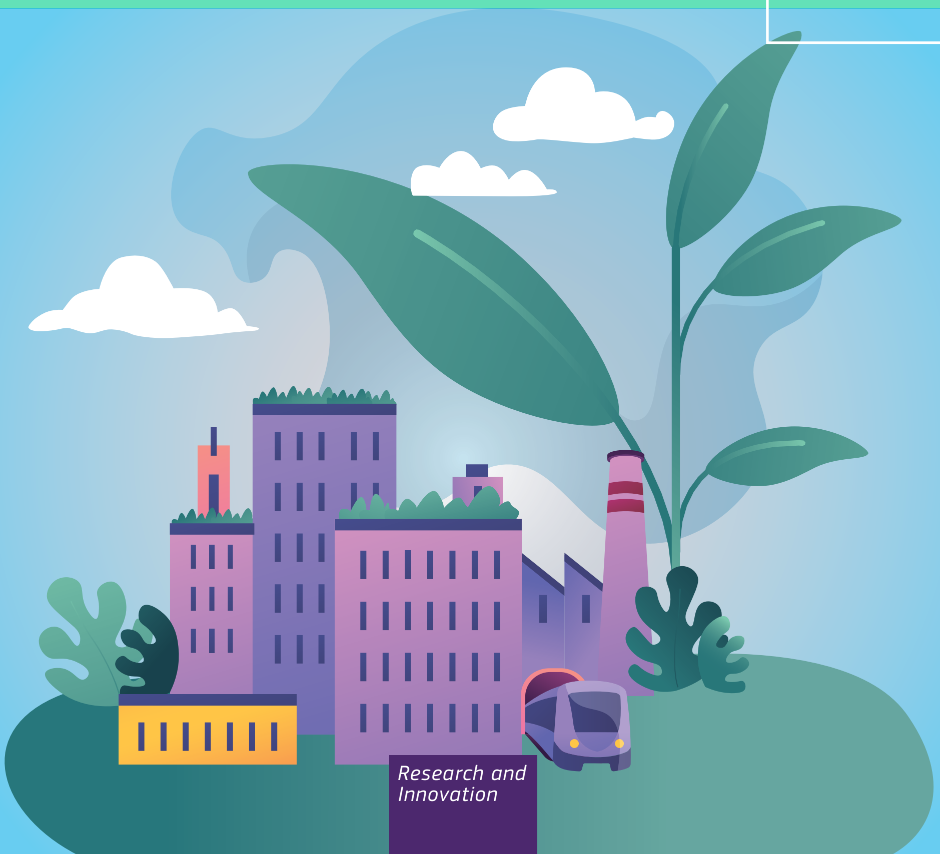
European Commission

Nature-based Solutions for climate mitigation

Analysis of EU-funded projects

Independent Expert Report



Research and Innovation

Nature-based Solutions for Climate Mitigation
Analysis of EU-funded projects

European Commission
Directorate-General for Research and Innovation
Directorate C — Healthy Planet
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EUROPEAN COMMISSION

Nature Based Solutions for Climate Mitigation

Analysis of EU-funded projects

Harriet Bulkeley

Valorisation of NBS projects
The initiative to analyse the impacts of EU-funded projects in the area of NBS and valorise their results in terms of EU added value and policy relevance was initiated in December 2019. Six policy reports and a final consolidated report were produced and can be found at: https://ec.europa.eu/research/environment/index.cfm?pg=nbs.

The present report aims to provide an overview of results from EU-funded NBS projects and how they support policy implementation in relation to Climate Change Mitigation.

2020 Directorate-General for Research and Innovation EN

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1. INTRODUCTION: THE POTENTIAL OF NBS FOR MEETING CLIMATE GOALS

The European Union has set out an ambitious goal to become carbon neutral by 2050 and to adopt a target to reduce total greenhouse gas emissions excluding those from land use cover and land use change to at least 450% below 1990 levels by 2030. Achieving these goals will require not only transformation of our energy and transport systems, but measures across the economy as well as efforts to harness the potential of nature to contribute to both mitigating climate change and enhancing our resilience to its impacts.

As has been shown over the past three decades, making progress towards these goals will require a multilevel approach that involves all levels of government as well as networks and partnerships between state and non-state actors (Bulkeley & Betsill 2013). Since its launch in 2008, the EU Covenant of Mayors has mobilised action at the local level, with now over 10,000 local signatories representing over 300M people committing to over 180,000 actions towards EU goals for climate mitigation. The success of the EU Green Deal will also depend on mobilising action across regional and local government, as well as the engagement of businesses, civil society and communities.

Nature-based solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services.

For more information visit the European Commission webpages on Nature-Based Solutions
https://ec.europa.eu/research/environment/index.cfm?pg=nbs

Within this context, the potential for NBS to play an important role in addressing climate mitigation is receiving increasing research, policy and public attention. In 2019, Science published a paper suggesting that planting trees, on a massive scale and sustained period of time, represented 'one of the most effective solutions at our disposal to mitigate climate change' (Bastin et al. 2019: 78). Although the potential and feasibility of such a strategy, and the scientific quality of the underlying research, has been hotly debated (e.g. Skidmore et al. 2019), it is increasingly clear that interventions that address how land is used are both an effective and necessary part of how society can respond to the climate mitigation challenge.

The IPCC have found that “all scenarios that limit climate change to 1.5°C rely heavily on land-use change mitigation methods, as well as decarbonizing the economy” and that “decreasing sources and increasing sinks of GHGs through terrestrial ecosystem stewardship and improvements in agriculture are widely cited as having the potential to provide around 30% of the CO2 mitigation needed through to 2030 to keep warming to less than 2°C” (Seddon et al. 2020: 2).

In this context, NBS for climate mitigation are seen primarily as those measures that conserve, restore or enhance “forests, wetlands, grasslands and agricultural lands” in order to either reduce CO2 emissions or remove CO2 from the atmosphere through specific measures such as “reforestation, forest conservation and management, agroforestry, cropland nutrient management, conservation agriculture, coastal wetland restoration, and peatland conservation and restoration” (Belamy & Osaka 2020: 98). In short, it is the capacity of NBS to sustain or enhance carbon storage and carbon sequestration that has to date attracted most interest.

