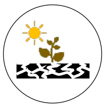
| Sector | NbS Measures | Drought | Heat | Flooding | Heavy Rain | Storm Surge |
|---|---|---|---|---|---|---|
| Built Environment | Tiny Forest | | X | | X | |
| | (Pocket) Parks | | X | | X | |
| | Greened Courtyards | | X | | X | |
| | Retention Ponds | | X | X | X | |
| | Rain Gardens | | X | | X | |
| | Bioswales | | X | | X | |
| | Unsealing of Surfaces | | X | | X | |
| | Planting of Trees | | X | | X | |
| | Hedges / Shrubs / Green Fences | | | | X | |
| | Green roofs / Green - blue roofs | | X | | X | |
| | Green walls / facades | | X | | X | |
| Agriculture | Planting of climate resilient plants | X | X | X | | |
| | Above-ground water reservoirs | X | | X | X | |
| | Grassland restoration | | X | X | X | |
| | Agroforestry | X | | | X | |
| | Vegetated buffer stripes | X | | | X | |
| | Slope vegetation | | | | X | |
| | Earth bunds | X | | X | X | |
| Forest | Reforestation | | X | | X | |
| | Diversification of Species | X | | | | |
| | Closing drainage ditches | X | | | | |
| | Create and fill water ponds | X | X | | | |
| River | Restoration of natural river courses | | | X | | |
| | Creation of retention areas | | | X | X | |
| | (Re-)connection of floodplains | | | X | | |
| | Riparian buffer zones | X | X | X | | |
| | Bank stabilisation | | | X | X | |
| Coast | Dune structures | | | X | | X |
| | Beach nourishment | | | | | X |
| | Restoration of coastal wetland | | | X | | X |

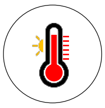
Each NbS description includes the name of the measure, the main climate impacts they mitigate, the co-benefits they can create, a concise description of their mode of function, as well as some literature to find more detailed information.

The following pictograms are used to explain the climate impacts the presented NbS mitigate.

 - Flooding

 - Heavy Rain

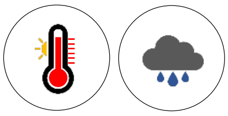
 - Drought

 - Heat

 - Storm Surge

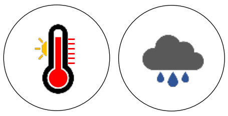
### 3.1.1 Built Environment

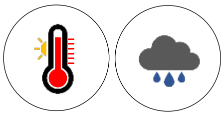
This chapter presents various example NbS that can be implemented within built environments. Each NbS is introduced in a fact sheet format. These fact sheets include information on climate impacts, co-benefits, and general details. Additionally, the fact sheets contain illustrative photographs of the NbS to visualize their implementation. Further literature references are also provided.

| **TINY FORESTS** | |
|---|---|
| <br>Figure 14: Tiny forest in Den Helder, Netherlands about one year after planting by Lars van der Heide, Wikimedia (CC BY-SA 4.0) | |
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, social impact |
| Description | Tiny forests are small-scale dense forests that mimic the structure and biodiversity of natural forests but are planted in urban or suburban areas. They are typically created by planting a variety of native tree species in a small area, often just a few hundred square meters. By providing shade and evaporative cooling, tiny forests help reduce temperatures in urban areas and mitigate the urban heat island effect. The vegetation in the tiny forest furthermore help to absorb and filter rainwater, reducing the risk of flooding. Further co-benefits tiny forests can provide are improvement of the air quality by storing carbon and social benefits due to the educational aspect for the community. |
| Literature | Cárdenas, Macarena L.; Pudifoot, Bethany; Narraway, Claire L.; Beumer, Victor; Hayhow, Daniel B. (2022): Nature-based Solutions Building Urban Resilience for People and the Environment: Tiny Forest as a case study. DOI: 10.5281/ZENODO.7053895<br><br>Earthwatch Europe (2024): Tiny Forest. Monitoring Report 2023. Available online at: https://tinyforest.earthwatch.org.uk/images/documents/Tiny-Forest-Monitoring-Report-2023.pdf, last checked on: 26.03.2024 |

## (POCKET) PARKS

Figure 15: Pocket Park, © Heinrich Stürzl, Wikimedia, (CC BY-SA 4.0)

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, social impact |
| Description | Pocket parks are small, usually public green spaces that are created in densely populated urban areas. These parks are often only a few hundred square metres in size and are usually created on small unused or derelict plots of land in urban environments. Pocket parks help to mitigate the urban heat island effect by providing green spaces that absorb less heat compared to concrete and asphalt surfaces. The vegetation in pocket parks can provide shade and cooling, reducing temperatures in surrounding areas. They can help manage stormwater runoff by absorbing and infiltrating rainfall. The vegetation and soil in these parks act as natural sponges, reducing the volume of water flowing into storm drains and alleviating pressure on drainage systems during heavy rain events. Additionally, parks can improve the air quality through the vegetation, create habitat for wildlife species and provide social impact for the community. |
| Literature | Blake, Alison (2013): Pocket parks. Available online at: https://depts.washington.edu/open2100/pdf/2_OpenSpaceTypes/Open_Space_Types/pocket_parks.pdf, last checked on 16.05.2024<br><br>Hamdy, Mennatallah & Plaku, Rovenna (2021): Pocket parks: Urban living rooms for urban regeneration. Civil Engineering and Architecture 9(3): 747-759 |

| GREENED COURTYARDS | |
|---|---|
| <br>Figure 16: Greened Courtyard on the campus of RWTH Aachen, ©Janine Lilia Freyer | |
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, social impact |
| Description | Greened courtyards are green and planted outdoor spaces located within or amidst buildings. They serve as private or semi-public green areas and can come in various shapes and sizes, from small courtyards between residential buildings to large communal gardens in residential complexes or office buildings. Greened courtyards can help manage the stormwater runoff and infiltrate water reducing the surface runoff. Furthermore, they can cool the surrounding area reducing the risk of urban heat islands. Additional co-benefits of greened courtyards are improvement of the air quality, increasing biodiversity within the built environment and social impacts due to the increased aesthetic value and recreational opportunities within the green area. |
| Literature | Leone, Antonio; Gobattoni, Federica; Pelorosso, Raffaele; Calace, Francesca (2020): Nature-based climate adaptation for compact cities: green courtyards as urban cool islands. Plurimondi 18: 83-110 |

## RETENTION PONDS

Figure 17: Retention Pond by Scott Schryvers, (CC BY-NC-SA 2.0), https://flic.kr/p/KM7VFe

