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Scaling up nature-based solutions for climate-change adaptation: Potential and benefits in three European cities

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ABSTRACT

Many exemplary projects have demonstrated that Nature-based Solutions (NBS) can contribute to climate change adaptation, but now the challenge is to scale up their use. Setting realistic policy goals requires knowing the amount of different NBS types that can fit in the urban space and the benefits that can be expected. This research aims to assess the potential for a full-scale implementation of NBS for climate-change adaptation in European cities, the expected benefits and co-benefits, and how these quantities relate to the urban structure of the cities.

We selected three case studies: Barcelona (Spain), Malmö (Sweden), and Utrecht (the Netherlands), and developed six scenarios that simulate the current condition, the full-scale implementation of different NBS strategies (i.e., installing green roofs, de-sealing parking areas, enhancing vegetation in urban parks, and planting street trees), and a combination of them. Then we applied spatially-explicit methods to assess, for each scenario, two climate change-related benefits, i.e. heat mitigation and stormwater regulation, and three co-benefits, namely carbon storage, biodiversity potential, and overall greenness. Finally, by breaking down the results per land use class, we investigated how the potential and benefits vary depending on the urban form.

Most scenarios provide multiple benefits, but each one is characterized by a specific mix. In all cities, a full-scale deployment of green roofs shows the greatest potential to reduce runoff and increase biodiversity, while tree planting -either along streets or in urban parks– produces the greatest impact on heat mitigation and greenness. However, these results entail interventions of different size and in different locations. Planting street trees maximizes interventions in residential areas, but key opportunities for integrating most NBS types also lie in commercial and industrial areas. The results on the pros and cons of each scenario can support policy-makers in designing targeted NBS strategies for climate change adaptation.

1. Introduction

In the last few years, the concept of Nature-Based Solutions (NBS) has become increasingly popular to designate actions that take advantage of nature to address urban challenges in a sustainable way (Babí Almenar et al., 2021). Research on, and innovative applications of NBS are supported by many policy initiatives, especially in the European Union (Faivre et al., 2017). The rationale for NBS implementation - as an alternative or in combination with more traditional “grey” measures - is that they provide a wide range of co-benefits while generating limited negative impacts, thus proving cost-effective on a medium-to-long term perspective (European Commission, 2015).

Among others, NBS can contribute to adapt cities to climate change, one of the main challenges that urban areas will face in the coming decades (Kabisch et al., 2017). Cities in Europe are already experiencing the effects of global warming, and in the near future they will need to cope with increasing frequency and intensity of extreme heat and heavy rains, often combined with other climate hazards such as sea level rise, drought, and fires (EEA, 2021). Meeting this challenge requires a mix of strategies targeting multiple sectors, from energy and transport to land use planning and health (Capela Lourenço et al., 2014; Reckien et al., 2014). Strategies based on a combination of grey (i.e., hard infrastructures), soft (i.e., knowledge and information systems), and green measures (i.e., NBS) are recommended as a way to promote a transformative adaptation that increases the overall sustainability of the urban systems (EEA, 2016).

Abbreviations: NBS, Nature-Based Solutions.

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As shown by recently-compiled collections such as the “Urban Nature Atlas” (Almassy et al., 2018) and the “Compendium of NBS in the Mediterranean” (Sapundzhieva et al., 2020), many exemplary projects have already demonstrated the potential of single, small- and medium-scale NBS, to foster climate change adaptation. NBS such as green roofs and rain gardens can increase water retention and infiltration and reduce stormwater runoff, thus helping to prevent urban flooding due to increasingly intense rain events (Haghighatafshar et al., 2018). NBS can also contribute to reduce air temperature through shading and evapotranspiration, thus limiting the negative impacts of more frequent and intense heatwaves (Zardo et al., 2017). Most of the time, these benefits come with additional co-benefits in terms of recreation, aesthetic value, air quality, even social cohesion and economic opportunities, to name just a few (Raymond et al., 2017).

The challenge now lies in moving from demonstration projects to a full-scale deployment of NBS (Fastenrath et al., 2020; Nature-based Solutions Coalition, 2019). We refer to this process as “scaling up”, although the term is still debated and other wordings, such as “scaling out”, have also been proposed (Smeds and Acuto, 2018). As discussed by Fastenrath et al. (2020), the scaling up of NBS may encompass several dimensions, not limited to the replication of niche innovations. NBS include traditional greening approaches (La Rosa et al., 2021), as well as conservation and management actions aimed at securing the provision of ecosystem services and improving the sustainability and multifunctionality of existing ecosystems (Eggermont et al., 2015). Scaling up these solutions may entail mainstreaming them at different spatial, temporal, jurisdictional, institutional, and management levels, simultaneously expanding networks and knowledge (Fastenrath et al., 2020).