Yet NBS can also contribute to climate mitigation through reducing energy demand. By providing thermal comfort from the scale of the building to the neighbourhood, NBS can reduce demand for heating and cooling and in turn create energy savings. Alternatively, NBS can be used to create a conducive environment for active transport – walking and cycling routes that connect green spaces and create space dedicated for pedestrians and cyclists – in turn potentially contributing to reducing the use of cars and their associated emissions. It may also be the case that NBS can contribute to reducing the generation of embodied emissions in urban development and infrastructure provision – by using alternative materials to concrete and steel, which are both globally important sectors when it comes to the production of greenhouse gas emissions, building with NBS may support climate mitigation.

This report explores how NBS can contribute to climate mitigation through both storing and sequestering carbon and through reducing energy demand. It suggests that both offer significant potential within Europe and beyond for addressing the challenge of climate mitigation, but do so in very different ways. The potential for storing and sequestering carbon is largely to be found in rural areas and depends on interventions that take place in the agricultural and forestry sectors. In contrast, the potential for energy demand reduction is largely an urban issue, requiring interventions in urban development, infrastructure provision and the management of both public and private green space in cities. As well as taking place in different settings and involving different key actors, the trade-offs involved in NBS for climate change also vary. When it comes to those that seek to mitigate climate through carbon storage and sequestration, concerns centre on their potential impact on biodiversity. While those NBS that are designed to contribute to addressing thermal comfort in the city might increase natural habitat and species diversity, here potential trade-offs arise through their demand for water and how this might be managed in increasingly drought-prone urban areas.

The sections that follow consider in turn how NBS can contribute to climate mitigation and provide some examples drawn from research and innovation projects taking place in Europe. Overall this report examines what works on the ground, as well as the challenges that have been faced and how these might be overcome. In conclusion, key lessons and areas where future research is needed are identified.

2. STORING AND SEQUESTERING CARBON THROUGH NBS

NBS that conserve or enhance carbon stocks have risen rapidly to prominence on the global agenda over the past few years. While the value of such interventions has long been recognised within the climate community, as successive IPCC reports and the development of the REDD+ instrument to enable the financing of land-use and forestry interventions has shown, the Paris Agreement and growing momentum behind the need to reach 'net zero' emissions have brought a new urgency to exploring their potential. Following the 2019 UN Climate Action Summit, which took NBS as a key theme, the NBS Contributions Platform and Compendium of Contributions on NBS have been developed under the auspices of the UN Environment Programme. If in the past a focus of such initiatives has been on how managing land use and land-use change should take place in the global South in order to mitigate climate change, NBS for climate mitigation are now seen to be applicable in all global regions.

In Europe, the evidence base reviewed for this report (see Annex 1) suggests that there is significant potential for using NBS for climate mitigation through storing and sequestering carbon (Figure 1). This evidence points to two key arenas for action, the management of agricultural land and the conservation and management of forest ecosystems. There is also a growing evidence base concerning the potential for urban NBS to contribute to the storage and sequestration of carbon. In addition, there is an increased interest in the potential for 'blue carbon' especially in the form of the restoration of sea grasses and salt marshes, which is being supported by a range of initiatives across Europe. While there is strong initial evidence that such interventions can support climate mitigation (see for example), the evidence base is currently not sufficiently extensive to be included in this report.

CARBON STORAGE	CARBON SEQUESTRATION
The absolute quantity of carbon held within a reservoir at a specific time is referred to as a carbon 'stock'. This reservoir is a component of the climate system, other than the atmosphere, which has the capacity to store, accumulate or release carbon.	The process of increasing the carbon content of a carbon reservoir other than the atmosphere. Biological approaches to sequestration include direct removal of carbon dioxide from the atmosphere. Vegetation removes CO_2 from the atmosphere through photosynthesis.

Figure 1. Carbon Storage & Carbon Sequestration

2.1 LAND MANAGEMENT

A critical factor shaping the carbon storage potential is the nature and extent of soil erosion, which leads to a loss of topsoil, including soil organic carbon as well as the extent to which organic matter is added to soil over time. Good soil management is thought to provide an especially long-term NBS for climate mitigation, given that soils can effectively sequester carbon, keeping it away from the atmosphere.

At present, soil management in agricultural systems is not proving to be effective in this regard, with calculations suggesting that there is a significant loss of soil organic carbon across diverse geographical regions and agricultural production systems so that European soils in agricultural areas are likely to be net contributors to rather than sinks of atmospheric carbon (Lugato et al. 2016). Indeed, research by the PEGASUS project suggests that "around 86% of the European agricultural areas showed soil organic carbon losses from erosion" (Pérez-Soba et al. 2018: 44), with greater losses in more intensively managed systems (e.g. vineyards or permanent crops) than in those with lower levels of management intensity (e.g. citrus farming or horticulture) (Pérez-Soba et al. 2018: 46). While this research suggests that the loss of soil organic carbon varies within different agricultural systems, due to the specifics of topology and climate, it also points to the importance of land management practices in shaping the potential for carbon storage in European soils.

Evidence suggests that agro-forestry, land use systems where trees are grown in combination with agriculture, can offer potential as an NBS to improve land management, including the enhancement of soil organic carbon (Hernández-Morcillo et al. 2018). When based on agrobiodiversity, these systems can also contribute to tackling biodiversity decline (e.g. see Naumann and Davis, 2020). Whilst such agro-forestry systems are rather widespread across Europe, comprising approximately 20m ha, "the expansion of existing areas of agroforestry and the establishment of new agroforestry systems has remained limited" (Hernández-Morcillo et al. 2018: 50). Specific kinds of NBS identified that could enhance the use and development of agro-forestry for climate mitigation included adopting management practices for improving soil organic carbon, intercropping with leguminous plants, and the use of tree varieties adapted for different climate conditions (Hernández-Morcillo et al., 2018: 49).