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|---|---|
| Climate Impact |  |
| Co-benefits | Air quality, water quality, biodiversity |
| Description | Retention ponds are artificially created water basins which are permanently filled with water and are often enhanced by riparian planting. They primarily serve to capture and store stormwater runoff to reduce the risk of flooding. Usually retention ponds are sealed to prevent the water level from dropping too low, so that large parts of the collected stormwater usually evaporates. In case the water level exceeds the height of the pond liner, the water seeps over the edge of the slope into the ground. There are no special size or location requirements, so retention ponds are basically applicable to all locations. However, in order to contribute effectively to stormwater management, a certain minimum size should be achieved. Additionally, retention ponds are often vegetated around increasing the biodiversity due to creation of habitat for wildlife. Furthermore, retention ponds can increase the air quality and also the water quality by filtrating pollutants. |
| Literature | Eisenberg, Bernd; Chiesa, Cecilia; Fischer, Leonie K.; Jakstis, Kristen; Polcher, Vera; Schwarz-v. Raumer, Hans-Georg (2022): Nature-based Solutions. Technical Handbook Factsheets. Hg. v. UNaLab URBAN NATURE LABS Institut für Landschaftsplanung und Ökologie - ILPÖ. Institut für Landschaftsplanung und Ökologie. Available online at: https://unalab.eu/system/files/2022-11/unalab-nbs-technical-handbook-factsheets2022-11-17.pdf, last checked on 09.04.2024. |

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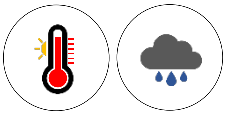
|---|---|
| | Staccione, Andrea; Broccoli, Davide; Mazzoli, Paolo; Bagli, Stefano; Mysiak, Jaroslav (2021): Natural water retention ponds for water management in agriculture: A potential scenario in Northern Italy. Journal of environmental management, 292, 112849 |

| **RAIN GARDENS** | |
|---|---|
| <br>Figure 18: Rain Garden by Arlington County, Flickr (CC BY-SA 2.0) https://flic.kr/p/24jE8Ki | |
| Climate Impact |  |
| Co-benefits | Air quality, water quality, biodiversity |
| Description | Rain gardens are shallow, vegetated depressions designed to capture and absorb stormwater runoff from impervious surfaces such as rooftops, driveways, and sidewalks. They are typically located in residential yards, along streets, or in public spaces where they can intercept runoff from nearby surfaces. Rain gardens are planted with a mix of native vegetation that can tolerate both wet and dry conditions. These plants help to absorb water, filter pollutants, and promote infiltration into the soil. The vegetation planted within rain gardens can provide reduction of temperatures in the surrounding area reducing the risk of urban heat islands. Furthermore, raingardens improve the biodiversity by creating habitats for beneficial insects and birds. |
| Literature | Bray, Bob; Gedge, Dusty; Grant, Gary; Leuthvilay, Lani: Rain Garden Guide. Available online at: https://raingardens.info/wp- |

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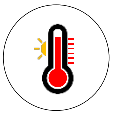
|---|---|
| | content/uploads/2012/07/UKRainGarden-Guide.pdf, last checked on: 03.04.2024.<br><br>Dietz, Michael E.; Clausen, John C. (2005): A Field Evaluation of Rain Garden Flow and Pollutant Treatment. In: Water Air Soil Pollut 167 (1-4), S. 123–138. DOI: 10.1007/s11270-005-8266-8.<br><br>Hinman, Curtis (2013): Rain Garden Handbook for Western Washington. A guide for design, maintenance, and Installation. Washington State University. Available online at: https://apps.ecology.wa.gov/publications/publications/1310027.pdf, last checked on 03.04.2024. |

| BIOSWALES | |
|---|---|
| <br>Figure 19: Bioswale by Aaron Volkening, Flickr (CC BY 2.0) https://flic.kr/p/dbsUk2 | |
| Climate Impact |   |
| Co-benefits | Air quality, water quality, biodiversity |
| Description | Bioswales are linear, gently sloping channels or swales designed to convey, filter, and treat stormwater runoff along its flow path. They are typically located in urban or suburban areas alongside streets, parking lots, or other paved surfaces where they can intercept and capture runoff. Bioswales are engineered with specialized soil mixes and vegetation to promote filtration, sedimentation, and pollutant removal as water moves through them. Unlike rain gardens, which are more localized and designed to capture runoff from specific |

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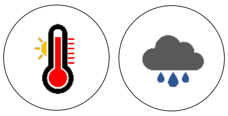
| | areas, bioswales are designed to manage larger volumes of runoff and can be longer in length to accommodate flow from multiple sources. |
| Literature | Anderson, Brian S.; Phillips, Bryn M.; Voorhees, Jennifer P.; Siegler, Katie; Tjeerdema, Ronald (2016): Bioswales reduce contaminants associated with toxicity in urban storm water. Environmental toxicology and chemistry, 35(12), 3124-3134. |

| **UNSEALING OF SURFACES** | |
|---|---|
| <br>Figure 20: Permeable pavers by NYS Stormwater, Flickr (CC BY 2.0), https://flic.kr/p/rNS3P6 | |
| Climate Impact |  |
| Co-benefits | Water quality |
| Description | Unsealing involves breaking through paved surfaces such as asphalt roads, car parks or concrete surfaces and replacing them with permeable surfaces. Suitable permeable materials are available for almost all areas of application as long as the substructure is permanently permeable to water. The following permeable surface materials are recommended:<br>• Gravel turf: The surface consists of a mixture of humus and gravel or chippings. Turf seed is scattered over the surface and then compacted.<br>• Gravel surface: The surface consists of gravel or chippings with a uniform medium grain size, which is laid on a permeable substructure. |

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| | Permeable surfaces can help reduce the surface runoff by collecting rainwater and trap suspended solids and pollutants. Furthermore, they can help recharge the groundwater and reduce surface temperatures. |
| Literature | Iwaszuk, Ewa; Rudik, Galina; Duin, Laurens; Mederake, Linda; Davis, McKenna; Naumann, Sandra (2019): Addressing climate change in cities. Catalogue of urban nature-based solutions. Warsaw: The Sendzimir Foundation.<br>Giudice, Benedette; Novarina, Gilles; Voghera, Angioletta (2023): Limiting soil sealing and depaving: local actions for regenerating public spaces to build green infrastructures. In Green Infrastructure: Planning Strategies and Environmental Design. Springer International publishing |

**PLANTING OF TREES**

Figure 21: Trees in urban environment, © Janine Lilia Freyer

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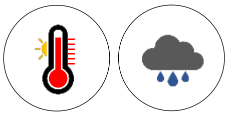
|---|---|
| Climate Impact |  |
| Co-benefits | Biodiversity, air quality |
| Description | The planting of trees involves adding vegetation to streets, parks, squares, and other spaces. Trees help to reduce the urban heat island effect by providing shade, lowering temperatures, and improving air quality through the absorption of pollutants and the release of oxygen. Furthermore, trees provide shelter and habitats for wildlife species. |