This requires acting on external factors such as regulatory frameworks, standards, business and financial models, and the societal acceptance of these solutions (Frantzeskaki et al., 2019; Kabisch et al., 2016; Wihlborg et al., 2019). However, focusing on the spatial aspect, intrinsic factors also limit the potential to scale up NBS in cities, hence their capacity to achieve the wanted results. A critical factor is the availability of space to implement NBS, for example to plant trees (Pataki et al., 2021). While new development projects can more easily integrate NBS since their realisation, the possibilities of interventions in existing built-up areas are constrained by pre-existing urban form and land uses. This is especially true in high-density neighbourhoods, which are at the same time also the most vulnerable to climate change impacts (Grace et al., 2021). These limitations affect the benefits provided by NBS both directly and indirectly, since different types of NBS have different space requirements, and the location and size of the solution itself differently affect the benefits produced (Andersson et al., 2020; Cortinovis and Geneletti, 2019).

Promoting NBS as priority measures and setting ambitious but realistic targets for their scaling up requires a preliminary investigation of the area available for different NBS types and of the benefits that can be expected from their full-scale implementation (Bradfer-Lawrence et al., 2021). So far, in cities, this has been mostly done for single solutions and a limited range of benefits. For example, Hall et al.(2012) investigated the potential for tree planting in high-density residential areas in Manchester and the effects in terms of temperature reduction, while Karteris et al. (2016) simulated a full-scale implementation of green roofs in Thessaloniki and measured the impacts on carbon storage, energy consumption, and runoff retention. An exception is the work by Majidi et al. (2019), who assessed the potential for implementing four different NBS (green roofs, pervious pavements, bio retention cells, and rain gardens) and the benefits in terms of reduction of flood risk and heat stress, but at the small scale of a neighbourhood in Bangkok. Still, little is known about the full potential of distinct NBS types to contribute to urban climate change adaptation, and on how this vary across cities and, within cities, across different areas (as suggested e.g. by Hall et al., 2012).

The main objective of this study is to assess the expected benefits and co-benefits of a full-scale implementation of NBS for climate-change adaptation in selected European cities. More specifically, the research focuses on three questions:

1 What is the potential to scale up the use of different types of NBS for climate-change adaptation in European cities?
2 What climate change-related benefits and additional co-benefits can be expected from a full-scale implementation of different NBS types in different cities?
3 How does the urban structure of the cities affect the potential to scale up NBS, and the expected benefit and co-benefits of their implementation?

Answering these questions would make it possible to identify the most effective (combination of) NBS to tackle climate change-related challenges in different urban contexts, hence support the definition of policy goals and targets for scaling up NBS.

Operationally, we selected as case studies three European cities partners of the H2020 project Naturvation: Barcelona (Spain), Malmö (Sweden), and Utrecht (the Netherlands). In terms of climate and urban form and structure, they are representative of a variety of conditions across the EU (see Section 2.4). For each city, we developed six spatially-explicit scenarios including the current condition (baseline), the full-scale implementation of four single NBS types, and a combination of them. Then, for each scenario, we mapped and assessed two main benefits for climate change adaptation and three additional co-benefits. Finally, we analyzed and compared the potential for, and benefits of NBS implementation across different land use classes corresponding to the variety of urban forms and functions that characterize existing cities.

The remainder of the article is structured as follows. Section 2 describes the methods and data used for the analyses, and briefly introduces the three case study cities. Section 3 presents the results for the three research questions. Section 4 discusses the results and highlights the implications for future policies and for their implementation. Finally, Section 5 draws from the study some concluding remarks.

2. Material and methods

The methodology consists of three steps, corresponding to the three research questions: i) developing NBS implementation scenarios; ii) assessing the benefits and co-benefits of NBS implementation; and iii) exploring the link between NBS, benefits and co-benefits, and urban structure (Fig. 1).

2.1. Developing NBS implementation scenarios

We use scenarios to simulate the full-scale implementation of different NBS in the case study cities. Following EEA (2009), scenarios are defined as “a consistent and plausible picture of a possible future reality”. For each city, we developed six spatially-explicit scenarios that simulate the effects of policies implementing different climate change adaptation strategies based on NBS (Table 1). One scenario represents the current condition, four scenarios focus on the full-scale implementation of a single NBS (installing green roofs, de-sealing parking areas, enhancing vegetation in urban parks, and planting street trees), and a last scenario simulates the combined implementation of the four strategies. The strategies of installing green roofs and creating permeable parking areas aim primarily at increasing water retention and reducing or retarding runoff, thus avoiding overloads of the network (Haghighatafshar et al., 2018). The strategies of planting street trees and enhancing vegetation in the parks aim primarily at increasing canopy cover, hence the cooling effect due to shading and evapotranspiration (Zardo et al., 2017). However, vegetation also contributes to increasing water retention through interception (Xiao and McPherson, 2002), while permeable areas can also -under certain conditions- contribute to microclimate regulation (Coutts et al., 2012).