Yet the uptake of such solutions remains limited, with key barriers identified as including the knowledge, skills, support and finance required to integrate trees into existing livestock or arable farming systems. Rather than lying in developing new solutions for managing agricultural land, much of the challenge that remains lies in (perceptions of) the socio-economic viability of such interventions, the traditional management systems within which they need to be implemented, and governance conditions which provide either limited incentives or send mixed messages about the value of these NBS within the agricultural sector. Furthermore, despite their higher overall productivity (Graves et al. 2007), the low profitability of such systems under the current regulatory and market conditions underlines the importance of developing "safe economic routes" or options for "the diversification of marketable products, and improvement of business opportunities through targeted marketing strategies" were seen to be critical in generating the wider uptake of these kinds of NBS (Hernández-Morcillo et al. 2018: 50).

DEVELOPING NBS TO SUPPORT LAND MANAGEMENT & LIVELIHOODS

The SOIL4WINE project has sought to address environmental challenges and the economic viability of this wine sector through the introduction of new soil management and agricultural practices. Pilot areas included in the project in Northern Italy were showing a significant decline in both the area under viticulture production, the productivity of vineyards, and their economic viability, with knock-on effects on the regional economy. Results indicate that improvements in soil management can yield important ecosystem service benefits, including water infiltration, reduced soil erosion, improving biodiversity and carbon sequestration, which are of significant value. Analysis suggested that the "potential total value of all ecosystem services provided by an appropriate management of the vineyard" supported by a new Decision Support Services "is equal at least to 20% of the value of total sales" from the vineyard. In order to capture this value for farmers, new 'payment for ecosystem services' tools and approaches may be needed that will not only encourage good environmental outcomes but help build the economic resilience and social cohesion of areas dependent on viticulture in the future.

In addition to managing agricultural land, the management of existing wetlands and peatlands is critical for carbon storage. Bonn et al. (2016) report that while peatlands cover <3% of the world's surface, they hold two times more carbon than the entire global forest biomass pool, and represent more than 30% of the total global soil carbon store. Holden (2005) stresses that the long-term ability of peatlands to absorb carbon dioxide is dependent on changing climate or management, which can alter peatland hydrological processes and pathways for water movement across and below the peat surface (driving carbon storage and flux). However, climate mitigation through NBS such as the creation and restoration of upstream wetlands is far from straightforward, not least because these habitats also emit other greenhouse gases such as methane (Green et al. 2018).

2.2 FORESTS AND FOREST MANAGEMENT

According to the IPCC, much of the "mitigation potential from terrestrial ecosystems comes from restoration and management of forests and from curbing deforestation", particularly in tropical areas due to the fast rates of tree growth and the lesser risk of adverse impact on the earth's albedo (Seddon et al., 2020: 4). The potential of such measures has been calculated by the IPCC to lie in the "range of 0.4–5.8 Gt CO2 yr−1 from avoided deforestation and land degradation, as well as a carbon sequestration potential of 0.5–10.1 Gt CO2 yr−1 in vegetation and soils from afforestation/reforestation" (Seddon et al., 2020: 4). Recent analysis suggests that restoring tree cover to 900 mha calculated to provide viable conditions for such interventions could 'draw down' some 200 Gt of carbon at full maturity, and that even if 10% of such an opportunity could be realised restoring forests offers a significant NBS for climate mitigation (Bastin et al. 2019). Yet concerns have also been raised that such potential relies on plantation forests, generating monocultures with little biodiversity value and where evidence that such systems can contribute to the long-term storage of carbon is still limited (Seddon et al. 2020).

FOREST MANAGEMENT FOR CARBON CREDITS

The CLIMARK project has the aim of contributing to "climate change mitigation and adaptation, increasing sink capacity and carbon stock protection in Mediterranean forests, promoting multifunctional management with the creation of a climate credit market." Through pilot projects across Catalonia the project will investigate how different forest management practices and agro-forestry techniques can support carbon storage and sequestration. A comprehensive evaluation of carbon mitigation through forestry management will then underpin the design of a Voluntary Climate Credit Market. This market will connect the producers of climate credits (forest owners with climate mitigation forests) and those looking to consume voluntary carbon credits to offset emissions from the businesses. The Volunteer Climate Credit Market is due to be trialled in Catalonia and Veneto.

In the European context, evidence suggests that existing forests may have the capacity to sequester carbon of the equivalent ofup to 13% of total EU greenhouse gas emissions from the burning of fossil fuels (Pérez-Soba et al. 2016: 24). While the rates of storage and sequestration in natural forest systems are largely a matter of their ecological composition and functioning, in managed forest systems this balance is driven by the economics of demand for forest products and the management practices through which they are produced (Pérez-Soba et al. 2018). As a result, research points to a trade-off between developing forestry systems for their non-market goods (carbon storage, biodiversity) and for commercial purposes of wood production (Pérez-Soba et al. 2018: 70-71). This suggests that there may be potential for developing NBS within managed forestry systems that can enhance the storage and sequestering of carbon, whilst also supporting the continued economic productivity of managed forests.

2.3 URBAN NATURE

Despite their small scale, there has been a growing interest in the potential for NBS that focus on the conservation and restoration of urban forests and which support the planting of urban trees and other ecosystems for the storage and sequestration of carbon. As cities have come to mobilise action towards both climate mitigation and adaptation, and in the face of critiques concerning the politics and ethics of 'offsetting' emissions to distant others, local interventions to store and sequester carbon has become a matter of considerable interest at the municipal level.

Yet studies reveal that the potential for using NBS to store and sequester carbon at the local level remains very limited. In Barcelona, in line with other studies, research found that "direct net carbon sequestration…makes a very modest contribution to climate change mitigation relative to total city-based annual GHG emissions (0.47%)" (Baro et al., 2014: 475). Despite the limited overall contribution to climate mitigation identified in this research, its findings demonstrate that certain kinds of urban land-use – urban green spaces and low-density residential areas containing private gardens – are the most valuable for storing and sequestering carbon, suggesting that future urban NBS that are delivering other benefits in these domains could also be contributing to climate mitigation (Baro et al., 2014: 472).