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|---|---|
| Literature | Eisenberg, Bernd; Chiesa, Cecilia; Fischer, Leonie K.; Jakstis, Kristen; Polcher, Vera; Schwarz-v. Raumer, Hans-Georg (2022): Nature-based Solutions. Technical Handbook Factsheets. Hg. v. UNaLab URBAN NATURE LABS Institut für Landschaftsplanung und Ökologie - ILPÖ. Institut für Landschaftsplanung und Ökologie. Available online at: https://unalab.eu/system/files/2022-11/unalab-nbs-technical-handbook-factsheets2022-11-17.pdf, last checked on: 09.04.2024.<br><br>Foster, Josh; Lowe, Ashley; Winkelmann, Steve (2011): The value of green infrastructure for urban climate adaptation. *Center for Clean Air Policy*, *750*(1), 1-52<br><br>Sampson, r. Neil (1992): Forestry opportunities in the United States to mitigate the effects of global warming. Water, Air, and Soil Pollution, 64, 157-180 |

| **HEDGES / SHRUBS / GREEN FENCES** | |
|---|---|
| <br>Figure 22: Green fence, © Janine Lilia Freyer | |
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, noise reduction |
| Description | Green fence are barriers consisting of vegetation, as hedges or shrubs. They create divisions within a landscape and can serve as boundaries or enclosures around a property, as residential garden, commercial properties or public spaces. Unlike traditional fences consisting of metal or wood, green fences consist of vegetation that grows and forms a natural barrier over time. Green |

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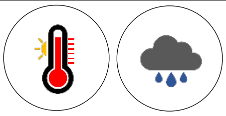
| | fences can help slow down the surface runoff by evaporation and interception of the leaves, which can help reduce pressure to the sewer system while extreme rainfall events. Green fences can help purify the air in the surrounding area, create habitat for wildlife and also reduce noise disturbance from the surrounding areas. |
| Literature | GeoIKP (2021): Green fences to control flood peaks at the University of Glasgow, Scotland, UK. Available online at: https://geoikp.operandum-project.eu/nbs/explorer/details/3478, last checked on: 17.05.2024<br>MOBILANE Building green: Benefits of green fences in the garden. Available online at: https://mobilane.com/en/news/benefits-of-green-fences-in-the-garden/, last checked on: 17.05.2024 |

| GREEN ROOFS / GREEN-BLUE ROOFS | |
|---|---|
| <br>**Figure 23: Green Roof of the Institute of Hydraulic Engineering and water management from the RWTH Aachen, ©Janine Lilia Freyer** | |
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, sound insulation |
| Description | A green roof is a rooftop partially or completely covered by vegetation growing in a suitable medium, planted over a waterproofing membrane. Green roofs can be installed on a wide range of buildings including residential homes or public office buildings. Green roofs can infiltrate rainfall, reduce the surface water runoff from roofs and alleviate stress on sewage systems. Additionally, they help cool and humidify the surrounding air, mitigating the urban heat island |

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| | effect and contribute to the local air purification. Additionally, green roofs can contribute to the improvement of biodiversity in the built environment and help reduce noise disturbance. Green roofs can be combined with blue roof systems and provide additional stormwater management function. Rainfall is stored and released into the environment gradually, allowing for reuse in irrigation or controlled discharge into the sewer system at a later time. |
| Literature | Shafique, Muhammad; Kim, Reeho; Rafiq, Muhammad (2018): Green roof benefits, opportunities and challenges – A review. In: Renewable and Sustainable Energy Reviews 90, S. 757–773. DOI: 10.1016/j.rser.2018.04.006.<br><br>World Bank (2021): A Catalogue of Nature-based Solutions for Urban Resilience. Unter Mitarbeit von World Bank Group. Washington, D.C. Available online at: https://openknowledge.worldbank.org/entities/publication/c33e226c-2fbb-5e11-8c21-7b711ecbc725, last checked on: 08.04.2024.<br><br>Iwaszuk, Ewa; Rudik, Galina; Duin, Laurens; Mederake, Linda; Davis, McKenna; Naumann, Sandra (2019): Addressing climate change in cities. Catalogue of urban nature-based solutions. Warsaw: The Sendzimir Foundation.<br><br>Eisenberg, Bernd; Chiesa, Cecilia; Fischer, Leonie K.; Jakstis, Kristen; Polcher, Vera; Schwarz-v. Raumer, Hans-Georg (2022): Nature-based Solutions. Technical Handbook Factsheets. Hg. v. UNaLab URBAN NATURE LABS Institut für Landschaftsplanung und Ökologie - ILPÖ. Institut für Landschaftsplanung und Ökologie. Available online at: https://unalab.eu/system/files/2022-11/unalab-nbs-technical-handbook-factsheets2022-11-17.pdf, last checked on: 09.04.2024. |

## GREEN WALLS / FACADES

Figure 24: Green Facade, © Janine Lilia Freyer

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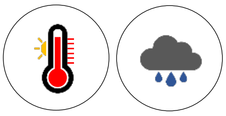
| Climate Impact |  |
| Co-benefits | Biodiversity, air quality, sound insulation |
| Description | Green walls or facades are partially or completely covered by vertically growing vegetation. The vegetation can grow directly at the façade/wall or along supporting structures installed in front of the wall or facade. Greening can also be carried out by planting the vegetation in boxes attached to the facade or wall. Any facade or wall can generally be greened with minimal space requirement. Green walls or facades can help reduce stormwater runoff by absorbing and retaining rainwater through the plants root system. Additionally, green walls help mitigate the urban heat island effect by shading building and surfaces, reducing heat absorption and promoting evaporative cooling. Furthermore, they can improve biodiversity within built environments, increase the quality of the surrounding air and provide sound insulation. |
| Literature | Eisenberg, Bernd; Chiesa, Cecilia; Fischer, Leonie K.; Jakstis, Kristen; Polcher, Vera; Schwarz-v. Raumer, Hans-Georg (2022): Nature-based Solutions. Technical Handbook Factsheets. Hg. v. UNaLab URBAN NATURE LABS Institut für Landschaftsplanung und Ökologie - ILPÖ. Institut für Landschaftsplanung und Ökologie. Available online at: https://unalab.eu/system/files/2022-11/unalab-nbs-technical-handbook-factsheets2022-11-17.pdf, last checked on: 09.04.2024. |

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|---|---|
| | World Bank (2021): A Catalogue of Nature-based Solutions for Urban Resilience. Unter Mitarbeit von World Bank Group. Washington, D.C. Available online at: https://openknowledge.worldbank.org/entities/publication/c33e226c-2fbb-5e11-8c21-7b711ecbc725, last checked at: 08.04.2024.<br><br>Iwaszuk, Ewa; Rudik, Galina; Duin, Laurens; Mederake, Linda; Davis, McKenna; Naumann, Sandra (2019): Addressing climate change in cities. Catalogue of urban nature-based solutions. Warsaw: The Sendzimir Foundation.<br><br>Radić, Mina; Brković Dodig, Marta; Auer, Thomas (2019): Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits. In: Sustainability 11 (17), S. 4579. DOI: 10.3390/su11174579. |

## 3.1.2 Agriculture

In this chapter NbS measures will be presented, that can help mitigate the impacts of the climate hazards relevant for the Land4Climate project in the agricultural sector.

