ETC-CA Report 2022/2

Understanding the scaling potential of Nature-based Solutions

Analysis of the scaling potential of selected cases of nature-based solutions for climate change adaptation and disaster risk reduction relevant to achieving overarching ecosystem restoration targets

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About this report

Nature-based Solutions and their scaling are considered an essential aspect to achieve multiple targets in terms of ecosystem restoration, adaptation, and disaster risk reduction. There are, however, limited documented experiences and evidence from cases of scaling ecosystem restoration measures to achieve multiple targets such as those linked to biodiversity and climate change adaptation.

The present report builds on a previous analysis of the EEA and intends to contribute to better understand how to scale Nature-based Solutions to achieve multiple objectives. It consists of developing insights from cross-analysis of specific Nature-based Solutions and their relevance for adaptation, ecosystem restoration and scaling potential.

This report aims at providing a basis to better frame and orient more quantitative assessment on the role of NBS. The authors developed and tested a framework to guide the case studies' analyses to assess the approaches required to upscale NBS of relevance to both adaptation to climate change and to ecosystem restoration, as well as to identify specific enabling conditions for the scaling of these NBS.

Further developing a scaling approach can support decision makers in planning for Nature-based Solution in achieving specific climate adaptation policy targets by mainstreaming NBS, as expected in the context of the EU Adaptation Mission. The proposed scaling approach should be refined taking into consideration the relevance and interplay of multiple enabling conditions for scaling, to identify the most promising cross-cutting approaches combining scaling up, out and deep options.

Firstly, the report introduces the concept and relevance of Nature-based Solution, and touches upon the need for systemic approaches to NBS implementation and scaling. Then, a four-step approach to scale Nature-based Solution is proposed, and specific qualitative insights are provided based on the analysis of a small set of NBS cases relevant to the following contexts: peatlands, agriculture, urban areas, forests. Those insights focus on the scaling enablers and may form a solid basis to identify data and information relevant to perform quantitative assessments at regional or European level. Finally, overarching key findings and conclusions are provided to support a better understanding on how Nature-based Solutions' scaling can be planned and implemented to achieve multiple policy objectives.

For the next stage in the research, the team proposes to review the climate change adaptation and ecosystem restoration targets and identify relevant data and information on the scaling potential of NBS in specific ecosystems with a focus on their socio-economic aspects.

The present ETC report is intended for internal use at EEA and should form a basis for more comprehensive work on the scaling of NBS[1].

[1] As reported in the Task description the decision on publication as an EEA output is to be taken later.

1 Introduction

The threat of serious damage from the impacts of climate change is increasing and the adaptation gap is growing (UNEP, 2021). While Europe has made strides in taking adaptation actions (EEA, 2020), the complexity of thriving in the face of climate shocks and stresses means many regions and communities are struggling to avoid losses. The state of biodiversity and ecosystems in the European Union (EU) continues to decline at an alarming rate, along with the benefits they provide to society (EEA, 2021; IPBES, 2019). The EU Biodiversity Strategy for 2030 (Directorate-General for Environment (European Commission), 2021) as well as the proposed regulation on nature restoration (European Commission, 2022) highlight- the importance of restoring ecosystems across land and sea and proposes setting legally binding EU restoration targets. It suggests several important ecosystems and habitats to be considered, such as wetlands/peatlands; free-flowing rivers; floodplains; primary and old-growth forests; marine ecosystems (in particular, seagrass and seabed); coastal ecosystems; soil; and urban ecosystems.

The EU Adaptation Strategy (European Commission, 2021a) sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. It is underpinned by four main objectives: to make adaptation smarter, faster and more systemic, and to step up international action on adaptation to climate change. The EU Mission for Adaptation to Climate Change (European Commission, 2021b) aims at knowledge development, innovation and upscaling of promising local and regional initiatives, it will support at least 150 European regions and communities towards climate resilience by 2030. It intends to adopt a more systemic approach by addressing several key community systems on critical infrastructure, health and wellbeing, water management, land use and food systems, and ecosystems and nature-based solutions (NBS).

In line with the EU Mission's approach, this report addresses the scaling potential of nature-based solutions and particularly focuses on the development of a viable approach to scale NBS to achieve overarching adaptation and ecosystem restoration targets. The report documents the analyses of selected NBS cases, particularly on the scaling potential, and identifies an agile framework to plan for and implement NBS scaling.

The European Commission's proposal for a Nature Restoration Law (European Commission, 2022) is the first continent-wise, comprehensive law of its kind and will be a key element of the EU Biodiversity Strategy. The proposal combines an overarching restoration objective for the long-term recovery of nature in the EU's land and sea areas with binding restoration targets for specific habitats and species. These measures should cover at least 20% of the EU's land and sea areas by 2030, and ultimately all ecosystems in need of restoration by 2050. The proposal targets the following habitats and species:

- targets based on existing legislation for wetlands, forests, grasslands, rivers and lakes, heath & scrub, rocky habitats and dunes,
- pollinating insects,
- forest ecosystems,
- urban ecosystems,
- agricultural ecosystems,
- marine ecosystems,
- river connectivity.

According to the proposal, EU countries are expected to submit National Restoration Plans to the Commission within two years of the Regulation coming into force, showing how they will deliver on the targets. Such increased importance being placed on ecosystem restoration is linked also on the role of biodiversity for climate change resilience, and the need to achieve multiple targets amongst others in terms of adaptation, biodiversity, and carbon sequestration.

There are, however, limited documented experiences and evidence from cases of scaling ecosystem restoration measures that quantify their impacts or potential impacts for multiple targets such as those linked to biodiversity and climate change adaptation. Therefore, the present report aims at contributing to better understand how to assess the potential and the impact of restoration actions. Likewise, to plan for their scaling in a variety of landscapes and different contexts to support Europe to meet its new ecosystem restoration targets.

A study developed by (Simonson et al., 2021) states that ecological restoration is a tool for climate change mitigation and adaptation, and yet its outcomes are susceptible themselves to climate change impacts. The authors developed a framework as a mean to support global restoration targets and the UN Decade on Ecosystem Restoration 2021–2030 through more climate resilient restoration. The framework identified seven areas of restoration design and implementation in which climate change is important to address (Figure 1):

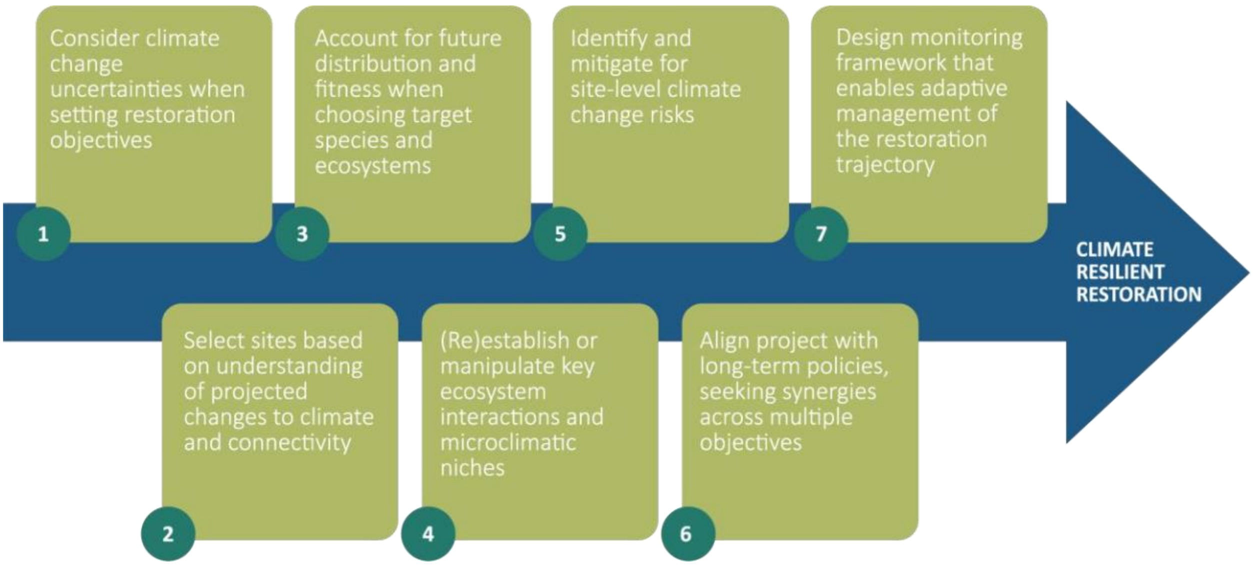

Figure 1. Seven areas that practitioners should consider when designing and implementing an ecological restoration project to build its climate change resilience according to Simonson, et al., (2021).

For the identification and mitigation of site-level climate change risks (area number 5), the authors mentioned that there are many threats to natural environments which are directly related to climate change:

- more intense and frequent extreme weather events and increasing sea surface temperatures,
- the result of tangible human actions such as increased nutrient input leading to eutrophication,
- some are the result of directed actions which are then exacerbated further by climate change, such as invasive species and the spread of disease.

These global change hazards can have local, site-specific impacts and must be considered to enhance the resilience of restoration projects, Figure 2 summarizes climate change related risks. Whilst certain risks may be minimised using the approaches outlined elsewhere in this framework, some might be difficult to tackle. Potential impacts should be anticipated and mitigated within the design and implementation of the restoration activity (Simonson et al., 2021).

Figure 2. Hazards that have the potential to impact local restoration projects can be grouped into distinct themes. The ones shown here are not exhaustive (Simonson et al., 2021).

2 Towards a systemic approach to Nature-based Solutions scaling

Given the challenge posed by climate change, a fundamental systems' change that addresses root causes of vulnerability is needed, however the understanding of what transformative adaptation looks like in social-ecological systems and when it can be implemented is limited (Fedele et al., 2019). Still, Nature-based Solutions would be part of more complex dynamics in sustainability transitions, for which it is important to understand and interpret both build-up and breakdown patterns (Hebinck et al., 2022).

The present report builds on a previous analysis of the EEA on the methodologies for the evaluation and assessment of NBS (Giannini, 2021) and intends to contribute to better understand how to scale Nature-based Solutions to achieve multiple objectives. It consists of developing insights from cross-analysis of specific Nature-based Solutions and their relevance for adaptation, ecosystem restoration and scaling potential.

The authors developed and tested a framework to guide the case studies' analyses to assess the approaches required to upscale NBS of relevance to both adaptation to climate change and to ecosystem restoration, as well as to identify barriers and enablers for the scaling of these NBS. Ultimately, the present report should be seen as a basis to better frame and orient more quantitative assessment on the role of NBS, as it intends to contribute to a more systemic approach to NBS implementation and deployment by exploring the following questions:

- How can we contribute to assessing the role of NBS to achieve multiple policy objectives, especially in terms of ecosystem restoration, adaptation and mitigation?
- How do we assess the scaling potential of Nature-based Solutions?
- How can we support a better understanding of the impact of adopting NBS in Europe at scale?
- How can we deploy NBS beyond Natura 2000 areas?
- What are the enabling conditions for NBS to be scaled and be self-sustainable over time?

We identified and followed a generic approach to scaling (Figure 3) consisting of the following steps:

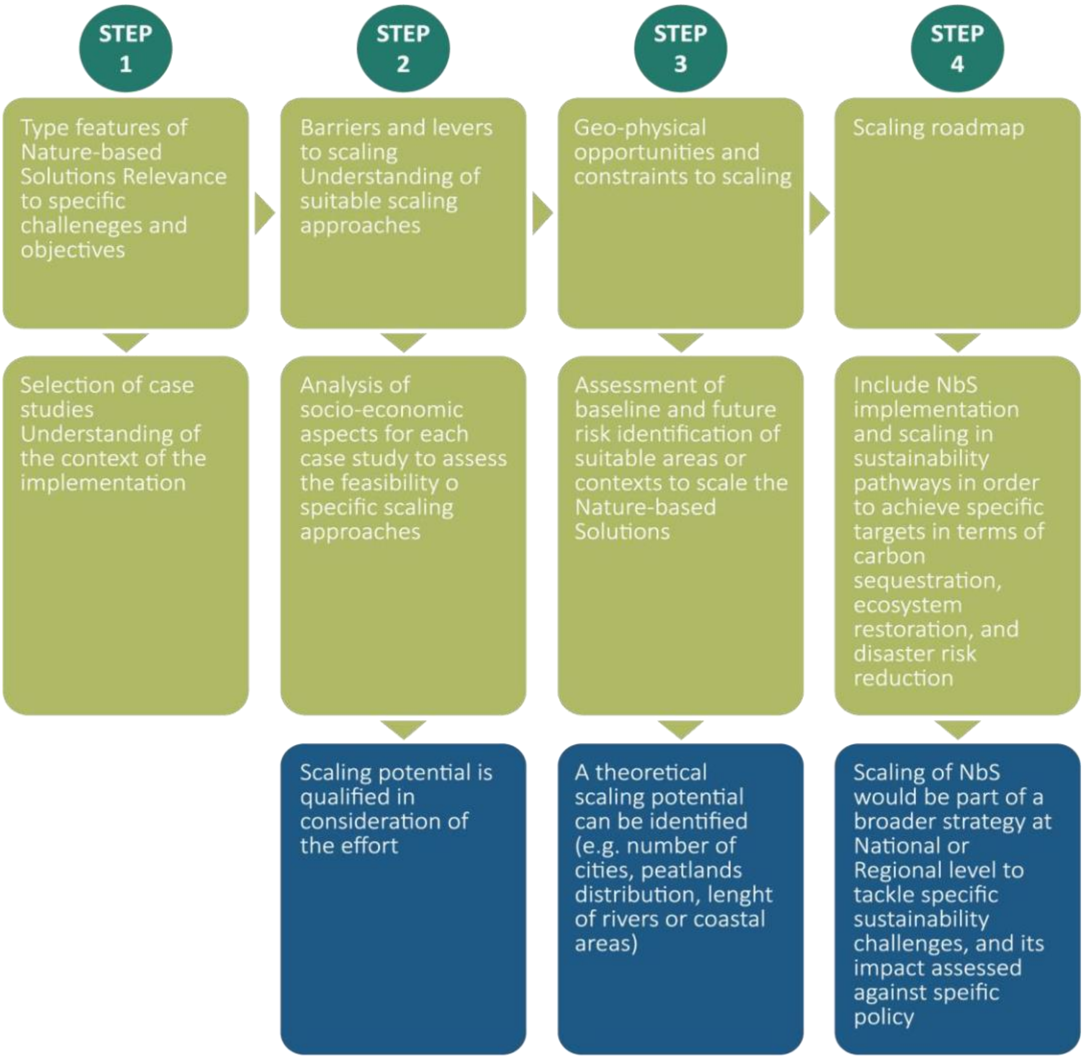

Figure 3. Proposed scheme of the scaling approach.

1. Identification of key features of Nature-based Solutions, such as ecosystem type, measures to be implemented, financing mechanisms and stakeholders' involvement, and their relevance to specific challenges and objectives such as climate change adaptation and ecosystem restoration:
   a. In this step a number of case studies can be selected in order to understand the context of their implementation.

2. Definition of barriers and enablers to scaling in order to identify suitable scaling approaches:
   a. In this step the analysis focuses on socio-economic aspects and the feasibility of the scaling approaches building on qualitative information in terms of effort and contextual information. Such analysis relies on the present conditions. Therefore it is important to project Nature-based Solutions in a future context by referring to different approaches to scaling (Moore et al., 2015). Four categories of scaling approaches are proposed and explained (Salafsky et al., 2021):
      i. **Scaling out:** replication of the Nature-based Solution in other contexts with similar features. Scaling out requires replicating the solutions already piloted using a similar approach to remove the barriers to deployment and implementation. External conditions would, if ever, need to change only slightly to allow for further implementation of the pilot strategy in other places. Therefore, scaling in a different "context" where only a few barriers differ and where similar levers could be used would be a bit more difficult but manageable after slight adaptation of the solutions.

   ii. **Scaling up:** change in terms of enabling conditions to increase impact and deployment at scale of the Nature-based Solution (e.g., addressing regulatory barriers at the regional, national or European level). The upscaling strategy of NBSs would need to account for enablers and system barriers and enhance, as far as possible, ways for tackling those e.g., with specific regulatory instruments and participatory tools. The scale-up of a Nature-based Solution would increase its impact and support the achievement of specific objectives, for example in terms of ecosystem restoration or disaster risk reduction. A scaling up would be triggered by institutional or policy changes which would allow its deployment at scale, e.g. adopting the solution over more hectares.
   iii. **Scaling deep:** the Nature-based Solution is in this case is in service of a deep transformation of the context in which it is piloted or implemented, including policy and institutional settings. A systemic analysis is in that case needed to guide communities in a systemic transformative journey toward resilience. Alongside system transformation, cultural values change would be observed, resulting in a change of relationships between socioeconomic and natural systems.
   iv. **Cross-cutting approaches:** refer to scaling of Nature-based Solutions without a specific scaling "out", "up" or "deep" strategy, but rather taking stock of the existing condition and developing mixed approaches to scaling and impact. Cross-cutting approaches can consist in building alliances between similar initiatives in various contexts, or "connecting the dots" by putting in contact various initiatives which tackle similar challenges, for example using different methods or tools to achieve similar ecosystem restoration, carbon sequestration, or other policy targets for a given ecosystem.