INNER-CITY TREE PLANTING, BOLOGNA, ITALY

Funded under the LIFE programme between 2012 and 2013, the GAIA project, in Bologna, Italy, established a public-private partnership through the 'green areas inner-city agreement,' where private firms pledged to plant trees in the inner city. This allowed local enterprises to decrease their carbon footprint while also generating environmental and social benefits for the community. To date some 2,300 of the target 3,000 trees have been planted, and a toolkit was created to monitor the contribution to carbon sequestration and air pollution. The intention is to continue until the tree planting target is met.

Summary of cost and benefits:

Project budget:	€ 1 202 000
Number of trees planted:	2320
Cost of 1t CO_2 sequestrated (over 30 years)	€ 1 202 000 /2320 = € 518

*with one tree sequestrating 1 ton of CO2 in 30 years

Source: https://naturvation.eu/atlas

Most studies to date have included relatively few urban domains in their analysis of the potential for storing and sequestering carbon – this is in part because the most frequently used evaluation tool available for urban assessment, the i-tree Eco model is intended to be used for evaluating the contribution of urban forests/ individual trees, based on estimates of the carbon sequestered by above ground tree mass in North American trees (Elmqvist et al. 2015; Table 1). More recent approaches have sought to develop more comprehensive analyses of the potential for storage and sequestration in the urban arena. The InVEST (Integrated Valuation of Environmental Services and Trade-offs) model, developed by the Natural Capital Project, based at Stanford University in the USA, uses maps of land use along with stocks in four carbon pools (i.e. above-ground biomass, below-ground biomass, soil and dead organic matter) to estimate the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time. However, while this approach can be applied to the urban arena, it has yet to be specifically developed for this context.

TABLE 1: Estimated climate mitigation contribution from urban nature
Estimates of the contribution of urban forestry and urban trees to storing and sequestering carbon in cities using the I-tree model

CITY	ESTIMATED CONTRIBUTION TO MITIGATION	REFERENCE
Barcelona, Spain	Net annual carbon sequestration per hectare: 536 kg/ha/ year	Baro et al. 2014
Syracuse, USA	Net annual carbon sequestration per hectare: 540kg/ha/year	Nowak and Crane 2002
Baltimore, USA	Net annual carbon sequestration per hectare: 520 kg/ha/year	Nowak and Crane 2002
Averaged over 28 cities and 6 states in the United States	Average carbon storage density per unit tree cover: 7.69 kg C/m2 and average gross carbon sequestration rate per unit tree cover: 0.28kg C/ m2/year	Nowak et al. 2013
Averaged over 5 European cities	Averaged net carbon sequestration 2.43 t/ha/year, carbon storage 20.85 t/ha;	Baro et al. 2015

Source: Elmqvist et al. 2015; Naturvation 2019a.

The NBS Navigator, developed to support decision-makers in identifying the potential synergies and trade-offs for different kinds of NBS in contributing to sustainable development goals, has sought to extend the number of urban domains for which the storage and sequestration potential is understood. Of particular significance is their finding that urban blue areas can also contribute to climate mitigation (Table 2).

TABLE 2: Relative contribution of NBS in different urban domains for carbon storage

NATURE-BASED SOLUTION	SCORE	VALUE (average) (kg carbon/m2)
Parks and (semi)natural urban green areas	5	32.6
Urban green areas connected to grey infrastructure	4	28.9
Blue areas	5	36.1
External building greens	2	5.4
Allotments and community gardens	4	23.7
Green areas for water management	2	12.5

Source: Naturvation 2019a. NB The scoring is designed to provide an indicator of the relative contribution of nature-based solution in each domain to the indicator (carbon storage), with five being a relatively very good contribution and 1 being a relatively very weak contribution.

3. ENERGY DEMAND REDUCTION

Despite efforts to address climate change, research suggests that society will experience a range of impacts from the changing climate over the next thirty years and into the second half of this century. One particularly acute challenge which has significant implications for our future energy demand is that of increased incidents of extreme heat. Research undertaken by the UCCRN for the C40 Cities Climate Leadership group suggests that some 970 cities with a population of over 100,000 people will be regularly exposed to a three-month average temperature of 35°C or above, with 45% of the world's urban population living in cities with these conditions an increase of 700% on today's figures (UCCRN, 2018).

While these impacts, and the risks they pose in terms of food and water shortages and health, will be felt most outside of Europe, this analysis shows that many southern European cities will be exposed to these extremes (Figure 5). In addition, it is expected that other cities across Europe will experience a higher number of extreme heat days, as witnessed in the Summer of 2019 across large parts of the region. Indeed, recent analysis suggests that in addition to the cities of Madrid, Rome and Athens that are commonly associated with extreme temperatures, "other cities, namely Valletta, Sofia, Wien, Zagreb, and Zurich should expect serious impacts in the future" (Smid et al., 2019: 399).

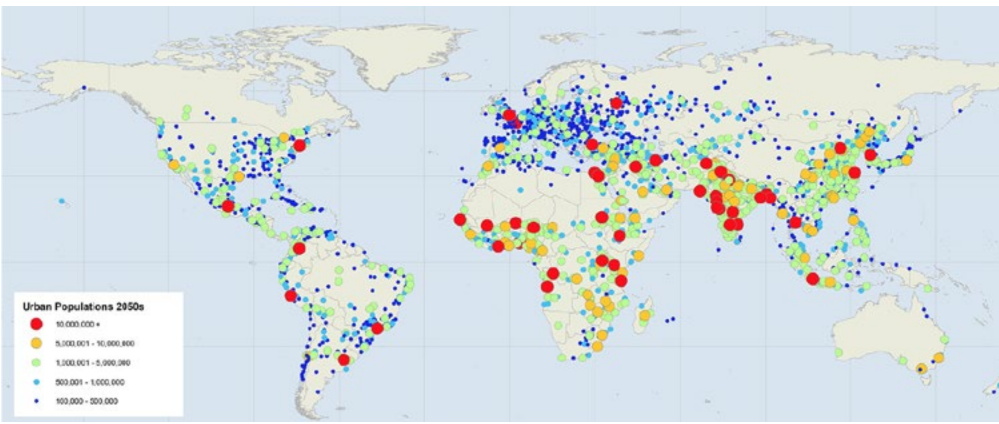

Figure 2: Urban Population Centres experiencing 3-month average 35 degrees in the 2050s. Source: UCCRN 2018: 13 © UCCRN.