**PLANTING OF CLIMATE-RESILIANT PLANTS**

Figure 25: Salicornia salt-resistant plant © Jens-Christian Svenning, iNaturalist (CC BY 4.0)

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| Climate Impact |  |
| Co-benefits | Seawater intrusion, soil health |
| Description | Climate-resilient plants are crop varieties, that are bred or planted to tolerant biotic and abiotic stresses. They should maintain or increase the crop growth under climatic stresses such as droughts, floods (submergence), heat or salinity. In coastal areas for example, salt-tolerant plants can help reduce the intrusion of saltwater. Plants like Salicornia have the ability to filter pollutants and salt from the soil, which can help counteract soil and groundwater salinization. |
| Literature | Glenn, E. P., Brown, J. J., & Blumwald, E. (1999). Salt Tolerance and Crop Potential of Halophytes. Critical Reviews in Plant Sciences, 18(2), 227–255. https://doi.org/10.1080/07352689991309207<br>Acevedo, M., Pixley, K., Zinyengere, N. *et al.* A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nat. Plants* **6**, 1231–1241 (2020). https://doi.org/10.1038/s41477-020-00783-z<br>Katel, S., Yadav, S. P. S., Turyasıngura, B., Mehta, A. (2023). Salicornia as a salt-tolerant crop: potential for addressing climate change challenges and |

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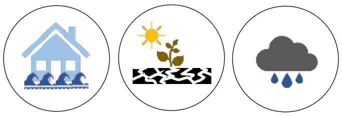
|---|---|
| | sustainable agriculture development. Turkish Journal of Food and Agriculture Sciences, 5(2), 55-67. https://doi.org/10.53663/turjfas.1280239<br>Climate Adapt (2019): Use of adapted crops and varieties. Available online at: https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/use-of-adapted-crops-and-varieties, last checked on: 17.05.2024 |

| **ABOVE-GROUND WATER RESERVOIRS** | |
|---|---|
| <br>Figure 26: Pond near agricultural land, PxHere | |
| Climate Impact |  |
| Co-benefits | Biodiversity |
| Description | Above-ground water reservoirs, as ponds or lakes can store and collect rainwater above the ground for irrigation purposes of agricultural land. They can capture and store stormwater runoff, that can help to ensure water availability during times of water scarcity. They can provide water for crops during dry periods or droughts. Furthermore, they can minimise the risk of flooding during heavy rainfall events in summer and increasing the biodiversity by creating habitat. |
| Literature | Pistocchi, A. (ed.), Nature-based solutions for agricultural water management — Characteristics and enabling factors for a broader adoption, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/343927, JRC131465.<br>Yorkshire Dales National Park Authority (2017): Natural Flood Management Measures. a practical guide for farmers. Available online at: https://thefloodhub.co.uk/wp-content/uploads/2018/10/A-practical-guide-for-farmers.pdf, last checked on: 15.05.2024. |

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|---|---|
| | Staccione, Andrea; Broccoli, Davide; Mazzoli, Paolo; Bagli, Stefano; Mysiak, Jaroslav (2021): Natural water retention ponds for water management in agriculture: A potential scenario in Northern Italy. Journal of Environmental Management Volume 292, 112849<br><br>Yazdi, Mohammad N.; Scott, Durelle; Sample, David J.; Wang, Xixi (2021): Efficacy of a retention pond in treating stormwater nutrients and sediment. Journal of cleaner production, 290, 125787 |

**GRASSLAND RESTORATION**

Figure 27: Grassland, © Janine Lilia Freyer

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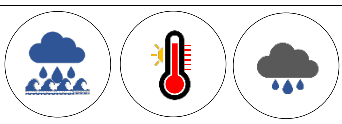
|---|---|
| Climate Impact |  |
| Co-benefits | Soil health, air quality, wind erosion |
| Description | Grassland restoration intends to rehabilitate degraded or disturbed grassland ecosystems to a natural and functional state, to recover biodiversity, ecosystem functions and services. Grassland can help reduce soil erosion induced by wind as well as water runoff. Grassland can help remove pollutants from the stormwater runoff and contribute to aquifer recharge. They show high diversity of biodiversity and create habitat for different wildlife species as pollinators and birds. Furthermore, grasslands can reduce the air temperature and cool the ground at a local scale through transpiration of the vegetation. Grasslands are able to store carbon and have air quality purification functions. |

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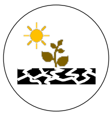
| Literature | Zhao, Y., Liu, Z. & Wu, J. Grassland ecosystem services: a systematic review of research advances and future directions. Landscape Ecol 35, 793–814 (2020). https://doi.org/10.1007/s10980-020-00980-3<br><br>Török, Péter; Brudvig, Lars A.; Kollmann, Johannes; N. Price, Jodi; Tóthmérész, Béla (2021): The present and future of grassland restoration. In: *Restoration Ecology* 29 (S1), Artikel e13378. DOI: 10.1111/rec.13378. |

| **AGROFORESTRY** | |
|---|---|
| <br>Figure 28: Agroforestry, ©AGFORWARD project, Flickr (CC BY-NC-SA 2.0), https://flic.kr/p/nvDVfJ | |
| Climate Impact |   |
| Co-benefits | Biodiversity, air quality, soil health, wind erosion |
| Description | Agroforestry is a landscape management system, where woody vegetation as trees, shrubs and hedges are integrated into agricultural and productive landscapes. Agroforestry can slow down stormwater runoff and therefore contradict the loss of nutrients through soil erosion. The woody vegetation provides shade for the fields and therefore reduces high temperatures and reduces crop damage. Agroforestry can help filtering stormwater from pollutants, reducing the risks of groundwater contradiction and increasing the soil quality. The roots of the woody vegetation can increase the water infiltration and retention capacity of the soil and therefore improve the resistance of croplands to droughts. Agroforestry can increase biodiversity as it creates habitat for wildlife species and the vegetation gives shelter and therefore can reduce wind erosion. Additionally, Agroforestry can help increase the air quality on a local scale. |