3. Analysis of the geophysical opportunities and constraints to scaling:
   a. In this step provides more information about the baseline and the identification of future risks to identify suitable areas or contexts to scale the Nature-based Solutions.
   b. Such assessment provides a theoretical scaling potential to NBS. This analysis relies on the comparison between (i) potential needs (i.e., total area or the number of similar cases in a given territory in need of enhanced adaptation or restoration) and (ii) potential supply of the NBS considered.

4. Designing of a scaling roadmap:
   a. In this step the financing and implementation of the efforts over time in the deployment of the NBS at scale are articulated. Possibly, scaling of Nature-based Solutions is part of a broader strategy to implement resilience pathways to achieve specific policy targets and sustainability challenges in terms of carbon sequestration, ecosystem restoration, and disaster risk reduction.
   b. It must be noted that a relevant approach to include Nature-based Solutions in a broader strategy is offered by the Implementation Plan of the EU Mission on Climate Change Adaptation (European Commission, 2021b) which aims at supporting at least 150 European regions and communities to become climate resilient by 2030. The initiative identifies "Ecosystems and nature-based solutions" as a key area for innovation and transformation under specific enabling conditions which could be used to define a scaling roadmap for NBS:
      i. Access to knowledge and data;
      ii. Promotion of inclusive governance models and citizen engagement;
      iii. Focus on behavioural change and social tipping points;
      iv. Mobilization of resources and sustainable financial mechanisms.

3 NBS case studies' selection

In the previous report "Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction" (EEA, 2021), the authors collected 97 cases of Nature-based Solutions. Figure 4 below reports the categorisation of those cases into thematic areas/sectors. More than 45% of the selected cases relate to urban areas, and less than 10% refer to Agriculture and Agroforestry or Forests and Forestry respectively. It is likely that NBS in urban environments are easier to be defined as NBS as compared to rural areas, and therefore identified when performing desk research, while land use and ecosystem management practices might not be defined as NBS because more sustainable management practices are already aiming at multiple objectives (carbon sequestration, production, adaptation, biodiversity) and therefore might not be reported explicitly as "NBS".

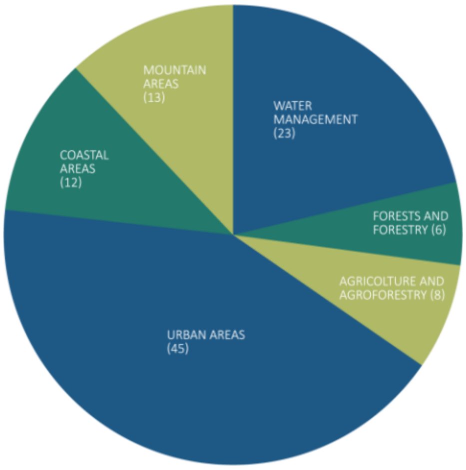

Figure 4. Distribution of the 97 case studies across sectors/thematic areas. The Table sums to 107 because the selected screened cases include multinational projects having demonstration locations in several countries.

For the present report, a subset of NBS cases was selected from the 97 cases identified. The analyses of those case studies were intended to test and refine the 4-step approach. Relevant insights to better understanding the scaling potential of NBS for a given ecosystem are included in the analysis' findings, however a more technical assessment through mapping and quantification is not part of the present report.

The cases were selected based on the relevance to adaptation, disaster risk reduction, ecosystem restoration and scaling potential, as well as geographical spread and its relevance for various across habitat/ ecosystem types. The cases were selected to cover the following ecosystems: cities, rivers and river catchments, forests, wetlands and peatlands, and agricultural ecosystems. The selected cases are:

- Germany: peatland restoration through paludiculture for climate change mitigation and adaptation.
- Sweden: Tullstorpsån 2.0 - adapting agriculture to wetter and drier climates.
- Serbia: Blue-green corridors - mitigating natural hazards and restoration of urbanised areas.
- Germany: green roofs - combining regulation, dialogue, incentives, and science.
- France: flash flooding and wildfire hazards in a Mediterranean catchment.
- Germany, Portugal, and Spain: coupling water, fire and climate resilience with biomass production in forestry to adapt watersheds to climate change".

Analyses of the selected case studies were conducted through desk research and when needed, by conducting interviews with contact persons for each of the case studies. Further, the task team exchanged the findings through dedicated sessions to identify patterns and challenges of scaling Nature-based Solutions, and aspects that should be considered in implementing them for reaching diverse policy targets. Analyses and exchange sessions targeted three main aspects:

- Relevance of Nature-based Solutions for adaptation and disaster risk reduction;
- Relevance of the NBS for ecosystem restoration and biodiversity targets;
- Scaling potential: barriers and enablers.

4 Case studies

In the following section, a short description of the different case studies is presented, highlighting their relevance for the scope of this analysis. More information on the case studies is part of a longer list of those elaborated in the ETC report “Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction”(EEA, 2021). Two of the case studies have an additional longer description in the Annexes.

4.1 PALUDICULTURE CASE: PEATLAND RESTORATION FOR CLIMATE CHANGE MITIGATION AND ADAPTATION

4.1.1 Summary of the case study

In the federal state of Mecklenburg-West Pomerania, 291 361 ha are peatlands. Currently, 57% of the peatland area is used for agriculture (20 531 ha as arable land, 143 998 ha as permanent grassland) and therefore drained, causing greenhouse gas (GHG) emissions of 4.5 Mt CO_2 per year. This means that drainage-based agricultural use of peatlands is the largest single source of GHG emissions in the federal state of Mecklenburg-West Pomerania. Moreover, the lowering of the water table leads to a large loss of water, exacerbating climate change impacts, in particular droughts. To preserve the peat layer, the water level has to be close to or at the soil surface throughout the year to guarantee saturation of the peat body. In addition, regular soil disturbance, e.g., by ploughing or by harvesting below-ground biomass, must be excluded.

Paludiculture, defined as “the productive land use of wet and rewetted peatlands that preserves the peat soil and thereby minimizes CO_2 emissions and subsidence” (Wetlands International Europe, 2022), is being piloted as a solution to peatland restoration. Paludiculture preserves the peat soil and the other ecosystem services of the peatland. Paludiculture is useful mainly in drained peatlands used for agricultural production. The idea is to compensate the land users’ revenue losses due to the abandonment of their classical production by introducing new products and value chains. These are mostly new plant species or occasionally new cattle such as water buffalos that strive in extremely wet conditions. In certain cases, paludiculture can also be used for wastewater treatment or water purification[2].

Many plant species have already been identified as having potential for paludiculture, yet only a dozen have been tested [3]. The harvested biomass of these new crops can be used as food, feed, fibres, isolation or construction material, biofuel or biomass or feedstock for various pharmaceutical or cosmetics products.

[2] See for instance the REMEMBER project aiming to reduce nutrient discharges into the Baltic Sea https://www.moorwissen.de/en/paludikultur/projekte/remember.php

[3] See: https://www.moorwissen.de/background.html

4.1.2 Objectives and trade-offs of the Nature-based Solution

- **BIODIVERSITY AND ECOSYSTEM RESTORATION:** rewetted conditions create the potential to regenerate at least partly the humid ecosystems of the original peatland. Peatlands play a critical role for biodiversity being hosts of a range of rare, threatened, or declining habitats, plants and animals.
- **PROTECTION AGAINST OUTBREAKS OF PESTS AND INVASIVE SPECIES**: increasing the biodiversity will in turn enhance the resilience of the region in different ways by e.g., creating reservoirs of species that can prevent the outbreaks of pests or prevent invasive species to replace native species in a detrimental way.
- **RESTORATION OF SOIL AND WATER QUALITY:** the restoration of peatlands through paludiculture reduces the harmful effects of traditional agricultural management of the land (crops and livestock): increased nitrogen, reduced quality, and quantity of water.
- **DROUGHT AND FLOOD PROTECTION:** peatland restoration and rewetting also provide recreates the water buffer that can mitigate water stress during drought periods by maintaining water flows in this period. This can be extremely useful for drinking water supply. In certain cases, it can also mitigate floods in adjacent downstream areas if excess water can be diverted to the peatland.
- **REDUCTION OF CO_2 EMISSIONS:** there is a quasi-linear relationship between annual average depth to water table and co_2 emissions. This relationship is valid in both directions: when peatland is drained and when peatland is rewetted.
- **ALTERNATIVE INCOME STREAM FOR FARMERS:** paludiculture can potentially provide an alternative income stream for farmers to transition to more regenerative agricultural practices.
- **POTENTIAL INCREASE OF METHANE EMISSIONS:** in terms of greenhouse gas emissions, there may be a trade-off between co_2 and methane. In anoxic conditions, peatlands may become methane emitters when again saturated with water. Recent studies show that even in that case the overall benefits in terms of emissions remain positive (Günther et al., 2020).
- **LIMITED FLOOD BUFFER FUNCTION:** drainage and intensification usually destroy the network and number of small gullies of the peatlands which have a key role in mitigating floods.
- **PALUDICULTURE NOT BENEFICIAL TO REPLACE FORESTED PEATLANDS:** a specific difficulty lies with the forested peatlands. Afforestation contributes to water table drawdown and hence to carbon emissions that the absorption function of the trees does not compensate (emissions linked to degradation of peat may typically be at least twice as much as carbon absorption by tree growth). However, the benefits of tree replacement by paludiculture may take too long to generate significant benefits given the carbon losses that will be generated by the tree harvest.

4.1.3 *Scalability insights*

Scaling out

Paludiculture could in theory be implemented in many drained peatlands converted to agriculture. The question remains whether from an economic perspective it is not more feasible to rewet these peatlands without being used for paludiculture. Demand for paludiculture is hardly emerging and most of the projects are currently in their pilot phase. The reason for this is that the value chains related to the commodities of paludiculture (see Table 1) need to be developed nearly from scratch and this requires a minimum scale and medium-term visibility to the potential investors. Pilot projects bigger than the current ones (often limited to a large field plot) would need to be supported to become real demonstrators.

Table 1. Potential productions and associated value chains from paludiculture.

PRODUCTION / SERVICE	TYPE OF CROP	TYPE OF MARKET
Bioenergy	Reeds (Pharagmites sp), cattail, black alder*, sedges	Biogas, biofuel, including biochar
Horticulture growing media	Sphagnum	Substrate for containerised plant raising
Food, feed and fibre	Cattail, reeds, sedges, cranberry	Fruit juice, fodder, filing material
Construction material	Reeds, black alder, cattail	Thatched roofing, insulation products, lightweight construction boards, timber
Packaging	Sedges, reeds	Packaging and disposable tableware
Chemical products	Sundew	Pharmaceuticals
Water purification	Cattail	Treatment of polluted water

* Black alder may also reduce methane emissions.

Scaling up

Scaling up potential of paludiculture is limited due to at least 4 reasons: 1. it requires coordinated water management rules across all land users. 2. It depends on market valorisation and value chains for the produced commodities, 3. It requires specialised farming practices and technology. 4. The EU Common Agriculture Policy does not specifically support paludiculture: the transformation of peatlands into conventional agricultural land is not discouraged.

Scaling deep

The main levers to paludiculture deployment relate to policies and to economic and financial support from a variety of actors. While past policies have triggered peatland “valorisation” through conventional agriculture, new policies could and should support the reverse transformation into paludiculture through a mix of regulations, subsidies and market instruments. Financial instruments and incentives should go beyond the agriculture part since entire value chains need to be created. Holistic approaches to value chain development would need to be designed and implemented and tap also into policies of the built sector or of the energy transition. The public sector could also play a role in developing *guarantee mechanisms* to help innovators, entrepreneurs and investors take risk. Another important lever to this deployment is the *market of voluntary carbon credits*. The huge mitigation potential of peatland rewetting should foster the development of peatland codes across the EU. It should be noted here that biodiversity and increased resilience are not key drivers or levers for paludiculture despite of the benefits they may generate for these issues. Maximizing the benefits of paludiculture for biodiversity and resilience would require specific pilots or demonstrators.

Cross-cutting approaches

Paludiculture remains at an experimental stage and implementation is not enough to generate momentum across multiple experiments.

From a geophysical perspective, all drained peatlands utilised for agriculture could be rewetted and used for paludiculture. Some restrictions may be related to areas where the entire catchment hydrology has been degraded so that the rewetting would not be possible or would remain incomplete. The potential of paludiculture is therefore very large. Across Europe, 43000 km^2 have been drained and converted to agriculture, about 3% of the European total agricultural land. A major part of this area remains in permanent grassland (as for Mecklenburg-West Pomerania), which means that the replacement of grass by other fodder crops would be a major challenge, unless complete transformation of the farming systems in these areas would be implemented.

The analysis resulted in the identification of the following scaling enablers and barriers:

- Scaling enablers:
    - *Policy*: past policies have triggered peatland "valorisation" through conventional agriculture, new policies could and should support the reverse transformation into paludiculture through a mix of regulations and subsidies.
    - *Financial incentives*: Financial instruments and incentives should go beyond the agriculture part since entire value chains need to be created.
    - *Risk sharing*: The public sector could also play a role in developing guarantee mechanisms to help innovators, entrepreneurs and investors take risk.
    - *Voluntary carbon credits*: peatlands offer interesting potential for offsetting (for companies facing difficulties to reduce their emissions such as the aviation sector) or in-setting for companies engaged in the value chains of the paludiculture products.
    - *Land users' coordination*: requires coordinated water management rules between land users.
- Scaling barriers:
    - *Market development*: markets for the new products already potentially exist but the value chains ensuring sufficient product transformation and commercialisation still need to be developed.
    - *Farming practices & technology*: Most of the plants to be produced are not conventional ones. Their cropping practices require special machinery due to the specific wet conditions in which practices are implemented. This also means that the cropping practices need to be tested and probably adjusted to the local context.
    - *EU Common Agricultural Policy*: so far, the CAP used to support conventional agriculture and innovative practices such as paludiculture were not incentivised.

Toward a roadmap for implementation at scale Paludiculture deployment needs to go hand in hand with the rewetting of large peatland areas. This rewetting is likely to involve infrastructure development to block the drainage systems and ensure enough water are brought back to the peatland. While this rewetting is implemented support to the farmers who are losing their production capacity needs to be put in place. Classical support such as CAP subsidies needs to be redirected to this support. Paludiculture itself needs to be implemented soon after rewetting to reduce the transition costs and ensure farmers can restore their revenue. Given the lack of existing value chains a systemic approach is required to select and implement a portfolio of actions revolving around (i) appropriate policies and regulations, (ii) appropriate subsidies to the whole systemic transformation, (iii) training of the farmers, (iv) market incentives, (v) investments in product transformation facilities, (vi) continuous monitoring and learning.

An extended version of this analysis can be found in the Annex.

4.2 TULLSTORPSÅN CASE: ADAPTING AGRICULTURE TO WETTER AND DRIER CLIMATES

4.2.1 Summary of the Case study

The Tullstorp stream (or Tullstorpå) is in the southern plains of Sweden in a region known for its agricultural potential. The yield per unit area is higher than in any other region in Sweden thus making the area important for agricultural production. The stream is 30 km with a catchment area of 63 km^2 and has a limited number of water bodies (EEA, 2022; Graversgaard et al., 2018; Tullstorp Stream Economic Association (TSEA), 2020).