The impacts of extreme heat will not only affect urban populations, but also their demand for energy. Cities are considered to contribute approximately 70% of all energy-related greenhouse gas (GHG) emissions globally. A key source of increasing energy demand will be in the form of air-conditioning, as cities seek to manage extreme heat. The International Energy Agency estimates that 10% of all global electricity demand is used for cooling today, and that this figure is set to triple by 2050 (IEA, 2018a).

Of particular concern is that demand for cooling drives peak electricity demand. Meeting peak electricity demand often necessitates the building of new (fossil fuel) power stations just for this purpose or the use of standby generation capacity that is often very inefficient, for example the use of diesel generators. As a result, demand for electricity for air conditioning can disproportionately increase demand for fossil-fuel electricity power and contribute to increasing levels of greenhouse gas emissions.

Finding ways to cool the city are therefore going to be critical if we are to stay within the boundaries of a 1.5 or even 2 degree future world. NBS may have a critically important role to play, especially if they can be implemented before air conditioning becomes normalised across cities where it has yet to become 'locked in' to the built environment and everyday life. This section examines how NBS can be deployed at the city, neighbourhood or street level in order to address the urban heat island effect, before considering the potential for NBS integrated into the built environment in reducing demand for energy use in this sector.

FEELING THE HEAT?

One fifth of the energy used in buildings today – or 10% of the global total - is consumed by air conditioners and electric fans for cooling.

By 2050, the International Energy Agency expects this figure to triple – creating an additional demand for electricity equivalent of all of that used by the US, the EU & Japan today.

Left unchecked, the global total stock of air conditioners is estimated to grow to 5.6 billion, or 10 ACs sold every second for the next 30 years.

Source: IEA 2018b

3.4 COOLING THE CITY

The impacts of increasing global temperatures under climate change are exacerbated by what is known as the urban heat island effect, a phenomenon whereby urban areas experience both day and night time temperatures several degrees warmer than their surrounding areas. Of the four most commonly suggested approaches for managing this challenge - increasing the reflectivity of urban surfaces, changing urban morphology to enable greater ventilation at night, the use of vegetation and the use of water bodies - two require active intervention in the form of NBS (Aram et al. 2019; see also Calfapietra, 2020). Indeed, such approaches are actively encouraged by the EU's Strategy for Strategy on Heating and Cooling (COM/2016/051) which suggests that "Nature-based solutions, such as well-designed street vegetation, green roofs and walls providing insulation and shade to buildings also reduce energy demand by limiting the need for heating and cooling."

GREEN CORRIDORS COOL THE CITY

As part of the GROW GREEN project Valencia is seeking to create a Green Corridor through the city by creating a series of green spaces or gardens that connect to existing green areas in the neighbourhood and provide a pedestrian route for citizens to use. In addition, green pergolas – structures built for shade and with planting to remove pollutants – as well as planning to maximise shade will be used to reduce heat stress. The intention is not only to create a more comfortable environment for citizens in the city, but also by taking account of natural ventilation and wind patterns to also cool the overall environment and reduce the energy demand of buildings in the neighbourhood.

There is now a significant body of literature that demonstrates that urban green infrastructure (GI) can have a significant impact on cooling the city not only directly within urban green spaces but also in their surrounding areas, known as the 'Park Cool Island' or 'Green Space Cool Island' effect (Aram et al., 2019). For example, an analysis of 47 studies comparing the cooling effects of green spaces in cities found that they "are on average 0.94°C cooler in the day than urban spaces, with stronger effects the larger the green space" (Seddon et al., 2019: 3).

In their analysis of the services provided by urban ecosystems, Elmqvist et al. (2015) report on a study conducted in Manchester, UK by Gill et al. (2007), which showed that "a 10% increase in tree canopy cover may result in a 3–4.8C decrease in ambient temperature." This is consistent with a recent comparative analysis of studies conducted globally also demonstrates that urban green spaces are consistently found to reduce temperatures in the city both during the day and, crucially, during the night. The cooling effect of urban green spaces was seen to increase not only with the size of such interventions, but also in relation to their density of their vegetation, species composition, shape, orientation and connectivity (Aram et al., 2019).

Urban NBS for cooling the city are not only to be found in green spaces, but also through interventions aimed to cool specific streets or open spaces in the city. In their analysis of the effect of tree planting in public streets and squares, Nature4Cities found that "trees can mitigate heat stress more effectively than low-hanging sun sails, installed right above the head of pedestrians. In the period of 9:00–16:00, the average Physiological Equivalent Temperature (PET) reduction by trees and low sun sails was 9.0 °C and 5.8 °C respectively" (Kántor et al. 2017). Their analysis suggests that given that shading in streets and squares can be provided by other buildings, the most important urban spaces for interventions of this kind are those which do not receive shade in this way, "sidewalks facing SE, S, and SW" where the use of NBS to provide shading from trees will be of particularly high importance (Kántor et al. 2017). Evaluating the relative effects of different urban NBS in terms of their potential for air cooling, NATURVATION finds that blue areas are an order of 2 – 3 times more effective than urban parks, with green areas connected to grey infrastructure (such as street trees) also producing an important cooling effect in the city (Table 3).

TABLE 3: Relative contribution of NBS in different urban domains for air cooling

NATURE-BASED SOLUTION	SCORE	MEAN VALUE (°C)
Parks and (semi)natural urban green areas	2	0.94 (95% CI of mean = 0.71–1.16)
Urban green areas connected to grey infrastructure	3	1.6 (0.43 – 3.06)
Blue areas	5	3.1 (1.6 – 5.2)
External building greens	2	1.1 (0.03 – 3.0)
Allotments and community gardens	No score	No values found
Green areas for water management	No score	No values found

Source: Naturvation 2019b. NB The scoring is designed to provide an indicator of the relative contribution of nature-based solution in each domain to the indicator (air cooling), with five being a relatively very strong contribution and 1 being a relatively very weak contribution.