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| Literature | Climate Adapt (2014): Agroforestry: agriculture of the future? The case of Montpellier. Available online at: https://climate-adapt.eea.europa.eu/en/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier/#source, last checked on: 17.05.2024<br><br>Blanco-Canqui, Humberto (2024): Assessing the potential of nature-based solutions for restoring soil ecosystem services in croplands. In: *The Science of the total environment* 921, S. 170854. DOI: 10.1016/j.scitotenv.2024.170854.<br><br>European Environment Agency, Castellari, S., Zandersen, M., Davis, M. et al., Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction, Publications Office, 2021, Available online at: https://data.europa.eu/doi/10.2800/919315, last checked on: 24.05.2024 |

**VEGETATED BUFFER STRIPES**

Figure 29: Vegetated buffer strip by Ohio NRCS, Flickr, https://flic.kr/p/2mxooub

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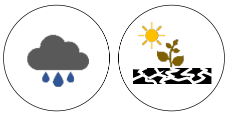
| Climate Impact |  |
| Co-benefits | Biodiversity, soil health, wind erosion |
| Description | Vegetated buffer strips are areas of perennial vegetation at the edges or within agricultural fields. The buffer zones can be implemented with different vegetation types. Prairie strips for example are a mixture of native perennial plant species including grasses, legumes, wildflowers and sedges. Grass buffers include grass hedges and vegetative filter stripes, grass hedges often consist of monocultures of perennial warm-season grasses as switchgrass and miscanthus and vegetative filter strips consist of cool-season short-growing |

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| | grass. Vegetated buffer zones can reduce stormwater surface runoff, preventing soil erosion and the loss of sediments and nutrients from the crop fields and improve the water infiltration functions. They can help improve the water retention capacity within cropland soil and therefore favouring drought resilience. Additional benefits vegetated buffer zones can provide are increased biodiversity by creating habitat for wildlife species, increasing the soil health and reducing soil erosion through wind hazard. |
| Literature | Yorkshire Dales National Park Authorithy (2017): Natural Flood Management Measures. a practical guide for farmers. Available online at: https://thefloodhub.co.uk/wp-content/uploads/2018/10/A-practical-guide-for-farmers.pdf, last checked on: 15.05.2024.<br><br>Blanco-Canqui, Humberto (2024): Assessing the potential of nature-based solutions for restoring soil ecosystem services in croplands. In: The Science of the total environment 921, S. 170854. DOI: 10.1016/j.scitotenv.2024.170854.<br><br>Haddaway, N.R., Brown, C., Eales, J. et al. The multifunctional roles of vegetated strips around and within agricultural fields. Environ Evid 7, 14 (2018). https://doi.org/10.1186/s13750-018-0126-2 |

| **SLOPE VEGETATION** | |
|---|---|
| <br>Figure 30: Slope vegetation near an agricultural area by Alfons, Flickr, https://flic.kr/p/KDJAAD | |
| Climate Impact |  |
| Co-benefits | Biodiversity, soil Health |
| Description | Planting vegetation as trees, shrubs and others at a slope in agricultural areas or also near streams and rivers can stabilize the slope or hillside and serve as a natural barrier against soil erosion or mass movement. The roots of the |

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| | vegetation help stabilizing the slope by binding soil particles. The planted vegetation can help capture and restrain sediments, slows down surface water runoff and increase the infiltration functions within extreme weather events such as heavy rainfall. |
| Literature | Stokes, A. *et al.* (2008). How Vegetation Reinforces Soil on Slopes. In: Norris, J.E., *et al.* Slope Stability and Erosion Control: Ecotechnological Solutions. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-6676-4_4<br><br>Durán Zuazo, Víctor Hugo; Rodríguez Pleguezuelo, Carmen Rocío (2008): Soil-erosion and runoff prevention by plant covers. A review. In: *Agron. Sustain. Dev.* 28 (1), S. 65–86. DOI: 10.1051/agro:2007062.<br><br>BaseCore (2024): The Role of Vegetation in Slope Stability, Available online at:<br><br>https://www.basecore.co/vegetation-in-slope-stability/#:~:text=few%20different%20ways.-,Below%20the%20Surface,reduces%20the%20likelihood%20of%20erosion, last checked on: 17.05.2024 |

| Earth bunds | |
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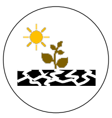
| <br>Figure 31: Earth and stone bunds adjacent to an agricultural area, Wikimedia (CC BY-SA 4.0) | |
| Climate Impact |    |
| Co-benefits | Biodiversity |
| Description | Earth bunds are barriers or embankments, that are shaped with soil, stone or mixed-material. They are typically built along contour lines or across slopes to reduce soil erosion, promote water retention, and increase crop production. Depending on the characteristics of the landscape and the use purpose earth |

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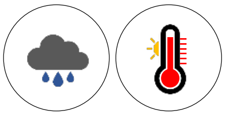
| | bunds can vary in size and shape. Earth bunds can also be reinforced with vegetation or stone for more stabilization. |
| Literature | WOCAT: Glossary. Available online at: https://www.wocat.net/en/glossary/#heading-b, last checked on: 17.05.2024<br>Mekdaschi Studer, R. and Liniger, H. (2013). Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; MetaMeta, Wageningen; The International Fund for Agricultural Development (IFAD), Rome.<br>Yorkshire Dales National Park Authorithy (2017): Natural Flood Management Measures. a practical guide for farmers. Available online at: https://thefloodhub.co.uk/wp-content/uploads/2018/10/A-practical-guide-for-farmers.pdf, last checked on: 15.05.2024. |

### 3.1.3 Forest areas

This chapter of the deliverable introduces NbS examples that can be implemented within forest areas.

| **REFORESTATION** | |
|---|---|
| <br>Figure 32: Forest, © Janine Lilia Freyer | |
| Climate Impact |  |
| Co-benefits | Biodiversity, air quality, water quality, soil health |
| Description | Reforestation is the conversion of previously forested land back to forest. Reforestation can help restore deforested land and improve the quality of degraded forests. Reforestation can increase the infiltration rates of runoff into the soil and slow down the surface runoff reducing the risk of soil erosion. Forests have the ability to filter out pollutants and sediments from runoff. Forests reduce the local temperatures through evaporative cooling and shading. Forests act as a carbon sink, accumulating carbon dioxide from the atmosphere into the soil and the vegetation. Reforestation can create habitat for local wildlife species, enhancing the local biodiversity and improves the soil structure. Reforestation areas should be included in ongoing or planned national monitoring schemes to evaluate their economic, environmental, social and cultural impacts and respective carbon balances. |
| Literature | Climate Impact (2019): Afforestation and reforestation as adaption opportunity. Available online at:<br>https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/afforestation-and-reforestation-as-adaptation-opportunity#:~:text=However%2C%20they%20can%20also%20help,migration%20under%20climate%20change%20conditions, last checked on 17.05.2024 |