The measures in the Tullstorpå area have been implemented in two projects (Figure 5):

- **(I)** The first development project (2009-2013) of the Tullstorpå agricultural region, focused on the meandering of the riverbed, the restoration of riverbed vegetation and wetlands and the development of buffer zones and restoring biodiversity. **The aims of the project were to mainly improve the water quality in the catchment area but there were benefits also for flood protection.**
- (II) The second project (2019-2025), Tullstorpå 2.0, focuses on constructing a system with multifunctional water reservoirs (wetlands) with recirculating irrigation and customized drainage. The excess water is stored in reservoirs during wet conditions and can be harvested in times of drought. The project is carried out in two pilots: one focusing on the restoration of the old mill water retention basins and the other on the construction of a new water retention basin. **The aim of the project is to improve the climate resilience of the regional agriculture** (EEA, 2022; Tullstorp Stream Economic Association (TSEA), 2020).

The second project was heavily triggered by extreme weather events in Sweden with the wet summer of 2017 and the dry summer of 2018. Storing and recirculating water is expected to be a highly effective and sustainable way of climate-proofing Swedish agriculture. The case study in Tullstorspå project is an example of a bottom-up process initiated and driven by the landowners and local farmers. Local farmers and landowners founded the Tullstorp Stream Economic Association which is currently responsible for the project.

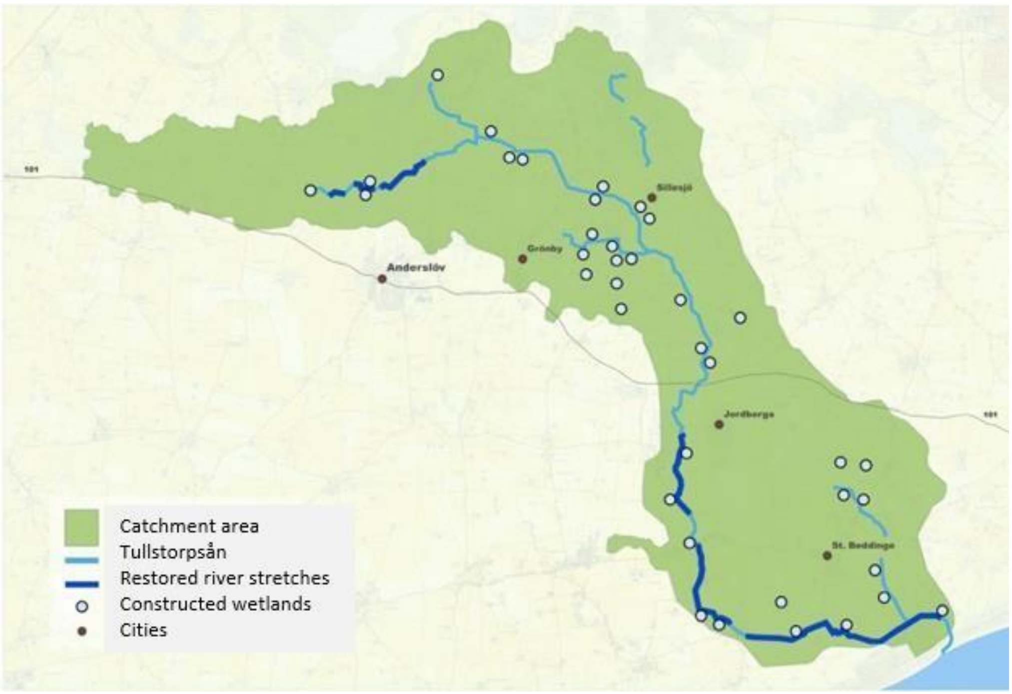

Figure 5. Map of the Tullstorp case in Sweden. Adapted from (Tullstorpsån Project Website, 2022).

4.2.2 *Objectives of the Nature-based Solution*

- Ecosystem restoration:
  - Restoring wetland ecosystems.
  - Restoring the ecological status of the stream.
  - New habitat creation or existing habitat improved, increased connectivity of habitat in agricultural landscapes.
  - Reducing nutrient leaching to Baltic Sea.
- Adaptation and disaster risk reduction objectives:
  - Flood risk mitigation.
  - Improving the extreme weather resilience of the region's agriculture (protection from wet and dry conditions).
- Increasing the possibilities of recreation and outdoor activities.

The climate change adaptation and disaster risk reduction objectives are synergetic with the ecosystem restoration objectives. There may be trade-offs with land use and ownership. The associated landowners own the area and can use it as far as it is not contrary to carrying out activities connected to the restoration and future management of the land.

4.2.3 *Scalability insights*

Scaling out

Scaling out is possible in similar climatic and financial conditions. However, in drier areas the capacity of water retention pools can prove to be problematic, and the implementation can be costly (Tullstorp Stream Economic Association (TSEA), 2020). In different regulatory environment the support for NBS on a national level and national funding systems need to be considered. The bottom-up approach helps to facilitate the measures and helps to adapt the measures to a new environment. The measures are also linked to achieving the objectives of the EU Water Directive. (Davis et al., 2017).

Scaling up

According to the EEA 2021 report, the transferability of this type of action will be high, both within Sweden and across parts of northern Europe subject to the same climate challenges (EEA, 2021). Storing excess water during wet periods for use during dry periods with the added benefit of water purification is expected to be a highly effective and sustainable way of climate-proofing Swedish agriculture. Water retention and recirculation measures are particularly beneficial in agricultural areas where both floods and droughts are risk factors and are expected to increase with climate change. The measures are identified to have the opportunity to simultaneously achieve ecological, economic, and social benefits such as restoring ecosystems, increased crop yield, and creating recreational wetlands (Wamsler et al., 2016). The bottom-up process which includes landowners from the start of the project adds a strong sense of ownership and facilitates approval and implementation of the project. It is however very important that the measures don't cause negative impact on the crop or economic yields for the farmers. NBS receive an implicit but vague support from the Swedish governance (Davis et al., 2017). However, funding may present a challenge since these measures are costly and irrigation & drainage projects are not currently considered in Swedish agricultural funding systems (Tullstorp Stream Economic Association (TSEA), 2020).

Scaling deep

In different conditions the feasibility of wetland-based flood prevention and water retention pools must be reassessed. In high flood and/or drought risk areas measures may not be adequate and other solutions may be required. It is very likely that land use and values concerning land use are different in high flood and or drought risk area, which may cause difficulty. Support for NBS and finding the appropriate funding may pose the biggest challenges.

Cross-cutting approaches

Large wetland restoration programs exist in the Netherlands, the UK, Germany and other European countries. Those can be better connected to exchange on levers and barriers and identify financial sustainability mechanisms. The successful implementation of similar measures may lead to further construction of other such systems. This would contribute to climate proofing agriculture on a larger scale and increase food security.

The analysis resulted in the identification of the following scaling enablers and barriers:

- Scaling enablers:
  - *Biogeographical*: protection against both floods and droughts.
  - *Financial gains*: improved cultivation and higher yield on the land.
  - *Social benefits*: tourism and recreational, linking to wetland projects within the locality.
  - *National policy*: Swedish policy measures provide vaguely expressed but implicit support for nature-based solution.
  - *National & international regulation*: realising environmental quality objectives and the EU Water Directive.
  - *Landowner buy-in*: a bottom-up process initiated and driven by the landowners themselves.
  - Structured decision-making formal decisions are taken by a board of representative an Association for the project.
- Scaling barriers:
  - *Funding*: measures are costly and irrigation & drainage projects might not be considered in national funding programs.
  - *Financial losses*: Possibility for decrease in economical or agricultural yields if not properly implemented.
  - *Biogeographical*: in drier areas the capacity of water retention pools can prove to be problematic and the implementation costly.

4.3 BLUE-GREEN CORRIDORS CASE (BELGRADE, SERBIA): MITIGATING NATURAL HAZARDS AND RESTORATION OF URBANISED AREAS

4.3.1 Summary of the case study

Belgrade is the capital of Serbia and a big regional centre, with 2,000,000 inhabitants, it covers a territory of 3500 km^2. Belgrade is an urbanized areas that constantly needs new surfaces for building of commercial, residential or infrastructure facilities. The dynamic and uncontrolled urban development of Belgrade have caused the vanishing of great green complexes and the occupation of spaces in riparian areas, and this is still an ongoing process. Furthermore, in Belgrade region, decreasing of surfaces under forest vegetation, land use change, high speed of urbanisation and inadequate agricultural measures have caused intensive erosion and more frequent torrential floods. Therefore, Belgrade authorities have defined a new strategy for land use and urban planning in order to decrease the risk from destructive erosion processes and torrential floods and help the establishment of new recreational areas, preservation of biodiversity and mitigation of the heat island effect. The different policies, plans and actions found in literature review regarding blue-green corridors in Belgrade date since 2010 until 2021. The restoration of blue-green corridors has been planned in the 2014–2020 period (Cvetković et al., 2019; EEA, 2021; Ristić et al., 2013).

The General Regulation Plan of Belgrade Green Urban Areas, 2019, proposed to integrate basin management and their revitalisation as blue-green corridors, based on the specific landscape characteristics of the Belgrade region. In early 2015, the city of Belgrade adopted the Action Plan for Climate Change Adaptation (hereinafter APCCA), emphasizing the planning and implementation of green infrastructure networks throughout the metropolitan territory as a measure of the highest priority. At the national level, policies also push towards creating green infrastructure to connect the natural and cultural value of urban settlements, peri-urban mosaics and rural areas in the form of blue-green corridors in the previous Spatial Plan (2010-2020) and in the New Spatial Plan of the Republic of Serbia (Ristić et al., 2013; Simić et al., 2017; Vasiljevic et al., 2018).

The aim of this case study is to show how the planned restoration of the blue-green corridors at two experimental watersheds of the Kaljavi and Jelezovac streams, as well as adequate land use changes, can help to the improvement of hydrological conditions in the endangered watersheds, the provision of effective erosion and torrent control, and the achievement of environmental and social goals (Figure 6).

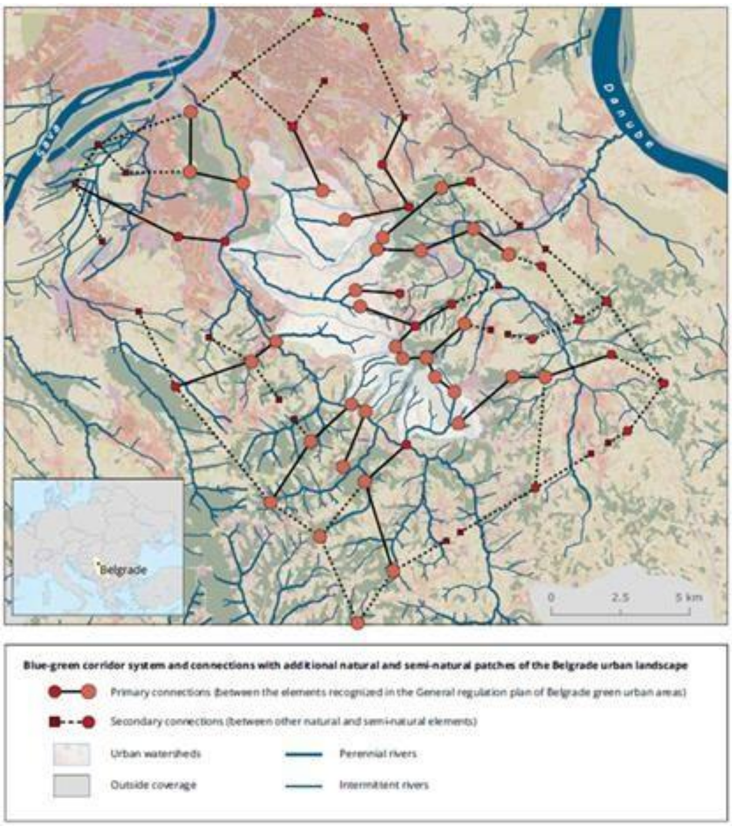

Figure 6. Blue-green corridor system and connection with other natural and semi-natural patches of the Belgrade urban landscape. (Source:(EEA, 2021)).

4.3.2 *Objectives of the Nature-based Solution*

- Ecosystem restoration objectives (EEA, 2021; Ristić et al., 2013):
  - Increase the current forest cover by 1.38 km (18.11% of the total area).
  - Decrease the values of maximal discharges (p = 1%) by about 50%, and the volumes of direct runoff by about 40%.
  - Decrease erosive material production and transport by about 44% in the Kaljavi stream watershed, and 37% in the Jelezovac stream watershed.
  - Reduce agricultural land use and converting it to organic farming.
  - Afforest degraded arable land with steep slopes.
  - Re-grass degraded meadows.
  - Establish orchards on terraces and in gardens instead of on abandoned plough land.
  - Protect forest belts along stream beds.
  - Implement bans on clear-cutting.
  - Implement bans on cutting on steep slopes.
  - Implement bans on straight row farming down the slope.
  - Stop uncontrolled urbanisation.
  - Create a 10 km of sealed walking and cycling paths and 1.7 km of unsealed forest paths.
  - Create six open gyms and seven rest areas for recreation and sports.
- Adaptation and disaster risk reduction objectives (EEA, 2021; Ristić et al., 2013):
  - Climate change adaptation by preventing or reducing the risk of torrential floods and destructive erosion processes.
  - Climate change mitigation by CO_2 sequestration, O_2 emission and reduced heat island effect.
  - Bringing people back into the city space and increasing sports and recreational facilities.
  - Conserving, restoring and protecting biodiversity and helping protect and control the use of the natural and cultural value of the area.
- The city of Belgrade has applied a holistic approach to countering erosion processes and torrential floods, backed by research and models in ecological engineering and landscape planning (Ristić et al., 2013; Simić et al., 2017).
- The research conducted by the municipality and the university of Belgrade (Green Regulation of Belgrade, 2002), suggests changes in agricultural practices, reductions in the farmland area, reforestation, and regulating and banning unsustainable land use practices. (Ristić et al., 2013; Simić et al., 2017).

4.3.3 *Scalability insights*

Scaling out

- **Expand Scope of Pilot Strategies:**
  - The Green City Action Plan (GCAP) 2021 of Belgrade city, also provides a financially sustainable plan to meet their ambition of winning the Green City Capital Award in the near future. This plan establishes a roadmap for maximising economic, environmental, and social co-benefits. Some of the plan's goals are to increase green infrastructure in the city, adapt to climate change and expand a programme of afforestation, biodiversity and environmental protection, among others (Vićanović et al., 2021).
  - The Urban Forest Management Plan for the City of Belgrade uses the spatial-ecological approach to create the plan and to establish connectivity as a new aim in forest management planning. This will show that the implementation of the green infrastructure concept, and the achieved multifunctional ecosystem values can be presented on the basis of the parameters of landscape metrics (Vasiljevic et al., 2018).

- **Replicate an initial pilot strategy to a new pilot location:**
    - The approach is transferable to most urban settings restoring and connecting blue-green infrastructure and changing land use practices to avoid environmental degradation and hazards (European Environment Agency, 2021).
    - A similar (blue-) green infrastructure research (spontaneous/community greening and formal/institutional cultivation and maintenance) was conducted within the city of Belgrade, in Block 45 and Savamala district near to the Belgrade green core and the river Sava. The Block 45 and Savamala district examples represent a dominant type of urban land cover in the terms of area, connectivity degree, continuity, and control over landscape(Simić et al., 2017).
    - In terms of the (blue-) green infrastructure development, the Action Plan for Climate Change Adaptation 2015 (APCCA) provides the foundation for the development of a network of green corridors along the promenade Lazaro Kardenas, which connects residents with the river Sava (Cvetković et al., 2019; Ristić et al., 2013; Simić et al., 2017).
    - The Municipality of Mladenovac, is a suburban part of the administrative area of the Belgrade metropolitan area. It has similar challenges as the city of Belgrade in terms of rapid urbanization, land use change, agriculture and land degradation, as well as vulnerability and exposure to climate impacts such as flooding. The implementation of the Belgrade Afforestation Strategy in 2011 through the Urban Forest Management Plan, has resulted in the afforestation of 416.86 ha of land owned by the Mladenovac municipality (Vasiljevic et al., 2018).
- **Replicate Pilot Strategies within a Program:**
    - The Green City Action Plan 2021 (GCAP) for the City of Belgrade has a series of 16 Strategic Objectives have been set out to tackle the environmental challenges identified and meet the city's vision. These are arranged in three core sectors (Urban Planning and Mobility; Energy and Efficiency; and Water and Waste). The Strategic Objective S.O.L3, aims to improve the importance and capacity of Green Infrastructure and provide access to public green spaces in all parts of the city. The Strategic Objective S.O.W2, aims to protect the city from the risk of flooding. The Strategic Objective S.O. CCA1, aims to raise awareness of the city's vulnerabilities to climate change and actively planning to adapt (disaster risk informed urban planning). The Strategic Objective S.O.GS1, aims to substantially increase the tree cover and level of porosity of Belgrade's territory, and to replicate or resemble the strategies on the restoration of blue-green corridors from the experimental watersheds the Kaljavi and Jelezovac streams (Vićanović et al., 2021).
    - The green infrastructure concept in the Urban Forest Management Plan for the City of Belgrade involves the application of a landscape approach to research, and connectivity is established as a new goal of afforestation (Vasiljevic et al., 2018).