However, when it comes to the capacity for NBS to have a direct effect on the thermal comfort of individuals, as measured by the PET indicator, urban parks as well as blue areas are the most effective intervention (Table 4).

TABLE 4: Relative contribution of NBS in different urban domains for reducing PET
Scores, physiologically equivalent temperature differences (°C) compared to parks

NATURE-BASED SOLUTION	SCORE	MEAN VALUE
Parks and (semi)natural urban green areas	4	0 (0 – 0)
Urban green areas connected to grey infrastructure	3	0.5 (-6 – 11)
Blue areas	5	-1.4 (-5.6 – 3)
External building greens	No score	No values found
Allotments and community gardens	(1)	Only a single value available (+3.5)
Green areas for water management	No score	No values found

Source: Naturvation 2019c. NB The scoring is designed to provide an indicator of the relative contribution of nature-based solution in each domain to the indicator (PET), with five being a relatively very strong contribution and 1 being a relatively very weak contribution.

To date, there are few studies that have explicitly considered 'blue' NBS for their capacity to provide climate mitigation benefits in this manner. A study by Kleerekopera and colleagues in the Netherlands suggests that "water can cool by evaporation, by absorbing heat when there is a large water mass – which functions as a heat buffer – or by transporting heat out of the area by moving, as in rivers" (Kleerekopera et al., 2012: 32; see also Hathway & Sharples, 2012). Designing NBS to effectively make use of these types of cooling function – e.g. through including forms of 'fountain' that are effective in creating evaporation, or by including sufficiently large water bodies to absorb heat – will be important as new 'blue' NBS are integrated into the urban domain. At the same time it should be noted that the potential of such 'blue' solutions to offer cooling services for the city and in turn to reduce energy demand may be compromised by water availability, given that may of the urban environments that will experience heat extremes and therefore could benefit from such solutions are also those which will experience a shortage of water.

Water availability is also a key factor shaping the capacity of urban green NBS to deliver cooling benefits, with research finding that where water shortages occur lower density canopies develop or the nature of vegetation is such that it offers a more limited cooling effect. In Milan, research found that this lead to urban greening being most effective in providing cooling during June, but less effective in July and August where restricted water availability led to a reduction in the effectiveness of these measures (Mariani et al., 2016). The management and maintenance of NBS is therefore likely to have a strong impact on their effectiveness in terms of cooling the city and reducing energy demand and hence contributing to climate mitigation.

3.5 REDUCING ENERGY DEMAND IN BUILDINGS

In addition to cooling the city and reducing the impact of the UHI, NBS can be used directly to reduce energy demand in the built environment. Within Europe, it is estimated that 36% of total greenhouse gas emissions are attributed to the building sector (Besir & Cuce, 2018) with most of these emissions stemming from the energy consumed for space heating and cooling. By regulating the thermal requirements of buildings, green roofs and green facades can provide an effective means through which to reduce energy demand. A recent overview of research conducted on the potential of these NBS to reduce energy demand in the built environment found that both green roofs and green facades provide highly effective insulation for buildings, with roofs reducing the heat penetration by up to 80% in some cases such that buildings with green roofs consume between 2-17% less energy than their counterparts, and that overall green surfaces can reduce the energy demand of buildings between 10-30% (Besir & Cuce, 2018: 936).

Evidence suggests that green roofs are most effective in reducing demand for cooling in the summer months, but can also contribute to providing thermal comfort in the winter so that demands for heating are also reduced. The effectiveness of such solutions is determined primarily by the thickness of the green roof installed and the vegetation used, or by the structure of the green facade in terms of its density and capacity for evapotranspiration, with thicker materials and more dense and varied planting not only contributing to greater energy savings but also providing new biodiverse habitats in the city (Besir & Cuce, 2018).

ROOF GARDENS REDUCE ENERGY AND ENHANCE BIODIVERSITY

Implemented in 2008, a green roof using native planting was established at the Hellenic Treasury (Oikostegi) in Athens with the aim of evaluating the contribution that such NBS could make towards reducing energy demand. The plant selection was composed of indigenous Hellenic aromatic herbs and wild perennial flowers such as Hypericum and Phlomis and annuals such as poppies, grasses, and chamomile. The project led to a 50% reduction in the use of air conditioning on the floor directly below the installation. Energy savings totalling €5,630 per annum were recorded, translating into a 9% saving in air conditioning and a 4% saving in heating bills for the whole building. At the same time, the roof created a haven for birds and insects in the city.

Source: Urban Nature Atlas, NATURVATION

4. OPPORTUNITIES AND CHALLENGES: KNOWLEDGE, GOVERNANCE, AND INVESTMENT

That NBS offer a powerful tool for tackling the challenge of climate mitigation is now clearly established. Across Europe, projects and initiatives that are explicitly making this link have been able to effectively demonstrate the social, economic and environmental value of NBS. Given the prominence of the tackling climate change on policy and public agendas, showing how NBS can support a range of actors with their goals for climate change has provided a powerful means of attracting interest in and appreciation of the possibilities that NBS offer both for climate change and for sustainability more broadly.

In short, linking NBS to climate mitigation provides a clear means through which their value can be communicated and political support for their implementation generated. Equally, because carbon has an established monetary value, NBS that can demonstrate their capacity to store and sequester carbon are able to calculate the economic benefits they can generate, which in turn supports the development of viable business models and investment cases. Where NBS can lead to a direct reduction in energy consumption, creating a tangible and immediate reduction in expenditure, the cost-effectiveness of their implementation is also likely to increase. The explicit inclusion of climate mitigation goals in the design and development of NBS is therefore likely to enable the development of effective governance and business models that will support their mainstreaming. Yet realising these opportunities for mainstreaming and embedding NBS through climate mitigation is still fraught with challenges.