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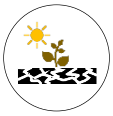
|---|---|
| | Cunningham, S. C.; Mac Nally, R.; Baker, P. J.; Cavagnaro, T. R.; Beringer, J.; Thomson, J. R.; Thompson, R. M. (2015): Balancing the environmental benefits of reforestation in agricultural regions. In: *Perspectives in Plant Ecology, Evolution and Systematics* 17 (4), S. 301–317. DOI: 10.1016/j.ppees.2015.06.001. |

**DIVERSIFICATION OF SPECIES**

Figure 33: Species-rich forest section © Anne Mozer

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Water security, biodiversity, soil protection |
| Description | Diversifying the species ensures that the forest becomes more diverse. Diversification of species within forest can lead to a lesser susceptibility against abiotic and biotic stresses as droughts and pest outbreaks. Forest conversion, which creates a mixed forest and thus diversifies the species within the forest, can increase the vitality of the forests. Forests with a high diversity of species can absorb more water, thus increasing the water storage capacity. Furthermore, diverse forest can increase the biodiversity and create habitat for wildlife. |
| Literature | Messier C, Bauhus J,Sousa-Silva R, et al. For the sake of resilience andmultifunctionality, let's diversify planted forests!Conservation Letters.2022;15:e12829.https://doi.org/10.1111/conl.12829<br><br>Yang, Yanbo; Jing, Lixin; Li, Qi; Liang, Chentao; Dong, Quanxing; Zhao, Shuting et al. (2023): Big-sized trees and higher species diversity improve |

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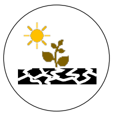
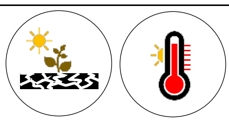
|---|---|
| | water holding capacities of forests in northeast China. In: The Science of the total environment 880, S. 163263. DOI: 10.1016/j.scitotenv.2023.163263<br><br>Adams, H.D., Zeppel, M.J.B., Anderegg, W.R.L. et al. A multi-species synthesis of physiological mechanisms in drought-induced tree mortality. Nat Ecol Evol 1, 1285–1291 (2017). https://doi.org/10.1038/s41559-017-0248-x<br><br>Scientific Advisory Board on Forest Policy (2022): Adaptation of forests and forestry to climate change. Berlin, 53 S. Available online at: https://www.bmel.de/SharedDocs/Downloads/EN/_Ministry/climate-adaptation.pdf?__blob=publicationFile&v=5, last checked on: 17.05.2024<br><br>Anderegg, W.R.L., Konings, A.G., Trugman, A.T. et al. Hydraulic diversity of forests regulates ecosystem resilience during drought. Nature 561, 538–541 (2018). https://doi.org/10.1038/s41586-018-0539-7 |

## CLOSING DRAINAGE DITCHES

Figure 34: Drainage Ditch in a forest by Paul Schulze, Humboldt-Universität zu Berlin, Flickr (CC BY 2.0), https://flic.kr/p/jdcTWJ

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Biodiversity, water availability in the soil |

| | |
|---|---|
| Description | A drainage ditch system allows rainwater to run off the surface instead of slowly seeping into the forest. It is therefore not available for the forest trees, which urgently need it in summer. In dry summers, this results in drought damage to the forest trees. Closing ditches is intended to prevent this and improve the water availability in the forest. Closing drainage ditches can improve the availability of water in the soil to increase the water availability to the vegetation. Furthermore, it can have positive effects for the local biodiversity. |
| Literature | Lidberg, William; Paul, Siddhartho Shekhar; Westphal, Florian; Richter, Kai Florian; Lavesson, Niklas; Melniks, Raitis et al. (2023): Mapping Drainage Ditches in Forested Landscapes Using Deep Learning and Aerial Laser Scanning. In: *J. Irrig. Drain Eng.* 149 (3), Artikel 04022051. DOI: 10.1061/JIDEDH.IRENG-9796.<br>Bieker,Elmer,Wittjen,Linnemann (2013), Mehr Wasser für feuchte Wälder und Moore, AFZ-DerWald 2/2018 S. 13 ff. Available online at: http://www.fit-fuer-den-klimawandel.de/wp-content/uploads/2018/01/Bieker_2018_Hydrologische-Optimierung_AFZ.pdf., last checked on: 17.05.2024 |

| **CREATE AND FILL WATER PONDS** | |
|---|---|
| <br>Figure 35: Fire suppression pond near a forest area by Dyan Bone, Flickr (CC BY 2.0), https://flic.kr/p/Z1xgrj | |
| Climate Impact |  |
| Co-benefits | Biodiversity |

| | |
|---|---|
| Description | A fire suppression pond is a pond that contains water used exclusively for fighting active fires. The pond's water, known as fire water, is often the primary firefighting system for rural and agricultural settings. Creating fire suppression ponds can also increase the local biodiversity but it is important that these ponds are easily accessible at all times so that quick action can be taken in case of a fire. |
| Literature | Kaulfuß, Susanne (2011): Technische Maßnahmen zur Waldbrandvorbeugung. Available online at: https://www.waldwissen.net/de/waldwirtschaft/schadensmanagement/waldbrand/technische-waldbrandvorbeugung, last checked on: 16.05.2024<br>BTL Liners: What is a Fire Suppression Pond? (n.d.). Available online at: https://www.btlliners.com/what-is-a-fire-suppression-pond , last checked on 17.05.2024 |

### 3.1.4 River

The following chapter is dedicated to example NbS, to mitigate the impacts of climate hazards in the river environment.

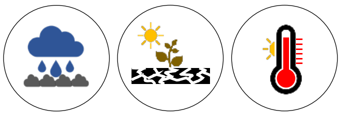
| **RESTORATION OF NATURAL RIVER COURSES** | |
|---|---|
|  Figure 36: Natural River Course, © Elena-Maria Klopries | |
| Climate Impact |  |
| Co-benefits | Biodiversity |
| Description | Restoration of river courses aims to restore the natural state and function of rivers and streams that might have been lost or are degraded because of human interventions. The aim is to improve the ecological status of the river and mitigate the negative effects resulting from human modifications. Restoration of river and stream courses helps to reduce the risk of flooding downstream. |
| Literature | Umweltbundesamt (2019): River restoration. Available online at: https://www.umweltbundesamt.de/en/topics/water/rivers/river-restoration-start#undefined, last checked on 16.05.2024<br>Golfieri, B.; Mason, E.; Goltara, A.; Silver, E. (2017): Benefits of European river restoration schemes. Available online at: https://europe.wetlands.org/publications/benefits-european-river-restoration-schemes/ , last checked on: 17.05.2024 |