Scaling up

- Integration of the blue-green corridors within Belgrade's policies to create green infrastructure in the city and in the region. These policies can be reflected on the Spatial Plan 2010-2020 and on the New Spatial Plan of the Republic of Serbia (Ristić et al., 2013; Simić et al., 2017; Vasiljevic et al., 2018).
- There are several policies in form of local plans, regulations and strategies, such as the Green Regulation of Belgrade in 2002, the General Regulation Plan of Belgrade Green Urban Areas 2019, the Action Plan for Climate Change Adaptation 2015 and the Master Plan of Belgrade 2021 (Cvetković et al., 2019; Ristić et al., 2013; Simić et al., 2017; Vasiljevic et al., 2018).
- Belgrade city has developed the Green City Action Plan (GCAP) 2021. It is a strategic document which diagnoses, prioritises and detects the environmental challenges of the city and presents a "Green City" vision for 2030 (Vićanović et al., 2021).
- The realisation of the green infrastructure concept in Belgrade, is presented through the example of the Urban Forest Management Plan and Afforestation Strategy (2011) for the City of Belgrade and Mladenovac Municipality (Simić et al., 2017).

Scaling deep

- There is a potential of the informal greening in Belgrade because of spontaneous activities of citizens and associations at the local level. Informal green areas can be the result of different individual or collective actions, both located on the private, as well as the common or public area (Simić et al., 2017).
- Informal green areas are diverse in terms of their spatial configuration and relation to the built and natural elements of surrounding, and thus to the components that constitute the green infrastructure. However, the physical level, which is linked to the neighbourhood-district or individual land/ building is common to all forms of informal greening (Cvetković et al., 2019; Ristić et al., 2013; Simić et al., 2017).
- The local community association can be considered a significant component for green infrastructure development as a part of future greening urban plan concept at local level. Elements of informal greenery contribute to ecological, economic and role in human well-being, and as such they are eligible to become a part of the formal, strategically planned network of green infrastructure (Simić et al., 2017).
- Working at a local scale in Belgrade and providing meaningful opportunities for community involvement, may facilitate acceptance of what necessarily needs to be implemented, and also could generate solutions that are more extensive and economically viable (Simić et al., 2017).
- The Green City Action Plan 2021 (GCAP) for the City of Belgrade has been co-developed with city officials, stakeholders, and citizens. They have established the following Green City vision for Belgrade which has guided the development of the Green City Action Plan (GCAP): "*We are a capital city which is developing smartly for its citizens, especially children, and pursuing the ideals of an even greener, healthier, and more sustainable future.*" (Pantić and Milijić, 2021; Vićanović et al., 2021).
- There are intentions of Belgrade city to win the European Green Capital Award. An agreement of cooperation and transmission of knowledge regarding the nomination for the European Green Capital Award (EGCA) was signed between the mayors of Belgrade and Ljubljana (EGCA 2016 winner) in September 2018. The candidacy of Belgrade was finally realized in October 2019. The City of Belgrade has applied for the EGCA 2023 competition (Pantić and Milijić, 2021; Vićanović et al., 2021).

Cross-cutting approaches

- This case study could be used as an example of NBS potential in "East" Europe. However, due to the context, this case study could be better used as an understanding of local and regional restoration solutions.
- This case study on the blue-green corridors in Belgrade Serbia, started with a top-down approach and with the support of local, regional and national policy programmes. On the other hand, there are similar cases of (blue-) green infrastructure within the city of Belgrade that were implemented as bottom-up approaches (community initiatives), that were targeting local needs to address climate adaptation, social resilience and ecosystem restoration.

The analysis resulted in the identification of the following scaling enablers and barriers:

- Scaling enablers:
    - *Cultural value:* Promoting the restoration of cultural values locally.
    - *Citizen wellbeing*: Establishment of recreational and sports areas.
    - *Land use and planning strategies*: Belgrade defined a new strategy for land use and urban planning in order to decrease the risk from destructive erosion processes and torrential floods, and a supportive Master Plan.
    - *National strategy*: Policies also push towards creating green infrastructure to connect the natural and cultural value of urban settlements, peri-urban mosaics and rural areas.

    - *Data & Information on land use*: A comprehensive insight into green areas of Belgrade (GIS of biotopes), introduced contemporary principles of green infrastructure and enabled identification of the so-called morphological units, according to the patch-corridor-matrix model of landscape structure.
    - *Climate Action Plans*: the city of Belgrade adopted the Action Plan for Climate Change Adaptation in 2015.
    - *Community-led greening*: can be the result of different individual or collective actions, both located on the private, as well as the common or public area.
- Scaling barriers:
    - *Landownership*: Since the 1990s, land has been organised in many small private parcels with many different owners.
    - *Land use*: A high concentration of housing, office and infrastructural facilities made Belgrade poor in green areas compared to other cities in Europe.

4.4 BRAGUE CASE (FRANCE): FLOOD PROTECTION MEASURES IN A MEDITERRANEAN CATCHMENT

4.4.1 Summary of the case study

The Brague river catchment was used as one of the 9 demo sites within the NAIAD project (NAture Insurance value: Assessment and Demonstration). The project aimed **at developing concrete nature-based solutions in response to floods and drought**. The Brague river catchment area, classed as a peri-urban and considered forest management as a nature-based solution/intervention in response to flooding and wildfire natural hazards. This demonstration case was aiming **to improve knowledge about torrential flood processes** and **the definition of alternative insurance business models and new multi-criteria decision making tools accounting for ecosystems and protection systems effectiveness**(“La Brague Basin | Naiad,” 2018) (Figure 7).

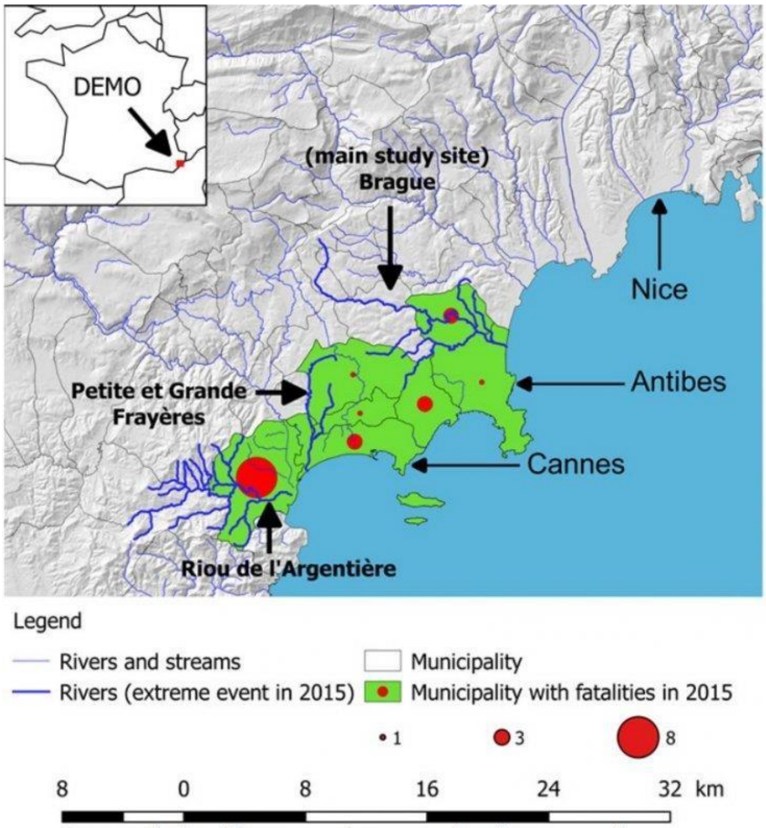

Figure 7. Location of main cities and most active rivers during the Oct. 2015 flood. Source: (Pengal, P., et al., 2017, p. 51).

On the 3rd of October 2015 the area between Nice and Cannes was hit by severe rainfalls which triggered dramatic floods. The three river basins are regularly subject to heavy rainfalls and torrential floods, however the 2015 floods were of extreme proportions, causing 20 deaths and about €550-650 million losses, with complications for the local businesses, transportation, communication and energy networks (Préfécture des Alpes-Maritimes, 2015). A particularity of this flood event were the wood jams created by the transport of large amount of wood pieces, which further exacerbated the physical damage and disturbance to the citizens (Pengal, P., et al., 2017).

The most damaged low laying areas which previously housed campsites were closed offering an opportunity to rethink the economic use of the valley. The NAIAD project used the Brague catchment to study the potential **efficacy and efficiency of NBS flood protection measures** based on green and grey measures and their potential co-benefits (Gnonlonfin et al., 2019).

Table 2 provides an overview of the three scenarios which were studied in the NAIAD project.

Table 2. Intervention scenarios studies in the NAIAD project, Own preparation, based on (Gnonlonfin et al., 2019).

	GREY STRATEGY	NBS HIGH AMBITION STRATEGY	NBS VERY HIGH AMBITION STRATEGY
Reduce flood excess water	Construction of two large retention dams upstream	Combination of small retention dams, widening of riverbed, restoration of riparian forests, restoration of wetlands	NBS high ambition strategy + Removal of more physical constraints (road, highway) to widen the riverbed
Reduce wood jams	3 large wood trapping facilities	5 large wood trapping facilities	5 large wood trapping facilities
Benefit	No land acquisition	Continuous cycle and footpath along the riverbanks Ecosystem restoration Water quality and quantity improvement	Continuous cycle and footpath along the riverbanks Ecosystem restoration Water quality and quantity improvement
Trade-off	The area used for the dams are located in national parks	Expropriation and demolition of houses in the floodplains	Expropriation and demolition of houses in the floodplains
Cost (over 50 years)[4]	€ 170 million	€ 77 million	€ 83 million

The **bio morphological characteristics** of the catchment area meant that different flood protection measures were proposed for hilly upper catchment, and the flood plains at the lower part catchment areas. In the upper catchment area the proposed flood protection measures included small retention damps, while the lower catchment areas were recommended to follow the so-called “giving-room-to-the-river” strategy, with specific measures including widening of the riverbed, restoration of the riparian forests and wetlands combined with management of large wood debris (Gnonlonfin et al., 2019).

The project involved the local stakeholders to co-define the **benefits** of the proposed NBS intervention scenarios, through focus group discussions and surveys. The stakeholders identified reduction of flood risk, but also impact on **biodiversity** and **natural habitats quality**, **economic development**, **quality of life** and **social cohesion** and **territorial coherence** (Gnonlonfin et al., 2019, p. 356).

The project recognised that dealing with NBS required the consideration of a mix of technical, physical, economic, environmental, human and social points of views. For this end, the NAIAD project recommended a 10 step guide to characterise the institutional framework that underpins the incentives driving many of the stakeholders (Rica, M. et al., 2019). **The benefit of such multicriteria analysis compared to a simple cost-benefit analysis is that it allows for the presentation of intangible criteria,** such as continuous cycle and footpath along the riverbank, which was previously fragmented.

[4] The estimated cost included: land acquisition costs, investment costs, maintenance cost over 50 years period, opportunity costs. For the table we used the median value for each scenario. The range of uncertainty were Grey strategy: 88M€; 270M€, NBS high ambitions strategy: 57M€; 128M€, NBS very high ambition: 60M€; 134M€. (Gnonlonfin et al., 2019, p. 324).

4.4.2 Objectives of the Nature-based Solution

Ecosystem restoration objectives:

- ecosystem restoration of river basins,
- improve the knowledge and monitoring of ecosystems and their services,
- prevent and reduce the impact of natural disasters,
- develop climate change adaptation planning,
- improve risk management and resilience:
    - flood peak reduction,
    - reduced drought risk,
    - reduced flood risk.

Adaptation and disaster risk reduction objectives:

- increased awareness of NBS and their effectiveness and co-benefits,
- increased population and infrastructures protected,
- increased willingness to invest in NBS/willingness by the citizens to finance NBS interventions,
- improved environmental health of the river, riparian forest and wetlands,
- capture and store carbon,
- deliver further benefits, such as soil health and pollination,
- rebuild the connection of citizens with the natural ecosystem,
- potential or measured trade-offs.

4.4.3 Scalability insights

Scaling out

The case study offers valuable lessons for other similar Mediterranean river catchment areas that face similar bio morphological conditions (NAIAD, 2019). Such as:

- The conclusion that flood retention measures in high and mid-catchment areas is unlikely to avoid flooding downstream. Sufficiently large corridors are needed to channel the river to the sea or to a downstream river.
- The implementation of giving-room-to-the-river strategies will likely require expropriation and demolition of infrastructure with high costs.
- Building assets in flood corridors will always mean that citizens and businesses will require more information about the flood risks and the measures undertaken to mitigate them.

Scaling up

- The proposed measures are developed with the full catchment area of the river Brague and it is based on the combination of several smaller measures in the upper catchment area and larger works to widen the river bed in the lower floodplains.
- The social, economic discussion initiated by a catastrophic extreme weather event contributed to focus public attention in the need to invest in flood protection measures and initiated a useful discussion about the options available, including NBS.
- The assessment of co-benefits of NBS measures is complex, however the inclusion of intangible benefits in a multicriteria analysis offer the advantage of including both the avoided damage and the restoration of ecosystems and new ways for the citizens to enjoy the catchment area (ie. New cycle and footpath along the river).
- The implementation of widening of the riverbed in the lower, floodplains is essential to avoid future flood damage, however it requires expropriation and demolitions, however the co-benefits are numerous and the cost is half of a grey measure with similar protection efficacy.

Scaling deep

It became clear from the case study that rethinking how the land is used across the catchment area is essential to understand the future flood risk and design plans to mitigate them.

- Land-use change involving the destruction of built assets and livelihoods need to be accompanied by multistakeholder engagement processes and compensation funds.

Investment in NBS solutions to enhance flood protection must be based on pluridisciplinary assessment framework including quantitative and qualitative indicators to insure economic viability and social acceptance.

Cross-cutting approaches

This case study can be used as an example for Mediterranean river catchment areas. It offers especially valuable learnings about the **management of wood debris** resulting from extreme flooding. The case study demonstrated that the annual management of dead and titling trees is not sufficient to avoid the recruitment and transfer of wood downstream in the case of extreme weather events. A relevant solution is to construct large wood trapping facilities before critical infrastructure such as bridges/dams and leave the upstream riparian forest natural, un-managed (NAIAD, 2019).

This case study is also valuable for learnings about the **giving-room-to-the-river strategy** and the social consultation and communication processes to enable such strategy.

Upscaling enablers:

- *Awareness:* project was triggered by a specific extreme weather event and the associated deaths, financial losses and land degradation resulting from it.
- *Citizen acceptance:* the flood retention approach was requested and accepted by citizens, who had been included in the co-design of strategies.
- *Financial resources:* the cost of implementation and maintenance of grey solutions is higher than the cost of NBS strategies for the same level of risk management.

Upscaling barriers:

- *Changing long-term land use strategies*: the approach involves asset (home, work, building) demolition and a change in land use.
- *Financing:* land-use, land cover control and protecting such areas may become extremely expensive as it involves buying out assets.
- *Multiple interventions:* the approach requires several smaller interventions working together, such as smaller retention dams, wood trapping facilities and larger riverbed widening measures.
- *Data and evidence:* there is a lack of evidence on grander catchment scales, it is important to obtain first estimates of NBS for natural flood management effectiveness and reliability on grander catchment scales for extreme-flood events.