Turning first to those NBS with the potential for storing and sequestering carbon, a number of key challenges can be identified. The first relates to **trade-offs** between climate mitigation and other goals. Evidence suggests that within the forest sector, increased management and use of wood product can negatively impact on the potential for forests to store and sequester carbon. In the agricultural sector, trade-offs between intensive production and climate mitigation are also found. There is a clear need to **develop transition pathways** for affected sectors and regions that take account of concerns about the loss of livelihoods, employment, social cohesion and cultural ties that may arise through the widespread uptake of NBS.

At the same time, environmental organisations have expressed concerns that the use of NBS may be to the detriment of goals for nature and biodiversity should interventions take place that do not consider these outcomes as of equal significance to climate goals. **The development and use of new standards for governing NBS** may be one means through which to identify trade-offs involved, engage affected communities and stakeholders, and develop governance processes and forms of investment that are sensitive to the competing demands for future land use in Europe.

When it comes to the potential for NBS to deliver direct reductions in energy demand, a key challenge stems from the fact that because the framing of 'natural solutions' to climate change tends to focus on land and marine-based ecosystems **the value of urban NBS for climate mitigation is often overlooked**. While there is growing interest in the ways in which NBS can reduce heat stress within cities, the wider benefits in terms of reducing energy demand are not often calculated beyond the scale of the individual building.

Furthermore, issues of implementation are likely to be more complex in urban arenas due to the multiple actors who are involved in owning, managing and inhabiting the built environment. Classic 'landlord-tenant' issues, where those responsible for building or maintaining office or residential space do not benefit from reduced bills over time are likely to hinder the development of effective business models and financing for NBS that reduce energy demand. Likewise, implementing interventions at the street, neighbourhood or city scale encounters the challenge of how to gather the relevant actors and ensure that all of those who might benefit from a scheme are also involved in meeting (at least part of) the costs. As with other benefits, NBS that are designed for climate mitigation provide both public and private benefits which current governance arrangements and business models tend not to be able to capture and distribute effectively. Across all areas where there is potential for implementing NBS to address climate mitigation three further challenges are frequently encountered.

First, **capacity to evaluate the climate benefits of NBS** remains limited. Research has tended to focus on individual case-studies or particular sorts of ecosystem, and our knowledge of the storage, sequestration and energy demand reduction potential of diverse kinds of nature-based solution is relatively weak. Furthermore, despite the development of new tools for evaluating NBS and their contributions for sustainability, many approaches lack sufficiently robust indicators or the potential to be applied to diverse NBS in different conditions. This may be because tools exist but there is limited knowledge or practical experience of their use amongst key stakeholders, or because appropriate evaluation techniques and models have not yet been developed.

Second, where implementation is taking place **the value of climate mitigation alone** is usually insufficient to build a business model or case for investment that can support the deployment or upscaling of specific NBS. Because NBS provide public as well as private benefits, some level of public finance is frequently required to enable and sustain such interventions over time. Equally, approaches are needed which enable the mitigation value of NBS for diverse beneficiaries to be combined with other benefits that they generate. Rather than seeking to establish business models that can make the economic case for NBS based on singular benefits or individual beneficiaries, achieving this outcome is likely to involving ‘stacking’ business models that can generate returns for a number of different actors and outcomes as well as finding diverse sources of finance that can be used to undertake initial investments.

Third, due to the multi-functional and multi-beneficiary character of nature based solutions, **they are often dependent on governance arrangements that bring diverse actors together**. The implementation of NBS for climate mitigation is taking place through new governance arrangements – such as public-private partnerships or business-civil society collaborations – which require kinds of capacities for governing, including those which work to enable and facilitate collective action. There is limited evidence that regulatory or planning powers have been deployed by local or regional authorities in pursuit of climate mitigation outcomes. There is a strong emphasis on experimentation and project-based implementation as a means through which to realise the mitigation benefits of NBS. Scaling up such solutions may require that they become embedded in policy frameworks and planning regulations (e.g. building codes, land-use plans), but equally there is evidence that further work on how to develop **just transitions** through the use of NBS will be required if existing forms of economic and social practice are to be shifted towards the inclusion of NBS.

Overall, the implementation of NBS for climate mitigation has tended to be a rather technical endeavour, with a focus on the importance of generating new kinds of expertise, techniques, calculations and tools through which particular sets of stakeholders can be informed about the value of such approaches and educated as to how they should be adopted. There is less evidence to date that where NBS are being designed and deployed for climate mitigation sufficient weight has been placed on how to enrol key agents of change (e.g. architects, building managers, tenants associations, SMEs working in the farm and forest supply chains and so on) or those communities who might stand to benefit most from their deployment – for example, urban neighbourhoods that experience both heat stress and an inability to afford energy for cooling. Further engaging different kinds of public with the potential of NBS for addressing the climate emergency may provide a further opportunity for generating political will for their implementation.

5. POLICY RECOMMENDATIONS & KNOWLEDGE GAPS

In order for the potential of NBS for climate mitigation to be realised, a number of recommendations for policy and practice can be identified:

- Climate mitigation benefits of NBS are often too narrowly framed. There is promising evidence that NBS can support climate mitigation through reducing energy demand as well as through direct effects on carbon storage and sequestration. Public and private actors need to consider the full range of NBS that can contribute to the climate mitigation challenge.

- Support and guidance is required to enable private sector and civil society actors to implement NBS in the face of complex trade-offs and safe-guarding is required to ensure that climate mitigation is not achieved at the expense of biodiversity goals. Ensuring that there are trusted knowledge brokers who can support the development and implementation of NBS will be crucial for their widespread uptake.

- New approaches that bring multiple and novel 'agents of change' together in order to enable the development of pathways for mainstreaming NBS and ensuring 'just transitions' are required. Government agencies will be crucial for mobilising and enabling the capacity of other actors.

- There are opportunities to scale up NBS by embedding them in policy frameworks and planning regulations (e.g. building codes, land-use plans) and involving key agents of change such as architects, building managers, tenants associations, SMEs working in the farm and forest supply chains, and urban neighbourhoods.

- Climate mitigation benefits provide a basis for leveraging finance for NBS that tackle this challenge in addition to addressing multiple other sustainable development goals. There is a need for governance arrangements that bring actors who are willing to invest in climate facing NBS with those who are interested in other benefits that NBS provide in order to generate sufficient investment and robust business models.