| CREATION OF RETENTION AREAS | |
|---|---|
|  Figure 37: Retention area near a river, © Elena-Maria Klopries | |
| Climate Impact |   |
| Co-benefits | Groundwater recharge, biodiversity |
| Description | Creation of retention areas are areas designed to temporarily hold and store water during periods of high flow for example while a heavy rainfall event. Retention areas are able to provide additional storage capacity during peak flow and therefore reduce the risk of flooding downstream. Retention areas slow down the water velocity, therefore reducing the risk of riverbank erosion. They also have water purification functions and have the ability to recharge the groundwater. The retention areas can also create habitat and therefore increase biodiversity. |
| Literature | Urban green blue grids (n.d.): Building a retention area. Available online at: https://urbangreenbluegrids.com/measures/measures-at-the-town-or-city-level/building-retention-area/, last checked on 16.05.2024 |

| (RE-)CONNECTION OF FLOODPLAINS | |
|---|---|
| <br>Figure 38: Floodplain of the River Elbe near Dresden, © Elena-Maria Klopries | |
| Climate Impact |  |
| Co-benefits | Biodiversity, water quality, carbon storage |
| Description | Reconnecting rivers with their floodplains and restoration of the floodplains focuses on removing barriers along the edges of river and streams. Therefore, the river can re-establish its natural course over time and the floodplain can be reconnected or a new one can be created. Reconnecting and restoration can include the removal or setting back of levees, raising of a deeply engraved riverbed or riverbank expansion. The river can also be manually restored to its natural state by digging and therefore establish a reconnection with the original floodplain and wetlands. Floodplains provide natural retention areas reducing the severity of flooding. Restoration reduces the flow velocity, reducing the erosion risk. Furthermore, restoration creates habitat in the river floodplains, water purification functions by reducing nitrogen loads in the nearby rivers and they provide carbon storage and sequestration. |
| Literature | UN climate technology centre and network (n.d.): Re-connecting rivers with floodflains. Available onlie at: https://www.ctc-n.org/technologies/re-connecting-rivers-floodplains#:~:text=Description,or%20creating%20a%20new%20one, Last checked on 16.05.2024 |

**RIPARIAN BUFFER ZONES**

Figure 39: Riparian Buffer Zone, © Philipp Henkens

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Biodiversity, water purification |
| Description | Riparian buffer zones are narrow strips along rivers or streams planted with permanent vegetation such as grass, trees, or shrubs. They are located between the bank-full water level and intensively used land such as farmland, roads, or built environments. The width of these protective zones depends on the conditions of the surrounding landscape. Riparian buffer zones can help in adapting to river floods by allowing space for the river's natural dynamics. They can contribute to slowing down streamflow and assisting in meandering development. This prevents riverbed erosion and thus reduces the potential for downstream flooding. Furthermore, they can support groundwater recharge by increased soil infiltration and therefore help adapting to drought. Furthermore, the vegetation give shade to the river course improving the microclimate, by increasing air humidity and cooling the temperatures. Other benefits riparian buffer zones provide are filtration of pollutions from intensively used land before reaching the water stream and also increasing biodiversity by creating habitat for wildlife species. |
| Literature | Climate Adapt (2016): Establishment and restoration of riparian buffers. Available online at: https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/establishment-and-restoration-of-riparian-buffer-s, last checked on 16.05.2024<br><br>Hickey, M. Brian C.; Doran, Bruce (2004): A Review of the Efficiency of Buffer Strips for the Maintenance and Enhancement of Riparian Ecosystems. In: |

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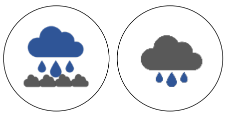
| | *Water Quality Research Journal* 39 (3), S. 311–317. DOI: 10.2166/wqrj.2004.042.<br><br>Natural Water Retention Measures Project (NWRM)(n.d.): Individual NWRM – Buffer strips and hedges. Available online at: http://nwrm.eu/sites/default/files/nwrm_ressources/a2_-_buffer_strips_and_hedges.pdf, last checked on: 17.05.2024<br><br>European Environment Agency, Castellari, S., Zandersen, M., Davis, M. et al., Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction, Publications Office, 2021, Available online at: https://data.europa.eu/doi/10.2800/919315, last checked on: 24.05.2024 |

| **BANK STABILISATION** | |
|---|---|
| <br>Figure 40: Fascine along a river course by Keep Wales Tidy, Flickr, https://flic.kr/p/bCYPwL | |
| Climate Impact |  |
| Co-benefits | Biodiversity, river bank erosion control |
| Description | River bank stabilization are practices to reduce or eliminate erosion or slumping of bank material into the river channel. For river bank stabilization different soil bioengineering measures can be used. In the following three examples namely live cribwalls, joint planting and live facines are presented.<br><br>Live cribwalls consist of interlocking logs or timbers, that have a boxlike structure. They are filled with rocks, soil and live cuttings or rooted plants. The |

| | |
|---|---|
| | aim is that the vegetation stabilise the structure and take over the functions of the logs.<br><br>Joint planting, also known as vegetative riprap, entails firmly embedding live cuttings of rootable plant material into the soil within the gaps or open spaces among rocks that have been positioned on a slope.<br><br>Live fascines are like long bundles of live plant cuttings tied together. They're placed along the bottom of the bank providing immediate protection for the river bank toe. The sites should not be too wet or dry due to being a surface treatment. Eventually, the live plant pieces grow roots and stabilising the river bank. |
| Literature | Holanda, Francisco; Rocha, Igor (2011): Streambank Soil Bioengineering Approach to Erosion Control. In: Progress in Molecular and Environmental Bioengineering-From Analysis and Modeling to Technology Applications.<br><br>Wohl, E., S. N. Lane, and A. C. Wilcox (2015), The science and practice of river restoration,Water Resour. Res.,51,5974–5997, doi:10.1002/2014WR016874. |

### 3.1.5 Coast

In this chapter, three NbS measures are presented, that can be implemented in coastal areas.

| DUNE STRUCTURES | |
|---|---|
| <br>Figure 41: Dune Structure to protect the inland from storm surges, © Elena-Maria Klopries | |
| Climate Impact |   |
| Co-benefits | Coastal erosion protection, biodiversity |
| Description | Dunes are natural or artificially formed sandy formations found along coastlines. They act as a natural barrier, to protect coastal infrastructure and settlements in the inland from storm surges by absorbing wave energy and reducing the impact of high tides. They help reducing the risk of flooding and coastal erosion. Artificial dunes mimic the functions of natural dunes in coastal areas but they consist of sand from an external source. |
| Literature | Warnell, Katie; Siegle, Aaron; Merritt, Melissa; Olander, Lydia (2023): Department of the Interior Nature-Based Solutions Roadmap. NI R 23-06. Durham, NC: Nicholas Institute for Energy, Environment & Sustainability, Duke University. Available online at: https://nicholasinstitute.duke.edu/sites/default/files/project/nature-based-solutions-roadmap/strategy/doi-nbs-roadmap-strategy_dune-restoration.pdf, last checked on 16.05.2024<br>Climate Adapt (2016): Dune construction and strengthening. Available online at: https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/dune-construction-and-strengthening, last checked on 16.05.2024 |