4.5 GREEN ROOF CASE: COMBINING REGULATION, DIALOGUE, INCENTIVES AND SCIENCE

4.5.1 Summary of the case study

Green roofs have been considered an attractive solution for renaturation in German cities since the 1960s as means of extending lifetime of roofs and for aesthetic reasons (Clar and Steurer, 2021). Green roof policies are quite frequent in German cities: the organization of greening of buildings counts actually more than 50 German local authorities with specific funding programmes for green roofs (BuGG, 2022). In Hamburg, district administrations had started making green roof coverage obligatory in development plans for new buildings since the 1970s with almost all new plans prescribing green roofs after 2010 (Richter and Dickhaut, 2019, p. 42).

In 2015, the city state of Hamburg has set up a green roof strategy for the whole city territory which aims at realizing, by 2024, 70% of all suitable rooftops on new buildings as green roofs. The strategy employed by the city is based on financial incentives, awareness raising, regulation and scientific advice. The initiative is part of a comprehensive strategy which aims at preparing the city for population growth and climate change. The policy is supported across different departments of the administration and is accompanied by scientific research improving the knowledgebase, information and acceptance campaigns to improve the uptake of the measure by building owners.

To ensure additional benefits in terms of restauration of ecosystem functions green roofs need to correspond to minimum standards with respect to substrate selection, surface modulation for biodiversity and appropriate choice and variety of species). In the case of Hamburg, only minimum soil layer thickness is defined as a requisite for the subvention programme, but the city provides further information regarding recommended plant species for extensive roofs[5].

The potential restorative function of green roofs with respect to urban biodiversity is recognized in the procedures the city of Hamburg has set up for the application of the national nature protection law, which assesses the biodiversity value of green roofs and recognizes them as (partial, but not full) mitigation measure requested for the compensation biodiversity losses caused by the construction of buildings (Richter and Dickhaut, 2019, p. 52). This recognition provides a further economic incentive, as the construction of green roofs would reduce costs of eventually required alternative measures in other places (Freie und Hansestadt Hamburg, 2017, p. 18).

4.5.2 Objectives of the Nature-based Solution

Urban storm water management and improvement of urban micro-climate

- Absorption of surface run-off caused by heavy precipitation events: extensive green roofs are able to absorb between 33 and 81% of stormwater, depending on thickness and type of plants, for intensive green roofs with thicker layers this rate is about 22% higher (Freie und Hansestadt Hamburg, 2017) in case of extreme precipitation, green roofs are able to delay peak run-off by approx. 79% and (Manso et al., 2021).
- Reduction of the urban air pollution (Manso et al., 2021).
- Improvement of building insulation and cooling due to evapotranspiration (Manso et al., 2021).

Restoration of urban biodiversity

- Green roofs represent a partial substitution of the vegetal soil coverage and ecosystem services provided by soil destroyed by the building, if possible, the plant communities used for greening should replace those removed for the building activities, restoring urban biodiversity.

[5] (in German) https://www.hamburg.de/contentblob/6152732/9cb8117cec6161dbe7ae889469ef19a3/data/d-naturdach-extensiv.pdf

4.5.3 Scalability insights

Scaling out

The strategy chosen by the city of Hamburg, which renounces on legal constraints like implemented for instance by the city of München where also buildings transformed or newly built outside building plans is eventually less successful, as the rate of green roofs in München and other cities shows in comparison to the percentages achieved in Hamburg (BuGG, 2022).

The growth of urban areas is the cause of ecological problems such as habitat fragmentation, degradation and destruction, over-exploitation of natural resources, the spread of alien species (Kronenberg et al., 2013). Furthermore, under changing climate conditions, the need for solutions for the management of intense precipitation events is common to practically all urban areas, and the co-benefits (thermal insulation, increase of albedo and of evapotranspiration) are also generically relevant for urban climates under rising temperatures, thus mitigation of losses of ecosystems and restoration of their services must represent a key objective for biodiversity protection and restoration. The use of rooftop surfaces for restoring biodiversity in urban areas has yet some limits.

1. *Physical considerations*

The possibility of realizing green roofs is physically limited by the availability of adequate roofs with a maximum roof inclination of 30°degrees, and by static requirements due to the implementation of a structure which is heavier than a normal "black tarmac" roof, yet in some cases comparable to the weight of gravel roofs. Both inclination of roofs and static requirements can limit, to some extent, a widespread implementation of green roofs in temperate climates and thus the possibility of restoring biodiversity, in particular of creating connectivity across the urban landscapes, and creating natural water storage capacity in particular dense inner-city areas.

2. *Governance and economic considerations*

Urban roofs are, to a large extent, part of private buildings, and their realization depends, if no coercive measures are taken, on the willingness of private property owners to invest in green roofs. The possibility of incentivising these investments and improving the willingness of private investors depends on the continuous availability of specific funding to compensate the higher building costs. With regards to maintenance building management, there is a need for more widespread awareness about the economic advantages of the solution, which can outweigh, over the lifetime of a green roof of 30-50 years, the higher building costs (Free and Hanseatic City of Hamburg, 2017, p. 22). Additional benefits which can be realized during the management period consist, eventually, in reduction of stormwater fees, in the case a city recognizes the private contribution to the management of stormwater, as well as economies in terms of thermal insulation, reducing expenditure for cooling and heating in upper floors, new economic opportunities offered by economic exploitation of green roof spaces, or use values under the form of green private outdoor spaces, a rare good in dense urban areas. On the real estate market, green roofs are not recognized or appreciated as an additional value, thus preventing the construction of green roofs in large development projects. as buyers "often do not realize they bought a building with a green roof" (Richter and Dickhaut, 2019, p. 46) and thus are not aware of the additional value these roofs can add to the building be of interest for objects dedicated to the rental market.

Front of a substantial lack of knowledge about the advantages of investments in green roofs, strategies for increasing willingness of private actors undertaken by the city of Hamburg consist in presenting and documenting good practice examples and scientific evidence on physical and economic characteristics of green roofs.

Public investments in green roofs can have a model function; and windows of opportunity as extreme events, if accurately framed and supported by influential change agents, can present a temporary opportunity for raising awareness about benefits from green roofs and positive aspects of climate change adaptation (Clar and Steurer, 2021).

Coercive measures can take effect only in those moments when investments in buildings (both new construction and eventually also in case of restructuring) are made and have no effect on the existing building stock. In Germany, the example of München, where a design by-law dating from 1996 made greening of flat roofs obligatory for new buildings. Actually, in a rating of green roof intensities among German cities, Stuttgart scores first with 4.1 m^2 per inhabitant, whereas Hamburg scores fifth with 1.5m^2/inh (BuGG, 2022).

3. *Redistribution of benefits/use values*

Green roofs generally provide benefits both to the public (cooling down of urban surfaces, storage of rainwater, creating new places for biodiversity) and to private users (thermal insulation, eventually use as private or commercial outdoor space). The exclusive use of green roofs as private or commercial spaces makes them different from green facades and urban park areas which provide benefits also in terms of visible and or usable urban green spaces.

Scaling up

In Germany, green roofs are already at a stage beyond the pilot phase, with numerous implementation examples, often made by public entities. The city of Hamburg has tried to achieve a scaling up of this measure providing a target threshold of 70% of all suitable roofs using specific incentives and legal enforcement. According to the analysis found, this threshold is not connected to biodiversity or stormwater management dimensions, eventually also because a quantification of the extent of suitable roof surfaces is difficult to achieve.

The analysis identified specific barriers for scaling up of green roofs:

- Due to lack of information, investors still associate green roofs with relatively high levels of financial uncertainty, and most local authorities lack locally specific expertise, especially regarding costs and benefits (Clar and Steurer, 2021).
- Slightly higher construction costs for buildings with green roofs with respect to those with traditional roofs represent a barrier in urban housing markets dominated by a quickly increasing demand for affordable living space and served as an argument for not introducing a legal obligation for green roofs in Hamburg (Clar and Steurer, 2021).
- Green roof policies often remain restricted to new buildings as it is difficult and relatively expensive to retrofit flat or slightly inclined roofs of existing buildings to make them support soil and plants (Clar and Steurer, 2021). The funding scheme set up in Hamburg tries to address this barrier by providing premium subsidies and additional finance for statical works to adapt existing buildings for green roofs.
- A fundamental barrier consists in the large diffusion of sloped roofs on existing buildings, which are not suitable for greening.
- Benefits generated by green roofs are realized mainly by the city as a whole (reduced run-off after extreme events, improvement of urban climate), while costs of implementation and maintenance are borne by mostly private owners of the buildings. Finding a solution that equally suits both sides is not simple (Clar and Steurer, 2021). Maintenance costs of green roofs are, according to assesments of the city of Hamburg, comparable to those of black roofs (Freie und Hansestadt Hamburg, 2017) so that the approach used in Hamburg to recognize public benefits provided by green roofs with a reduction of stormwater fees is, estimated to be sufficient for compensating maintenance costs of green roofs. Both the funding scheme for green roofs and reductions of storm water fees offered to owners of green roofs attempt to partially recognize services green roofs provide to the city.
- Due to short-term economic interests, aesthetic concerns, or simply misinformation about technical shortcomings of green roofs, developers and/or architects are often sceptical. Building owners often do not even consider installing green roofs because they lack the necessary awareness, knowledge, and/or financial capacities or expect high installation costs and maintenance efforts (Clar and Steurer, 2021).

- Land use competition: green roofs often compete with other interests, in urban areas mainly with a quickly increasing demand for affordable living space as they do slightly increase construction costs in the short term.
- New vs old build, regulations: green roof policies often remain restricted to new buildings as it is difficult to influence the built form of a city and relatively expensive to retrofit existing buildings to make their roofs support soil and plants.

With regards to individual or building level economies, upscaling of the solution can provide the following benefits:

- *Social benefits:* green roofs on new buildings made available to residents or employees for recreation (sports fields, parks, community gardens).
- *Planning regulations:* regulatory provisions in many parts of the expansion area actually require the realization of green roofs in development plans committing both the city and private investors through a binding framework regarding new construction.
- *National acts:* the Federal Nature Conservation Act is used for enforcing green roofs a compensation for ecosystem restoration measures in cases of new buildings.
- *Financial benefits:* reduction of stormwater fees for owners of buildings with green roofs.
- *Funding availability:* the organization of greening of buildings counts actually more than 50 German local authorities with specific funding programmes for green roofs.
- *Better insulation:* At the building level, the soil and plants layer provide a better insulation and can thus reduce heating and cooling costs for the spaces located immediately below the rooftops. Green roofs on new buildings can be made available to residents or employees for recreation (sports fields, parks, community gardens) or can be used for economic activities, and the operation of solar panels on green roofs is more efficient (Freie und Hansestadt Hamburg, 2017, p. 22).
- *Increased evapotranspiration and improvement of air quality:* Further to reducing the risk of surface flooding after intense precipitation events, at neighbourhood level, green roofs contribute to a reduction of air temperatures by increasing evapotranspiration and contribute to an improvement of air quality.
- In the case of new buildings, economies are offered by the recognition of green roofs as **mitigation measures** according to the national nature conservancy act**,** allowing the investor to reduce compensation measures replacing elements of biodiversity destroyed by the construction of the building.
- *Scientific research:* scientific research improving the knowledgebase and information.
- *Awareness campaigns:* acceptance campaigns to improve the uptake of the measure by building owners.
- *Cost savings:* the soil and plants layer provides a better insulation and can thus reduce heating and cooling costs for the spaces located immediately below the rooftops.

4.6 LIFE RESILIENT FOREST CASE COUPLING WATER, FIRE AND CLIMATE RESILIENCE WITH BIOMASS PRODUCTION IN FORESTRY TO ADAPT WATERSHEDS TO CLIMATE CHANGE

4.6.1 Summary of the case study

The LIFE Resilient Forest project develops a tool to assess to what extent it is profitable to carry out forest management when accounting for additional forest services. The project has developed a Decision Support Tool for multi-criteria forest management, which is based on the CAFE concept (Carbon, Aqua, Fire and Eco-resilience). This tool determines the optimum activities to manage biomass production, CO_2 sequestration, fire risk, water provisioning, climatic resilience and biodiversity. The software provides key information to forest managers on how to manage resilient forests at catchment scale under multiple objectives about management intensity, spatial distribution, frequency and type of management (thinning/planting). The tool is designed with the ambition to be implemented in Germany, Portugal and Spain and be relevant to forests with different forest cycles.
The project also plans to develop a complete monitoring system, including a Life Cycle Assessment of the forest management approach that intends to demonstrate the positive environmental as well as socioeconomic impacts of the project.

4.6.2 Objectives of the Nature-based Solution

The proposed solution does not target specific ecosystem restoration objectives, however a more integrated approach, including the assessment of biodiversity gains, is proposed in the context of the variables that are evaluated in the case study.
The proposed solution was assessed in two pilot sites using the following criteria:

- Carbon consisting in the calculation of available biomass, wood, Carbon-soil,
- Water cycle by assessing land percolation and surface runoff,
- Fire risk depending on the superficial humidity of the soil,
- Eco-resilience based on the modelled efficiency in the use of water.

Specific relevant insights from the two case studies were:

- Municipality of Sierra (Valencia) (Gonzalez-Sanchis et al., 2022). The tool was tested in the context of a natural park of the Sierra Calderona, using ecohydrological simulation and multi-objective optimization with evolutionary algorithms. Performing the multicriteria optimization it was observed an increase in biodiversity protection (+14) and resilience (+7.8%), a decrease in fire risk (-2%), slight decrease in carbon sequestration and no relevant changes in water protection.
- Municipality of Berriatua (Basque Country) (Pérez Romero et al., 2022). The tool was tested in the context of a forest plantation, collecting and analysing data (soil moisture, transpiration, etc.) and using the BIOME-BGC_MuSo simulation model to quantify and optimizing specific indicators related to ecosystem services' provision (water, wood, fire risk and C-sequestration) on a 30-years cycle. Consideration on the financial aspects (euro/ha) were included in performing the multi-criteria analysis. It was observed that the combination of objectives can be confusing for the forest manager, but it is necessary if plantations are to be adapted to the scenario of global change.

Climate change affects forest ecosystems in different ways, e.g. by altering tree growth or by making forests less resilient to disturbances (the altered frequency and intensity of pest and disease outbreaks, droughts, wildfires and windstorms). Non-management is a model that has resulted in complex socio-economic changes in rural areas. However, it is not a sustainable solution considering risks of wildfires exacerbated by climate change. The project promotes a forest management approach at the watershed scale that improves forest resilience to wildfires, water scarcity, environmental degradation, and other effects induced by climate change and land-use changes. The aim is to develop a system able to introduce climate change adaptation strategies in forest management with a specific focus on the quantification and optimization of ecosystem goods and services and scalability within the project.

4.6.3 Scalability insights

Scaling out

- The dialogue with stakeholders from different countries and socio-ecological realities has improved the DSS tool by opening the scope of management goals and alternatives. For instance, forest plantations were not included in the tool from the outset, but this was incorporated after involving forest owners and realizing the relevance of that.
- The tool was designed and developed to be usable in multiple Member States.

Scaling up

- The project itself set out to build a scalable model, by testing it in two different places - Valencia and Basque Country.
- Scaling will depend on the tenure structure, skills of foresters.
- When there is an economic concern, there is an incentive to build a business case to make the solution more sustainable, e.g. data collection is facilitated.

Scaling deep

- The project owners highlighted the crucial importance of stakeholder engagement in the definition of the management objectives.
- Scaling deep the solution would require a more participatory approach to land and resource management.

Cross-cutting approaches

At first, the multi-criteria management approach is applied at sub-catchment level in Spain (415 hectares), then at the catchment level in Germany, Portugal, and Spain (7824 hectares) and finally it will be further expanded to 350,000 hectares within five years from the project completion. Nonetheless, it can be beneficial to connect with other initiatives which aim at a better forest management, for example tackling the financial limitations given by fragmentations by mobilizing and bringing together smallholders of a given region.

A primary concern for forest managers is how to tackle resilience (incl. adaptation, carbon storage, biodiversity), and the project faces in adaptation in a specific sector (forestry), including aspects related to the extent to which it contributes to carbon sequestration, and biodiversity increase. The project was tested in specific cases (a natural park and a forest plantation) and it would be beneficial to better understand how the solution can be scaled at landscape level, and build connection with other initiatives which aim at understanding core objectives on Nature-based Solutions as coupling carbon sequestration, ecosystem restoration and disaster risk reduction.