With growing recognition of the importance of NBS for addressing climate change there are a number of key knowledge gaps that are critical to address in order to realise their potential:

- Our understanding of the carbon storage and sequestration potential of NBS tends to be dominated by particular ecosystems (forests) and derived from individual case-studies. Further research is required to establish how diverse NBS across multiple ecosystems and in rural and urban settings can store and sequester carbon.

- Our analysis of the potential impact of NBS for climate resilience and mitigation focuses on singular interventions. Further research is needed to develop both empirical knowledge and models/scenarios that can analyse the combined impact of multiple interventions at the landscape scale. There is also a need to build our understanding of the embodied carbon involved in the deployment of these initiatives and how this compares to other interventions aimed at ensuring sustainable development.

- There is a need to support research initiatives that calculate climate benefits at a broader multilevel scale, moving beyond individual buildings, case studies, and limited ecosystem types to understand the full diversity of NBS and involvement of diverse multilevel actors.

- There is a need to move beyond seeing the implementation challenge as primarily a 'technical' issue, to develop our understanding of the economic, social, political and cultural dimensions of designing and implementing NBS.

- There is limited understanding of the trade-offs involved in developing NBS for climate mitigation, both in relation to other environmental objectives (e.g. for biodiversity goals) and also in relation to other social and economic priorities. Further research on how NBS can be designed to contribute to the SDGs and the ways in which 'just transitions' can be enabled is needed.

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7. APPENDIX 1: LIST OF PROJECTS CONSULTED

ARTS (Accelerating and Rescaling Transitions to Sustainability), FP7, December 2013 – November 2016, EU contribution: € 2 996 826, project link

BLUENATURA LIFE Blue Natura Andalusian blue carbon for climate change mitigation: quantification and valorization mechanisms, LIFE, August 2015 – September 2020, EU Contribution: €1,508,275, project link

CLIMARK - Forest management promotion for climate change mitigation through the design of a local market of climatic credits, LIFE, October 2017 – September 2021, EU Contribution: € 716,947.00 project link

ENABLE (Enabling Green and Blue Infrastructure Potential in Complex Social-Ecological, project link Regions), BiodivERsA, December 2016 – May 2020, Total grant: € 2,540,309 (co-funded by the EU), project link

GreeninUrbs - Green Infrastructure approach: linking environmental with social aspects in studying and managing urban forests, COST, February 2013 – June 2017, EU contribution: € 706 000, project link

GrowGreen (Green Cities for Climate and Water Resilience, Sustainable Economic Growth, Healthy Citizens and Environments), H2020, June 2017 – May 2022, EU contribution: € 11 224 058, project link

GreenSurge (Biocultural diversity, green infrastructure and ecosystem services), FP7, November 2013 – October 2017, EU contribution: € 5 701 837, project link

NAIAD (Nature Insurance Value: Assessment & Demonstration), H2020, December 2016 – May 2020, EU contribution: € 4 994 370, project link

NATURVATION (NATure-based URban innoVATION), H2020, November 2016 – October 2020, EU contribution: € 7 797 878, project link

OpenNESS (Operationalization of natural capital and ecosystem services), H2020, December 2012 – May 2017, EU contribution: € 8 999 193, project link

PATHWAYS (Transition pathways to sustainable low carbon societies), FP7, December 2013 – November 2016, EU contribution: € 2 998 498, project link

PEGASUS (Stimulating long-lasting improvements in the delivery of social, economic and environmental benefits from agricultural and forest land), H2020, March 2015 – February 2018, EU contribution: € 2 977 525, project link

PHUSICOS ("According to nature" - Solutions to reduce risk in mountain landscapes). H2020, May 2018 – April 2022, EU contribution: € 9 472 200, project link

proGIreg ('productive Green Infrastructure for post-industrial urban regeneration': nature for renewal), H2020, June 2018 – May 2023, EU contribution: € 10 432 512, project link

RAMSES (Reconciling Adaptation, Mitigation and Sustainable Development for Cities), FP7, October 2012 – September 2017, EU contribution: € 5 200 000, project link

RESIN (Climate Resilient Cities and Infrastructures), H2020, May 2015 – October 2018, EU Contribution: € 7 466 004,50, project link

SOIL4WINE - Innovative approach to soil management in viticultural landscapes, LIFE+, January 2017 – December 2019, EU Contribution: € 914,999.00, project link

TURas (Transitioning towards Urban Resilience and Sustainability), FP7, October 2011 – September 2016, EU contribution: € 6 813 819, project link

UNaLab (Urban nature Labs), H2020, June 2017 – May 2020, EC contribution: € 12 768 932, project link

URBAN GreenUP (New Strategy for Re-Naturing Cities through Nature-Based Solutions), H2020, June 2017 – May 2020, EU contribution: € 13 970 642, project link

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Achieving the ambitious goals established by the European Union will require not only transformation of our energy and transport systems, but measures across the economy as well as efforts to harness the potential of nature to contribute to both mitigating climate change and enhancing our resilience to its impacts. Within this context, the potential for Nature-based Solutions to play an important role in addressing climate mitigation is receiving increasing research, policy and public attention. Nature-based Solutions that can enhance or increase carbon storage or generate new possibilities for sequestering carbon from the atmosphere can contribute to climate mitigation whilst also enhancing the conservation of biodiversity and contributing to a wide range of sustainable development goals. At the same time, Nature-based Solutions potentially have an important role to play in reducing energy demand through their role in cooling urban areas and providing thermal insulation for individual buildings.

This report explores how Nature-based Solutions can contribute to climate mitigation through storing and sequestering carbon and through reducing energy demand. It suggests that both offer significant potential within Europe and beyond for addressing the challenge of climate mitigation, but do so in very different ways and generate different kinds of trade-offs that will need to be negotiated if their potential is to be fully realised. Drawing on research and innovation projects taking place in Europe, this report examines what works on the ground, as well as the challenges that have been faced and how these might be overcome.

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