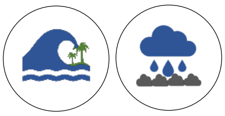
## BEACH NOURISHMENT

Figure 42: Beach nourishment by Christopher Blunck, (CC BY-NC-SA 2.0) Flickr, https://flic.kr/p/UDKgGC

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Coastal erosion protection |
| Description | Beach nourishment, also known as beach replenishment, refers to the process of adding sand or sediment from external sources to beaches to counteract beach erosion and expanding the beach width. Beach nourishment stands as an alternative to coastal armoring methods. Additionally, beach nourishment safeguards inland areas from inundation due to storm surge. |
| Literature | Buisson, Phillippe; Rousset, Alain; ANCORIM; Massey, James (2012): ANCORIM - Overview of Soft Coastal Protection Solutions.<br>Climate Adapt (2010): Beach and shoreface nourishment. Available online at: https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/beach-and-shoreface-nourishment, last checked on 16.05.2024 |

## RESTORATION OF COASTAL WETLAND

Figure 43: Coastal Wetlands by Kelly Fike, Flickr, https://flic.kr/p/8Uo8YM

| | |
|---|---|
| Climate Impact |  |
| Co-benefits | Air quality, biodiversity, water quality |
| Description | Wetland restoration involves rehabilitating and enhancing coastal marsh ecosystems (tidal or salt-marshes) that have suffered degradation or loss due to human activities. Tidal marshes serve as natural coastal defences by mitigating wave forces, thereby reducing coastal erosion by stabilizing shore sediments from storm surges and flooding. In some cases, coastal wetlands are used to absorb storm surge waters and thereby mitigating flood impacts. Furthermore, healthy tidal marshes enhance biodiversity by providing habitat for various species, have the capacity to improve water clarity and also air quality. |
| Literature | Buisson, Phillippe; Rousset, Alain; ANCORIM; Massey, James (2012): ANCORIM - Overview of Soft Coastal Protection Solutions.<br>https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/restoration-and-management-of-coastal-wetlands#:~:text=The%20restoration%20of%20coastal%20wetlands,which%20was%20previously%20re%2Dappropriated. |

# Conclusions

This deliverable outlines the cause-effect relationships of the climate hazards Drought, Heat, Flooding and Heavy Rain, which are all relevant for the front running regions of the Land4Climate project, by using climate impact chains. These chains visualise the effects of climate hazards on diverse social sectors, including agriculture and human health. Additionally, this document presents various NbS measures and their systemic effects on mitigating climate change effects. For all described NbS not only the effects on the climate hazards Drought, Heat, Flooding and Heavy Rain were included but also the additional co-benefits these measures give. Careful consideration was given to selecting measures feasible for implementation on private land as unique selling point of Land4Climate. This deliverable does not provide a complete NbS catalogue, but provides an important input and therefore starting point for WP 2 in general and WP 2.1 in particular (Methodological framework and indicators for NBS effectiveness and efficiency. Moreover, it guides Task 1.3 (Identification of NBS) and ultimately the front running regions regarding the selection of tailor-made NBS (see WP 4).

# References

Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. (2016): Nature-based solutions to address global societal challenges: IUCN International Union for Conservation of Nature.

Eisenberg, Bernd; Chiesa, Cecilia; Fischer, Leonie K.; Jakstis, Kristen; Polcher, Vera; Schwarz-v. Raumer, Hans-Georg (2022): Nature-based Solutions. Technical Handbook Factsheets. Hg. v. UNaLab URBAN NATURE LABS Institut für Landschaftsplanung und Ökologie - ILPÖ. Institut für Landschaftsplanung und Ökologie. Available online at: https://unalab.eu/system/files/2022-11/unalab-nbs-technical-handbook-factsheets2022-11-17.pdf, last checked on: 09.04.2024.

Umweltbundesamt. Eurac research and bosch & partner (2016): Klimawirkungsketten. Umweltbundesamt. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/380/dokumente/klimawirkungsketten_umweltbundesamt_2016.pdf, last checked on: 22.05.2024

European Commission; European Research Executive Agency (2022): Nature-based solutions – EU-funded nbs research projects tackle the climate and biodiversity crisis: Publications Office of the European Union.

European Environment Agency, Castellari, S., Zandersen, M., Davis, M. et al., Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction, Publications Office, 2021, Available online at: https://data.europa.eu/doi/10.2800/919315, last checked on: 24.05.2024

Haghighatafshar, S., Nordl¨of, B., Roldin, M., Gustafsson, L.G., la Cour Jansen, J., J¨onsson, K., 2018. The efficiency of blue-green stormwater retrofits for flood mitigation–conclusions drawn from a case study in Malm¨o, Sweden. J. Environ. Manag. 207, 60–69.

Nesshöver, Carsten; Assmuth, Timo; Irvine, Katherine N.; Rusch, Graciela M.; Waylen, Kerry A.; Delbaere, Ben et al. (2017): The science, policy and practice of nature-based solutions: An interdisciplinary perspective. In: *The Science of the total environment* 579, S. 1215–1227. DOI: 10.1016/j.scitotenv.2016.11.106.

Odongo, V., Barquet, K., & Green, J. (2022). Addressing Scale in Nature-Based Solutions. SEI discussion brief. Stockholm Environment Institute. https://doi.org/10.51414/sei2022.043. Available online at: https://www.sei.org/publications/scale-nature-based-solutions/, last checked on: 23.05.2024

URBAN GreenUP Consortium Partners (2017): NBS Catalogue. Available online at: https://www.urbangreenup.eu/insights/deliverables/d1-1---nbs-catalogue.kl, last checked on: 08.05.2024.

World Bank (2021): A Catalogue of Nature-based Solutions for Urban Resilience. Unter Mitarbeit von World Bank Group. Washington, D.C. Available online at: https://openknowledge.worldbank.org/entities/publication/c33e226c-2fbb-5e11-8c21-7b711ecbc725, last checked on: 08.04.2024.

Zebisch, M.; Schneiderbauer, S.; Renner, K.; Below, T.; Brossmann, M.; Ederer, W.; Schwan, S. (2017): Risk supplement to the vulnerability sourcebook. Guidance on how to apply the. Bonn. Available online at: https://www.adaptationcommunity.net/wp-content/uploads/2017/10/GIZ-2017_Risk-Supplement-to-the-Vulnerability-Sourcebook.pdf, last checked on: 07.05.2024.

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