The project has been designed with the idea to test and develop the tool by applying it in multiple locations in Europe and in different contexts depending on the stakeholder feedback. Scaling of increasingly advanced approaches to sustainable forest management greatly depends on understanding and leveraging the context-based enabling conditions, e.g., the willingness to test an innovative tool, the ability of smallholders to cooperate, the presence of skills and capabilities in forest management (as when there is a presence of bigger forest managers as state forest management organizations). The analysis resulted in the identification of the following scaling enablers and barriers:

- <u>Scaling enablers:</u>
    - *Funding:* dedicated EU Programme such as LIFE+ are fundamental to promote a sustainable forest management approach at the watershed scale that improves forests resilience to wildfires, water scarcity, environmental degradation and other effects induced by climate change especially in socioeconomic contexts where forestry is not profitable.
    - *Biomass production:* consideration on increasing or maintaining a sustainable biomass production is important to engage forest owners in planning for sustainable practices.

    - *Local leadership:* while there are multiple initiatives looking at advancing and improving sustainable forest management, it must be said that local knowledge or leadership is essential for experimenting and implementing management approaches that expand the concept of sustainable forest management by adopting innovative tools or approaches.

- <u>Scaling barriers:</u>
    - Fragmentation of the sector.
    - Lack of information on the multiple benefits that can be achieved through sustainable forestry.
    - Lack of awareness on sustainable forest management.

5 Key Findings

The assessed case studies are at different stages in maturity and the availability of data differs. For example, the Brague River basin (France) and the forest management cases represent plans/strategies or decision-support tools therefore they are designed to be scaled or applied in different contexts, the paludiculture case is at the piloting stage, whilst the agricultural case in Sweden and the roof top greening in Hamburg represent cases that have started to scale. This presents a greater breadth of insights on scaling, but it must be noted that those cases that are at pilot scales or have started to scale provide a great set of insights on what enablers or hinders upscaling (Table 3).

Table 3. Summary of the key findings for each of the analysed case study

AREAS	CASE STUDY	NBS SHORT DESCRIPTION	ADAPTATION AND DISASTER RISK REDUCTION	ECOSYSTEM RESTORATION AND BIODIVERSITY TARGETS	SCALING POTENTIAL: CHALLENGES AND ENABLERS
Paludiculture	Germany	Rewetting of drained and degraded peatlands Production of products suited to very wet conditions	Restoration of water storage function to prevent inundations and droughts	Restoration of peatland natural ecosystems	Possible trade-offs between level of rewetting and buffer function to floods Huge synergy with climate mitigation
Agriculture: river catchment restoration	Tullstorp stream, Sweden	Restoration of a stream catchment area in an agricultural setting. Including: restoring wetlands, re-meandering, re-naturalising riverbeds, levelling riverbanks, creating buffer strips, flooding areas & tree planting. Construction of multifunctional water reservoirs, recirculating irrigation and customized drainage.	Regulation of water levels, protection from flooding and drought through enhanced water holding, storage and recirculation	New habitat creation or existing habitat improved, increased connectivity of habitat in agricultural landscapes	Fully synergetic, but trade-offs with land use and ownership
City river catchment restoration	Belgrade city river catchment, Serbia	Basin management through the creation and management of blue-green corridors	Prevention or reduction of the risk of torrential floods and destructive erosion processes.	Conserve, protect and restore biodiversity (mainly autochthonous flora and fauna)	Fully synergetic, but with trade-offs on farmland usage

AREAS	CASE STUDY	NBS SHORT DESCRIPTION	ADAPTATION AND DISASTER RISK REDUCTION	ECOSYSTEM RESTORATION AND BIODIVERSITY TARGETS	SCALING POTENTIAL: CHALLENGES AND ENABLERS
City greening	Germany	Green solutions: green roofs, urban trees and forests, urban gardens…	Reduction of urban heat island, increased rainfall infiltration and storage	Improvement of the urban natural ecosystem and biodiversity	Fully synergetic, but trade-offs with water use during dry periods to be addressed. Space can also be a constraint.
Natural flood management: river catchment & coastal	Brague River and catchment area, France	Creation of buffers for water storage during flood periods, natural flood management (NFM) relies on small natural (or hybrid) retention measures spread in the catchment	Prevention of downstream inundations, alleviate current and future risks of river and coastal flooding	Restoration of natural floodplain ecosystems (and wetlands)	Fully synergetic, but land use trade offs
Forestry	Germany, Portugal, and Spain	Eco-hydrological-based forest management strategy, at watershed scale	Helps to reduce the impacts of climate change on Mediterranean forests to improve their adaptive capacity (i.e., wildfire risk management, flood risk management)	Forest habitat restoration at watershed scale	assessment still to be completed

A first set of the emerging enablers of scaling NBS in different contexts following the enabling conditions identified by the EU Mission Adaptation is provided in Table 4. Such categorization, even if not exhaustive, can help to identify specific needs for a NBS to be scaled or supported over time by public and private actors.

Table 4. Aspects of scaling specific NBS are presented according to the enabling conditions identified by the EU Mission Adaptation.

CONTEXT	INSIGHTS ON ENABLING CONDITIONS FOR SCALING			
	KNOWLEDGE AND INFORMATION	GOVERNANCE AND ENGAGEMENT	BEHAVIOURAL CHANGE	MOBILIZING SUSTAINABLE FINANCE AND RESOURCES
Paludiculture	More information on using non-conventional Farming practices & technology	Policy measures to support the reverse transformation into paludiculture (e.g. through new CAP measures)	Land user coordination for water management	Financial incentives should support entire value chains

CONTEXT	INSIGHTS ON ENABLING CONDITIONS FOR SCALING			
	KNOWLEDGE AND INFORMATION	GOVERNANCE AND ENGAGEMENT	BEHAVIOURAL CHANGE	MOBILIZING SUSTAINABLE FINANCE AND RESOURCES
		Developing risk sharing mechanisms by public sector to help innovators, entrepreneurs and investors take risk		Market development to support commercialization of paludiculture products
				Voluntary carbon credits schemes
Agriculture: river catchment restoration	Biogeographical water retention measures are particularly beneficial	National & international regulation could foresee measures which are costly (currently not considered in Swedish agricultural funding systems) however national policy implicitly supports NBS	Landwoners' buy-in is critical	Potential Financial losses for the farmer need to be counterbalanced
	Tourism and recreational benefits can be linked to wetland projects			
City river catchment restoration	Data on the concentration of housing, office and infrastructural facilities along the river basin, to plan for NBS in climate action plans and to foster community-led greening	Better governance due to the fragmented landownership (many small private parcels)	Linking NBS and restoration with cultural values locally	NBS linked to citizen wellbeing: establishment of recreational and sports areas
		Land use and planning strategies should aim at decreasing the risk of destructive erosion processes and torrential floods		
		National strategies should include urban green infrastructure to connect the natural and cultural value of urban settlements, peri-urban mosaics and rural areas		

CONTEXT	INSIGHTS ON ENABLING CONDITIONS FOR SCALING			
	KNOWLEDGE AND INFORMATION	GOVERNANCE AND ENGAGEMENT	BEHAVIOURAL CHANGE	MOBILIZING SUSTAINABLE FINANCE AND RESOURCES
City greening	Data on how greening can have a positive impact on costs of heating and cooling of buildings	legal acts: enforcing green roofs a compensation for ecosystem restoration measures in cases of new buildings	Green roofs often compete with other economic interests and for urban space	Funding schemes are needed as green roofs are still often associated with relatively high levels of financial uncertainty
		New vs old build, regulations: green roof policies often remain restricted to new buildings, implementation on existing buildings more complex from governance (only funding can be used as leverage) and technical reasons		Insurance schemes can be helpful, e.g. it could be beneficial to reduce stormwater fees for owners of buildings with green roofs
Forestry	Data and information on how to balance multiple objectives through forest management is useful, but trade-offs may occur	Measures aiming at supporting smallholders should be part of national and regional plans and strategies	Fragmentation can be tackled through the engagement of smallholders and connecting various initiatives and tools in support of Sustainable Forest Management	Consideration on biomass production can help to identify sustainable practices and engage forest owners and managers
	NBS in forestry seem to be often part of the overall planning for forest management	Fostering innovation in the sector is important to advance on Sustainable Forest Management		Ways to value carbon sink and other benefits should be considered
	Large holdings as state forests' organisation can hold data and skills relevant to specific contexts			

6 Conclusions

Nature-based Solutions have the potential to address climate mitigation and adaptation challenges, while providing additional benefits to society and the environment. If well implemented, NBS has the potential to provide ecosystem services, social and ecosystem resilience, and support biodiversity, but trade-offs and maladaptation results need to be also considered. However, the "NBS potentials" need further assessment before, during and after NBS implementation, mainly for their cost-effectiveness and social-cost benefits in comparison to hard infrastructure, as well as their co-benefits along with climate change impacts.

Looking at enablers and barriers several common themes emerge in line with the enabling conditions of the EU Mission Adaptation, including land tenure or land use issues, laws and regulations, strategies and plans, institutional mechanisms and governance, financial needs and opportunities, costs and benefits, risk sharing, or other systemic factors. Funding appears to be a pre-request across cases for scaling, nonetheless specific cases and economic values of other ecosystem services can play a significant role in fostering sustainability of specific NBS and for the engagement of relevant actors. Addressing climate adaptation and ecosystem restoration at the same time is challenging, however scientific studies and policy approaches exist where both aspects are considered. More quantitative studies of the scaling potential of these NBS in the EU could be beneficial in better informing policy makers about measures and actions that can be taken, and the connected challenges and opportunities.

Scaling NBS can bring potential impacts building on social initiatives, policy developments and nature restoration cases. It can be done by replicating successful case studies into different places with the aim to spread the effects and knowledge to more people and communities. As well, scaling up, out and deep can change or influence institutions, policy, and regulations to finally make a durable change in people's minds and values to transform the system. "Mixed" cross-cutting approaches are particularly promising as they can build on existing initiatives and networks. To this end, it is important to focus on the effects or impacts of the solutions, rather than in a specific method or tool which is used in a particular case.

The research to-date has been a case study led approach. More specifically, selecting a set of geographically diverse case studies that exemplify the different habitats and ecosystems of importance to Europe's ambitions on climate change adaptation and ecosystem restoration. The four-steps scaling approach was in fact first designed with step 2 and step 3 in reverse; first doing the physical assessment and second, the analysis of enabling conditions. However, when analysing the case studies, it was possible to identify levers and constraints but not all could conduct the physical constraints assessment. Nonetheless, it must be said that such step-by-step approach resulted helpful in guiding the case study analyses, and it can be a good basis to include NBS in transformative pathways as in the context of the EU Adaptation Mission, and if further refined, to conduct more quantitative assessment of how scaling NBS can contribute to multiple policy objectives.

Developing a scaling framework can support decision makers in planning for Nature-based Solution in achieving specific climate adaptation policy targets by mainstreaming NBS, as expected in the context of the EU Adaptation Mission. In these regards, system innovation is key to the upscaling of most types of Nature-based Solutions, in line with the following principles:

- Individual projects need to be envisaged as part of a wider portfolio of actions to achieve specific climate adaptation and restoration targets.
- The use of multistakeholder engagement has proven to be essential for considering the benefits and trade-offs of each project and to foster the feasibility and acceptance of the implementation of NBS.
- The financial sustainability of NBS is a major challenge in the long run: socioeconomic considerations should be prioritized in identifying scaling pathways for NBS.

The proposed scaling approach should be refined taking into consideration the relevance and interplay of multiple enabling conditions for scaling (i.e. policy, finance, incentives, technology, geographical and climatic contexts), in particular to identify the most promising cross-cutting approaches combining scaling up, out and deep options.

For the next stage in the research, the team proposes to review the climate change adaptation and ecosystem restoration targets and initiate a more quantitative assessment of the scaling potential of NBS with a focus on their socio-economic aspects. Particularly, it should be further developed in the steps 2 and 3 of the proposed approach, in which specific ecosystem and landscape considerations are relevant to the EU biodiversity and climate adaptation agendas, including a stronger synergy with the EU Mission Adaptation. This may help in the inclusion of insights on what would be needed to develop a more quantitative assessment for some ecosystems.

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Annex I – Additional material about the analysis of the Paludiculture case: Peatland restoration for climate change mitigation and adaptation

Location of implementation: Germany

Summary of Case study

In the federal state of Mecklenburg-West Pomerania 291 361 ha are peatlands. Currently, 57% of the peatland area is used for agriculture (20 531 ha as arable land, 143 998 ha as permanent grassland) and therefore drained, causing greenhouse gas (GHG) emissions of 4.5 Mt CO_2 per year. This means that drainage-based agricultural use of peatlands is the largest single source of GHG emissions in the federal state of Mecklenburg-West Pomerania. Moreover, the lowering of the water table leads to a large loss of water, exacerbating climate change impacts, in particular droughts. In order to preserve the peat layer, the water level has to be close to or above the surface throughout the year to guarantee saturation of the peat body. In addition, regular soil disturbance, e.g. by ploughing or by harvesting below-ground biomass, must be excluded. As alternative land uses, common reed (Phagmites australis), bulrush or cattail (Typha sp.), peatmoss (Sphagnum sp.) and many other crops could be cultivated for biomass production (e.g. for bioenergy and material use) or the sites could be used as wet grasslands.

Ecosystem restoration objectives

The benefits of paludiculture are important for the biodiversity first of all because the rewetted conditions create the potential to regenerate at least partly the humid ecosystems of the original peatland. Most of the crops introduced in paludiculture are indeed plants such as typha (cattail), sphagnus, reeds or black alder which originate from peatlands (fens or bogs) and are likely to bring in other plant or animal species that generally strive in wetlands.

Increasing the biodiversity will in turn enhance the resilience of the region in different ways by e.g. creating reservoirs of species that can prevent the outbreaks of pests or prevent invasive species to replace native species in a detrimental way.

Peatland restoration and rewetting also provide recreates the water buffer that can mitigate water stress during drought periods by maintaining water flows in this period. This can be extremely useful for drinking water supply. In certain cases, it can also mitigate floods in adjacent downstream areas if excess water can be diverted to the peatland.

Adaptation and disaster risk reduction objectives

Impacts of peatland drainage and degradation

Peatland drainage and degradation has many impacts on biodiversity. In their natural state, peatlands constitute rich habitats with very specific flora and fauna. This richness is destroyed by peat mining or peatland drainage particularly in case of land use change for either agriculture or forestry. Agriculture, be it for crops or livestock, adds to this reduction of biodiversity an increase in nitrogen availability that accelerates the mineralisation of the organic matter and the CO_2 emissions. Water availability and quality at the outlet of the peatland is also deteriorated.

The most important need: rewetting

Restoring peatland means primarily rewetting it. There is a quasi-linear relationship between annual average depth to water table and CO_2 emissions. This relationship is valid in both directions: when peatland is drained and when peatland is rewetted. A 40 cm drawdown of the average depth water table results in roughly 20tCO2e /ha of emissions per year (Figure 8).

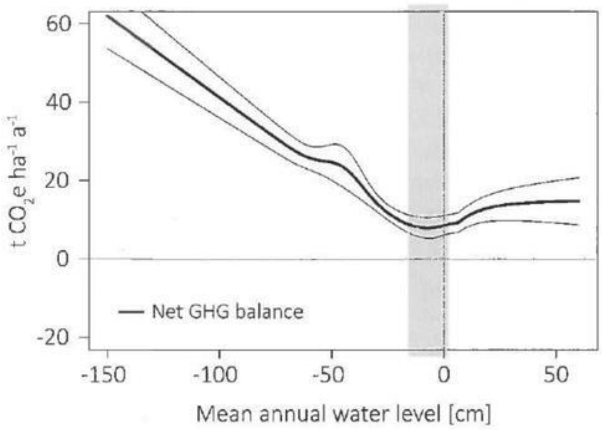

Figure 8. Relationship between groundwater level and greenhouse gas emissions (from Jurasinski et al., 2006). The hairline graphs illustrate the 95% confidence intervals, respectively. For this graph, CO_2, CH_4 and N_2O emissions were combined and expressed in CO_2 equivalents. CO_2 emissions occur primarily when water levels are below floodplain level (grey zone), CH_4 emissions when water levels are above floodplain level and N_2O emissions primarily when fertiliser is applied or grazing takes place.

Paludiculture is defined as the productive land use of wet and rewetted peatlands that preserves the peat soil and thereby minimizes CO_2 emissions and subsidence and preserves the other ecosystem services of the peatland.
Paludiculture is useful mainly in drained peatlands used for agricultural production. The idea is to compensate the land users' revenue losses due to the abandonment of their classical production by introducing new products and value chains. These are mostly new plant species or occasionally new cattle such as water buffalos that strive in extremely wet conditions. In certain cases, paludiculture can also be used for wastewater treatment or water purification[6].
Many plant species have already been identified as having potential for paludiculture, yet only a dozen have been actually tested (ref or table). The harvested biomass of these new crops can be used as food, feed, fibres, isolation or construction material, biofuel or biomass or feedstock for various pharmaceutical or cosmetics products.

Other benefits and trade-offs
Peatlands are sources of significant CO2 emissions when drained or degraded by farming practices or peat mining for biofuel production. Emissions are due to peat organic matter oxidation allowed by air entry into a drained soil. By contrast, the low content of oxygen in water prevents the degradation of organic matter which accumulates in vast areas, particularly in the North of Europe. Several sets of data show that receding the average water table in a peatland to a depth of 40cm below soil surface induces CO_2 emissions of around 20t/ha/year (Jurasinski et al., 2016).

Peatlands play also a critical role for biodiversity being hosts of a range of rare, threatened or declining habitats, plants and animals. Like other wetlands, they are also important water buffers that contribute to the resilience of the territories where they are located.

The total peatland area defined as "areas with a naturally accumulated layer of peat at the surface" is assessed at 593,700 km^2 in Europe at large (Tanneberger et al., 2017). Most peatlands are located in the northern part of Europe although some southern countries like Romania are also well endowed. Out of this total area, 320,000 km^2 are considered to be mires, the peatlands currently in a process of peat generation. Mires themselves can be categorized into bogs and fens. Bogs receive most of their water and

[6] See for instance the REMEMBER project aiming to reduce nutrient discharges into the Baltic Sea https://www.moorwissen.de/en/paludikultur/projekte/remember.php

nutrients from precipitations; they are nutrient poor and acidic; their vegetation is made to a large extent of sphagnum moss. By contrast, fens receive a significant amount of its water from mineral-rich groundwater or surface water; they are less acidic, and their vegetation is predominantly composed of graminoids and shrubs. For entire Europe, fens represent 57% of the peatlands and bogs 43% (Tanneberger et al., 2021).

In the EU alone, the peatland area amounts to 259,000 km^2 including 112,000 km^2 of mires. The degraded peatland area is estimated at 120,000 km^2 i.e. nearly 50% of the total peatland area on average. (Tanneberger et al, 2017 and 2021). In many EU countries, up to 75% of the peatlands are degraded by the processes mentioned above. They generate a total of 220 Mt CO2e/yr of emissions, i.e. 5% of the total EU GHG emissions.

The degradation of interest in this analysis is that associated with the farming practices that require a lowering of the water table obtained by drainage techniques. This degradation is assessed by the Greifswald Mire Centre to affect 43,000 km^2 across Europe that is 2.5% of the total productive agricultural area and 17% of the EU total peatland area (EUROSTAT data). These drained peatlands are those most likely to be used for paludiculture, given the fact that the revenues they generate for the farmers need to be replaced. It is in Germany and the Netherlands that the largest fraction of the peatlands has been drained to allow agricultural production.

In terms of GHG emissions, there may be a trade-off between CO_2 and methane. In anoxic conditions, peatlands may become methane emitters when again saturated with water[7].

Regarding resilience, the flood buffer function of peatlands is also not straight forward: drainage & intensification usually destroys the network and number of small gullies of the peatlands which have a key role in mitigating floods. However, the drawdown of the water table creates by contrast an increased buffer capacity. For average return period events (below annual return period), the buffer may be unaffected or even improved, while for more severe events (above annual return period), the overall buffer function is probably reduced since the buffer provided by the upper soil layer is usually negligible in such conditions since the water table is close to the soil surface in such events.

A specific difficulty lies with the forested peatlands. Afforestation contributes to water table drawdown and hence to carbon emissions that the absorption function of the trees does not compensate (emissions linked to degradation of peat may typically be at least twice as much as carbon absorption by trees). However, the benefits of tree replacement by paludiculture may take too long to generate significant benefits given the carbon losses that will be generated by the tree harvest (Günther et al., 2020).

[7] This explains the slight increase in the emissions (expressed in CO2e) on Figure 1 above for average water table depth above soil surface.

Scalability insights

The prerequisite of any paludiculture programme is the rewetting of the peatland. This requires in many cases a concerted action across landowners and water users and the establishment of institutional mechanisms for this purpose.
Differentiated tailored solutions need to be designed for bogs and for fens given the different trophic conditions. The two types cannot accommodate the same types of plants. Bogs have more constraints given their acidic conditions. They will be more suitable to e.g. Sphagnum production while fens have a larger array of possibilities.

The restoration would need to follow the following sequence:

1. Surface Degradation removed.
2. Rewetting with water table control structures that may allow for temporary drying to allow harvesting vehicles to circulate without degradation.
3. If cattle remains in the area, the number of animals should remain limited to reduce nitrogen inputs[8].
4. Paludiculture implemented in areas suitable to it, accessibility to machinery being a prerequisite.

1. Scaling paludiculture

Figure 9. Potential of paludiculture per country, in % of the agricultural land in the EU.

<u>Maximum scaling potential</u>
Paludiculture could in theory be implemented in many degraded peatlands. Given the difficulty to support new value chains of rather unconventional products, its realistic maximum potential scalability is in drained peatlands converted to agriculture. An estimate of these peatland areas across the EU has been released by the Greifswald Mire Centre in Germany that has developed an extensive data base on peatlands.
The detailed per country areas of these drained peatlands that could in theory be converted to paludiculture is presented hereafter (figure and table). Across the EU, around 43,000 km^2 (4,300,000 ha) could be converted from classical agriculture to paludiculture after rewetting. This represents 2.5% of the agricultural land and 17% of the total peatland area of the EU. This rewetting would also avoid 20.5% of the total emissions of the agriculture sector and a reduction of 20tCO2e of CO_2 emissions for each restored ha (Figure 9) (Table 5).

[8] Nitrogen inputs increase the presence of bacteria that play a role in organic matter degradation.

Table 5. Peatland areas drained for agriculture purposes that could in theory be rewetted for paludiculture (from Greifswald Mire Centre).

COUNTRY	PEATLAND AREA DRAINED FOR AGRICULTURE (KM2)	EMISSIONS POTENTIALLY AVOIDED (KTCO2E/YR)	% OF AGRICULTURE AREA	% OF AGRICULTURAL EMISSIONS
LATVIA	1159	1563	6	71
ESTONIA	498	973	5	65
FINLAND	2633	4104	12	62
LITHUANIA	1755	2250	6	53
ROMANIA	5001	9227	4	49
POLAND	5762	13421	4	41
SWEDEN	1511	2640	5	38
GERMANY	11701	22880	7	37
NETHERLANDS	2694	6001	15	34
IRELAND	3419	6553	7	32
DENMARK	1046	3160	4	29
HUNGARY	467	1712	1	24
UK*	1639	5854	1	14
BULGARIA	225	437	0,5	7
SLOVENIA	24	103	0,5	6
AUSTRIA	1068	358	4	5
FRANCE	1391	3659	0,5	5
GREECE	683	315	1,5	4
CROATIA	16	81	0,1	3
ITALY	126	886	0,1	3
BELGIUM	135	141	1	1,5
CZECH REPUBLIC	173	123	0,5	1,5
SPAIN	232	378	0,1	1
PORTUGAL	0	0		
TOTAL	**43356**	**86820**		

In the UK another estimate is 2400 km^2
https://lowlandpeat.ceh.ac.uk/sites/default/files/Policy%20Brief%20WP1.pdf

Assessing a more realistic scaling potential

These areas showing a maximum potential for paludiculture overestimate the areas that make sense from an agricultural perspective. Indeed, a significant proportion of them has been transformed into grassland for the dairy or meat sectors after being drained. While planting crops suited to peatlands that would increase the biodiversity could be feasible, it is extremely unlikely that farmers will change their production and from a climate perspective, changing the land use would mean ploughing the soil, which would have an impact on soil organic matter degradation. For these reasons peatlands valorised into grassland should simply prioritize their rewetting and should not move into paludiculture.

More generally, demand for paludiculture is hardly emerging and most of the projects are currently in their pilot phase. The reason for this is that the value chains related to the commodities of paludiculture (see Table 6) need to be developed nearly from scratch and this requires a minimum scale and medium term visibility to the potential investors. Pilot projects bigger than the current ones (often limited to a large field plot) would need to be supported to become real demonstrators.

Table 6. Potential productions and associated value chains from paludiculture.

PRODUCTION / SERVICE	TYPE OF CROP	TYPE OF MARKET
Bioenergy	Reeds (Pharagmites sp), cattail, black alder*, sedges	Biogas, biofuel, including biochar
Horticulture growing media	Sphagnum	Substrate for containerised plant raising
Food, feed and fibre	Cattail, reeds, sedges, cranberry	Fruit juice, fodder, filing material
Construction material	Reeds, black alder, cattail	Thatched roofing, insulation products, lightweight construction boards, timber
Packaging	Sedges, reeds	Packaging and disposable tableware
Chemical products	Sundew	Pharmaceuticals
Water purification	Cattail	Treatment of polluted water

* Black alder may also reduce methane emissions.

The *main barriers* to the deployment of paludiculture are at least four-fold:

(i) First, the rewetting of peatlands requires coordinated water management rules between land users. Rewetting requires to raise the water levels in the ditch network, which has consequences for all adjacent field plots. It may also require infrastructure (gates, culverts, pumps) to block the drainage system and to allow for water table control. Water table control maybe critical to allow machinery to intervene in the fields particularly during the harvest period.
One of the possible levers could be to use the infrastructure to create water storage in certain areas so as to provide water to non-rewetted adjacent fields during dry periods. This could increase the acceptability of rewetting.

(ii) The second barrier is market development. The markets for the new products already potentially exist (see Table 6) but the value chains ensuring sufficient product transformation and commercialisation still need to be developed. One of the constraints is that a critical mass of products needs to be available to support an entire transformation and commercialisation chain of actors. As mentioned before, the initial pilots would need to be transformed into real demonstrators that include all value chain components (and not just the production).

(iii) The third barrier to the scaling of paludiculture practices relates to farming practices and associated technology. Most of the plants to be produced are not conventional ones. Their cropping practices require special machinery due to the specific wet conditions in which practices are implemented. This also means that the cropping practices need to be tested and probably adjusted to the local context. The initial pilots launched by several projects across Europe are already providing guidance, but more would be needed given the diversity of the contexts and of the potential crops.

(iv) A fourth important barrier lies with the policies and particularly the EU Common Agriculture Policy. So far, the CAP used to support conventional agriculture and innovative practices such as paludiculture were not incentivised. Peatland transformation for agriculture was also not prohibited. In this context the large-scale transformation of peatlands into conventional agricultural land has been encouraged. The new CAP measures should by all means remove any incentive for detrimental transformation of peatlands and if possible, promote their rewetting. Given such rewetting would apply to 2.5% of the European agriculture, the reverse transformation seems possible. It would however be quite difficult in countries such as Finland or the Netherlands where converted peatlands represent more than 10% of the agricultural land.

The *main levers* to paludiculture deployment relate to policies and to economic and financial support from a variety of actors.

While past policies have triggered peatland "valorisation" through conventional agriculture, new policies could and should support the reverse transformation into paludiculture through a mix of regulations and subsidies. Financial instruments and incentives should go beyond the agriculture part since entire value chains need to be created. Holistic approaches to value chain development would need to be designed and implemented and tap also into policies of the built sector or of the energy transition.

The public sector could also play a role in developing *guarantee mechanisms* to help innovators, entrepreneurs and investors take risk.

Another important lever to this deployment is the *market of voluntary carbon credits*. The huge mitigation potential of peatland rewetting should foster the development of peatland codes across the EU. With average emissions of 20tCO_2e/ha, peatlands offer interesting potential for offsetting (for companies facing difficulties to reduce their emissions such as the aviation sector) or in-setting for companies engaged in the value chains of the paludiculture products. At a 20€/t of C emission prevented, such voluntary carbon credits could provide critical incentives for the farmers, particularly if combined with CAP subsidies.

It should be noted here that biodiversity and increased resilience are not key drivers or levers for paludiculture despite of the benefits they may generate for these issues. Maximizing the benefits of paludiculture for biodiversity and resilience would require specific pilots or demonstrators.

<u>A tentative roadmap for paludiculture deployment</u>

Planning phase:

1. **Total potential:** areas identified
2. **Rewetting possibilities and investment required:**
    - Subsidies/policy, ideally a directive? Transition period to remove current subsidies.
    - Value chain creation/support in relation to the other sectors involved.
    - Avoid too much nitrogen.
    - From pilots to demonstrators at scale + local transformation industries (supported by guarantee mechanisms).
    - Maintain a number of pilots to test and do research.
    - Devote living labs of the soil mission to peatland rewetting and paludiculture
3. **Contextual aspects/constraints**
    - Subsidence can be an issue.

Annex II – Additional material about the analysis of the Green roof case: Combining regulation, dialogue, incentives and science

Location: Hamburg, Germany

Legal instruments used in Hamburg:

(Clar and Steurer, 2021) in the past decades, Hamburg'sseveral district administrations have made green roof coverage obligatory in development plans for new buildings since the 1970ies and increased these requirements in particular since 2000 with percentages of almost 70% (2000-2010) and almost 100% (after 2010) of plans establishing some obligations for the realization of green roofs (Richter and Dickhaut, 2019, p. 42) (Figure 10).

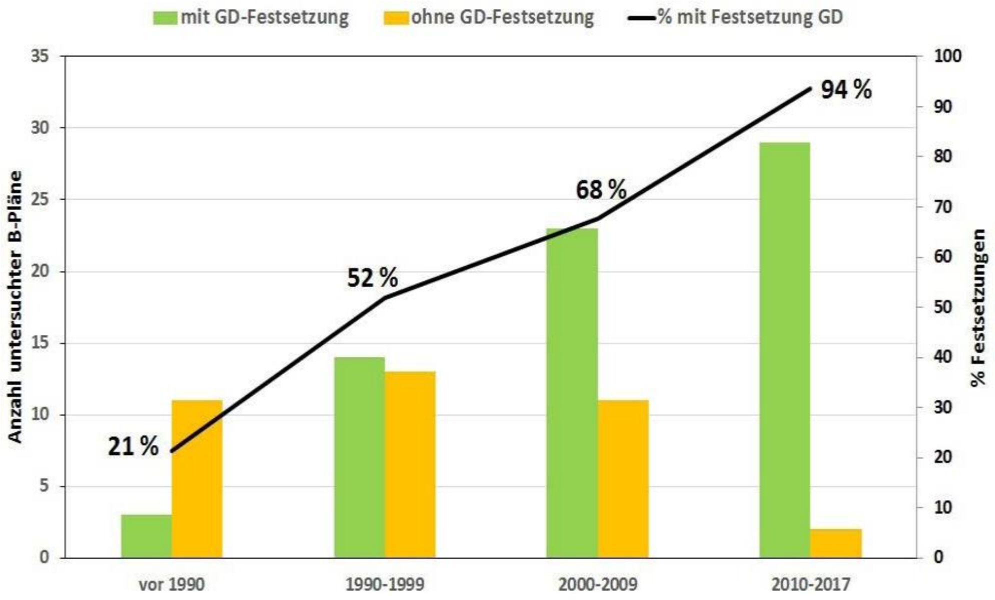

Figure 10. Number of development plans (Bebauungspläne) with (green column) and without green roofs (yellow column) provisions in different time periods and percentage of plans in the sample with green roof provisions until 2017. Source: Richter und Dickhaut, (2019, p. 42).

The Urban green roofs initiative, launched in 2015, is based on awareness raising, regulation, scientific advice and incentives from a budget of EUR 3 million h allocated by the Hamburg Ministry for Urban Development and Environment to encourage green roof construction on both new and renovated buildings Green roofing measures for residential and non-residential buildings are subsidised with up to EUR 100,000 per intervention. The policy is supported across different departments of the administration and is accompanied by scientific research improving the knowledgebase and information and acceptance campaigns to improve the uptake of the measure by building owners. The initiative is part of the city's climate change adaptation strategy.

Ecosystem restoration objectives connected to green roofs

Green roofs and facades provide a partial substitution of the vegetal soil coverage and ecosystem services destroyed by the building, and the plant communities used for greening should replace those removed for during construction. The potential for restoration of biodiversity depends mainly on the type of green roof established, and the use made of the green rooftop. Extensive and semi-intensive green roofs, once established, are usually left alone and native plant communities and invertebrates can colonize them (Thuring and Grant, 2016), so might have a higher ecological value than intensive greenings (Catalano et al., 2018, p. 23) while plant communities on intense green roofs are normally designed, often by horticulture specialists (Thuring and Grant, 2016, p. 5) and can host trees, shrubs, perennials herbs and lawns. Their potential for biodiversity restauration varies according to the design and the choice of plants, which may include, in the case of intense green roofs used as ornamental gardens, a high number of non-native species. The conventional typology of green roofs distinguishes according to more or less intense use made of these outdoor spaces, and consequent thickness of the substrate and the choice of plants distinguishes between extensive, semi-intensive and intensive green roofs, with extensive green roofs. This typology has been integrated by a further intermediate typology by the British code of best practice which aims at optimizing the function of biodiversity restauration: "Biodiverse green roofs aim to recreate habitats similar or even ameliorated compared to the one lost due to the construction. These roofs are sown, or plug planted with autochthonous species that in turn attract specific fauna; are constructed with different substrate thickness and kinds such as sand and gravel; are supplied with specific structural elements for habitat provisioning such as trunks and boulders. This approach provides for the spontaneous development of the vegetation, the reduction of the maintenance effort to the minimum but also the creation of areas without vegetation to mimic brownfields" (Catalano et al., 2018, p. 16 citing Kadas, 2006; GRO, 2011). Actually, some European norms and standards classify green roofs according to their capacity of restoring ecosystem services, referring mainly to the capacity of moisture storage and their ecological value (Catalano et al., 2018). In Hamburg, minimum requirements for green roof subventions regard only soil layer thickness, while standards with respect to substrate selection, surface modulation for biodiversity restoration goals and appropriate choice and variety of species.

Adaptation and disaster risk reduction objectives

In dense urban environments with high percentages of sealed surfaces, green areas can contribute to adaptation to climate change by absorbing surface run-off caused by heavy precipitation events and reducing the urban heat island effect, two climate change impacts which are particularly relevant for urban areas.

Under increasingly intense precipitation events as a consequence of climate change and high run-off-rates in dense urban areas due to high levels of soil sealing, sewage systems often are not able to provide the necessary drainage capacity. As a consequence, sewage overflow and surface flooding cause relevant damages. Vegetated roofs can partially substitute absorption and infiltration capacity of natural soil, which has been lost due to construction and soil sealing.
The presence of plants improves the albedo of urban surfaces and thus reduces urban heat storage in urban surfaces. Evapotranspiration by plants can furthermore contribute to reducing temperatures in urban areas. Both processes mitigate the trend of overheating in urban areas due to the urban heat island effect and rising temperatures.

Using roofs (and facades) for creating green spaces in urban contexts represents an opportunity as these solutions occupy urban spaces which cannot be used for other urban functions. This represents an advantage with respect to parks, street trees and other urban green areas which could be used for urban activities and services. The opportunity of allowing for more dense city structures offered by such a greening concept represents a motivation for the city of Hamburg to use green rooftops and facades for increasing urban greening.

The capacity of green roofs to reduce or delay runoff of rainwater depends on the thickness of the soil layer and of technical characteristics of the construction. Green roofs are generally classified in three different types according to their capacities of hosting different types of vegetation:

a. **Intensive green roofs** can host trees, shrubs, perennials herbs and lawns on a 15–200 cm thick growing medium.

b. **Simple-intensive green roofs** can host shrubs, perennial herbs and lawns on a 12–100 cm thick growing medium, which requires a reduced bearing structure to reduced loads.

c. **Extensive green roofs** can host sedum, grass and small plants. They require a layer of 5-15 cm and are "near-natural greened surfaces" … which should mimic natural habitats ... and should "promote spontaneous species colonisation and development in order to build self-sustaining ecosystems" (Catalano et al., 2018, p. 18). Given the reduced soil layer, extensive green roofs create low static loads and can thus in many cases implemented also on existing buildings.

According to the thickness of the soil layer and eventual technical water storing capacities, the capacity of green roofs of storing rainwater and delaying its release to the sewage system and or to the atmosphere in the form of evapotranspiration can vary greatly (Schlünzen et al., 2018). Under long periods without precipitation, extensive green roofs as any green area can lose their soil humidity and thus their heat and pollution mitigating functions. In intensive green roofs, continuous irrigation is assumed to mitigate this effect (Schlünzen et al., 2018).

The additional load represented by soil, plants and eventual storing facilities requires an adequate bearing structure and, eventually a higher parapet, compared to black roofs. Additional statics related costs for extensive vegetation are at most 3-4 €/m², while an increase in the parapet height is not necessarily required, and if it was, the costs were approx. 6.50 - 8.50 €/m². The overall construction costs of green roofs correspond, according to an economic assessment made by the City of Hamburg, between 0.4 and 1.3% of overall building costs, depending on the overall volume of a building (Free and Hanseatic City of Hamburg, 2017, p. 22). Considering also maintenance costs over the life cycle of a green roof of 30-50 years, compared to 15-20 years for a bitumen roof, and the economic advantages due to reduction of stormwater fees offered by the city, reduces the economic disadvantages in terms of construction and maintenance costs of green roofs on the long run (Figure 11).

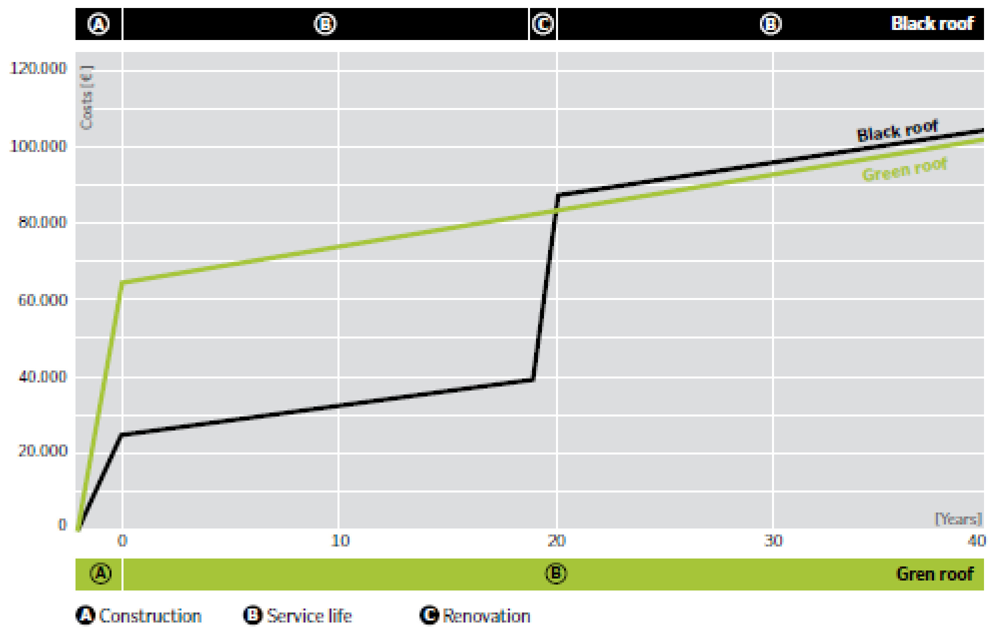

Figure 11. Graphic illustration of life cycle assessment for 40 years (source Free and Hanseatic City of Hamburg, 2017, p. 17).

Given the limits mentioned with regards to the potential of realization of green roofs in existing urban areas, the potential of green roofs for creating connectivity (as a means of restoration of biodiversity) and increases or re-establishment of urban biodiversity, in particular in the case of extensive green roofs, might be limited.

Other benefits and trade-offs

Clar and Steurer (2021) list 5 types of barriers for the implementation of green roofs, which all emerge to some extend also in the case of Hamburg, and addressed in the city's green roof strategy.

1. Green roofs are still often associated with relatively high levels of financial uncertainty, mainly because most local authorities lack locally specific expertise, especially regarding costs and benefits (Clar and Steurer, 2021). Despite economic advantages, the real estate market and private builders fear additional costs caused by green roofs and tend to refrain from their realization.(Richter and Dickhaut, 2019); the element of awareness raising, guidelines and knowledge generation, initiated with the Green roof strategy, strategy attempts to reduce the uncertainty among builders.
2. Green roofs often compete with other interests, in urban areas mainly with a quickly increasing demand for affordable living space as they do slightly increase construction costs in the short term (Clar and Steurer, 2021). In particular the competing policy objective of affordable and accelerated housing construction in Hamburg has prevented the generalized introduction of legal obligations for the realization of green roofs (Richter and Dickhaut, 2019, p. 54). Legal requirements remain thus limited to the cases of recent development plans which increasingly often prescribe the realization of green roofs not only on secondary buildings (garages, coverage of underground garages), but also on residential and commercial buildings.
3. Green roof policies often remain restricted to new buildings as it is difficult and relatively expensive to retrofit flat or slightly inclined roofs of existing buildings to make them support soil and plants (Clar and Steurer, 2021), Furthermore, many existiing buildings have sloped roofs, so are not adequate for being transformed into green roofs. The funding scheme set up in Hamburg tries to address this barrier by providing premium subsidies and additional finance for statical works for green roofs on existing building.
4. It is complicated to find a solution that equally suits those who bear the costs of implementation and maintenance, (often private owners) and those who realize the benefits (the city as a whole) (Clar and Steurer, 2021). Mintenance costs of green roofs are, according to assesments of the city of Hamburg, comparable to those of black roofs (Freie und Hansestadt Hamburg, 2017) so that the approach used in Hamburg to recognize public benefits provided by green roofs with a reduction of stormwater fees is, together for Hamburg, sufficient for compensating maintenance costs of green roofs. Both the funding scheme for green roofs and reductions of storm water fees offered to owners of green roofs attempt to partially recognize services green roofs provide to the city.
5. Due to short-term economic interests, aesthetic concerns, or simply misinformation about technical shortcomings of green roofs, developers and/or architects are often sceptical. building owners often do not even consider installing green roofs because they lack the necessary awareness, knowledge, and/or financial capacities or expect high installation costs and maintenance efforts (Clar and Steurer, 2021).

A major barrier for implementation of green roofs consists in higher costs of realization for green roofs, which depending on the type of green roof realized. Compared to about 10 €/ m² for a traditional gravel roof, construction costs for green roofs range between 15 and 50 €/m² for extensive green roofs and go from 50 €/m² upward for intensive green roofs (Richter, 2019). The economic assessment made by the city of Hamburg to increase reduce economic concerns, quantifies the increase of building costs with 1,3% of the overall building costs. In the case of a 6 storey building, this quote would go down to 0.4% (Freie und Hansestadt Hamburg, 2017). While over a lifetime of 40 years, costs of physical maintenance of green are comparable to those of black roofs, considering that lifetime the soil protects the insulating layers, economies can be realized by discounts on stormwater fees, which can be reduced by 50% in the case of an extensive green roofs (Freie und Hansestadt Hamburg, 2017, p. 22).

Furthermore, nature in cities is able to create nuisance. In Hamburg, several large green roofs on top of commercial premises have become important breeding colonies for seagulls (Die Zeit, 2022). Breeding of sea gulls in urban areas is not specifically related to the presence of green roofs, but it is observed as a general tendency in urbanized areas since some decades, due to increase in food availability in urban areas (Rock, 2005) and to increasing rates of disturbances in traditional breeding areas (Partridge and Clark, 2018). Breeding activities might increase maintenance costs of extensive green roofs interested due to increased nutrient availability.

At the building level, the soil and plants layer provide a better insulation and can thus reduce heating and cooling costs for the spaces located immediately below the rooftops. Green roofs on new buildings can be made available to residents or employees for recreation (sports fields, parks, community gardens) or can be used for economic activities, and the operation of solar panels on green roofs is more efficient (Freie und Hansestadt Hamburg, 2017, p. 22). Further to reducing the risk of surface flooding after intense precipitation events, at neighbourhood level, green roofs contribute to a reduction of air temperatures by increasing evapotranspiration and contribute to an improvement of air quality. These effects will be more pronounced, provided that construction of green roofs covers more roofs in the area, as for instance in those areas where, as in the case of some districts in Hamburg, green roofs are made mandatory by development plans. In these cases, the dimension of sewage systems can take into account the storage capacity of green roofs. Future status.

The city’s policy for incentivising green roofs can contribute to reducing negative effects of urban densification under climate change. While the number of green roofs is increasing in the urban periphery, where most of the new construction is taking place, the uptake of green roof measures in the denser city areas might speed up, while it appears to be lower and on existing buildings (see results of the strategy. (green facades instead?)

Scalability insights

The growth of urban areas is the cause of ecological problems such as habitat fragmentation, degradation and destruction, over-exploitation of natural resources, the spread of alien species (Kronenberg et al., 2013) furthermore, under changing climate conditions, the need for solutions for the management of intense precipitation events is common to practically all urban areas, and the co-benefits (thermal insulation, increase of albedo and of evapotranspiration) are also generically relevant for urban climates under rising temperatures, thus mitigation of losses of ecosystems and restoration of their services must represent a key objective for biodiversity protection and restoration. The use of rooftop surfaces for restoring biodiversity in urban areas has yet some limits.

The possibility of realizing green roofs is physically limited by the availability of adequate roofs with a maximum roof inclination of 30°degrees, and by static requirements due to the implementation of a structure which is heavier than a normal “black tarmac” roof, yet in some cases comparable to the weight of gravel roofs. Both inclination of roofs and static requirements can limit, to some extent, the widespread implementation of green roofs in existing urban areas and thus the possibility of restoring biodiversity and creating natural water storage capacity in particular dense inner-city areas.

Urban roofs are, to a large extent, part of private buildings, and their realization depends, if no coercive measures are taken, on the willingness of private property owners to invest in green roofs. The possibility of incentivising these investments and improving the willingness of private investors depends on the continuous availability of specific funding to compensate the higher building costs. With regards to maintenance building management, there is a need for more widespread awareness about the economic advantages of the solution, which can outweigh, over the lifetime of a green roof of 30-50 years, the higher building costs (Free and Hanseatic City of Hamburg, 2017, p. 22). Additional benefits which can be realized during the management period consist, eventually, in reduction of stormwater fees, in the case a city recognizes the private contribution to the management of stormwater, as well as economies in terms of thermal insulation, reducing expenditure for cooling and heating in upper floors, new economic opportunities offered by economic exploitation of green roof spaces, or use values under the form of green private outdoor spaces in dense urban areas. Other strategies for increasing willingness of private actors consist in presenting and documenting good practice examples and scientific evidence on physical and economic characteristics. On the real estate market, green roofs are not recognized or appreciated as an additional value, thus preventing the construction of green roofs in large development projects. as buyers "often do not realize they bought a building with a green roof" (Richter and Dickhaut, 2019, p. 46) and thus are not aware of the additional value these roofs can add to the building be of interest for objects dedicated to the rental market. Public investments in green roofs can have a model function; and windows of opportunity as extreme events, if accurately framed and supported by influential change agents, can present a temporary opportunity for raising awareness about benefits from green roofs and positive aspects of climate change adaptation (Clar and Steurer, 2021).

Coercive measures can take effect only in those moments when investments in buildings (both new construction and eventually also in case of restructuring) are made. In Germany, the example of München, where a design by-law dating from 1996 made greening of flat roofs obligatory for new buildings.

Green roofs generally provide benefits both to the public (cooling down of urban surfaces, storage of rainwater) and to private users (thermal insulation, eventually use as private or commercial outdoor space). The exclusive use of green roofs as private or commercial spaces makes them different from green facades and urban park areas which provide benefits also in terms of visible and or usable urban green spaces.

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