The scenarios are designed by considering the constraints to scaling

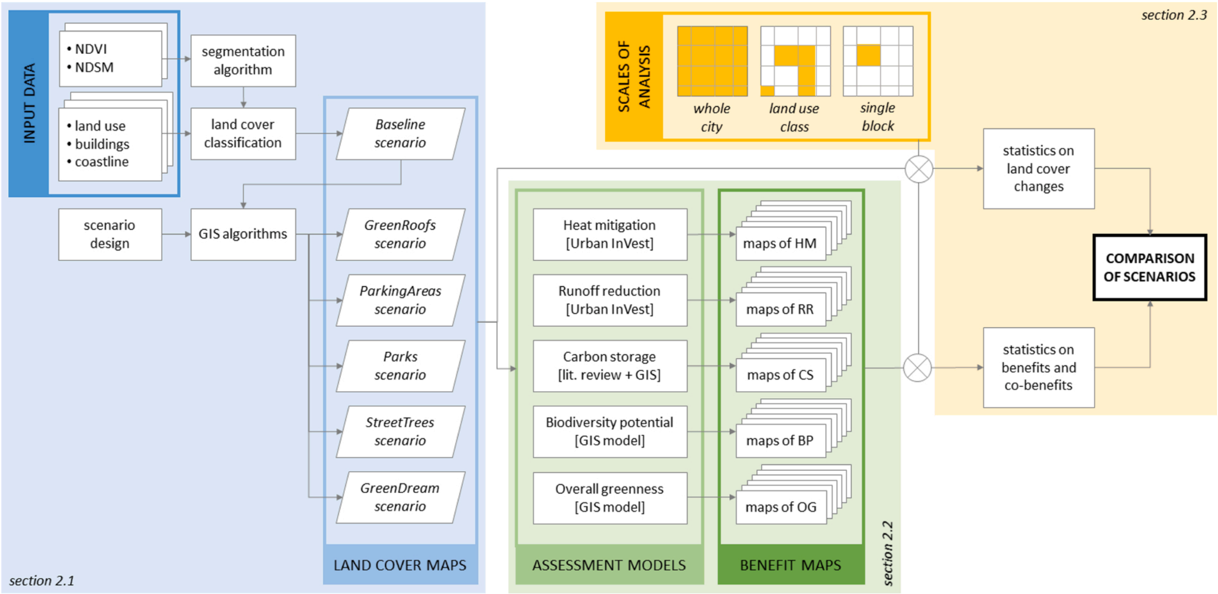

Fig. 1. Overview of the methodology applied in the study, with reference to the sections describing the different steps.

Table 1
NBS implementation scenarios simulated in the study. For a detailed description of the rules, please refer to Section 2 of the Supplementary Material.

Scenario	Strategy	Land cover transition rules
Baseline	–	current land cover
GreenRoofs	installing green roofs	extensive green roofs are installed on all roofs with size above 40 m^2 and angle below 20 degrees
ParkingAreas	de-sealing parking areas	existing parking areas are de-sealed and converted into concrete-reinforced lawns; trees existing on the areas are maintained
Parks	enhancing vegetation in urban parks	part of the areas currently sealed (excluding paths, sport fields, allotments, and cemeteries) are converted into low vegetation; the tree coverage is increased by adding a tree every 100 m^2 of plantable area
StreetTrees	planting street trees	trees are planted along secondary streets and residential roads, whenever enough space is available (no interference with traffic)
GreenDream	all of the above	a combination of all of the above

up NBS determined by space availability and technical feasibility. Additional economic, social, and institutional aspects potentially affecting the process of NBS implementation are not considered. The simulation of NBS implementation in the scenarios is based on land cover transitions, i.e. NBS are implemented through changes in land cover. The current land cover of the three cities at a resolution of 1 m was classified through a segmentation algorithm and a tree-low vegetation classifier. Input data include orthophotos and derived products (i.e., Normalized Difference Vegetation Index and Normalized Digital Surface Model), Urban Atlas data on water and agriculture, and vector data on building footprints and coastline (Table 1.1 in the Supplementary Material). The final land cover maps include the following classes: water, trees, low vegetation, impervious (non-built), agriculture, buildings (without green roof), green roofs, and vegetation over water (i.e., portions of tree crowns hanging over water areas). More details on the land cover classification can be found in Section 1 of the Supplementary Material.

To ensure a homogeneous approach across cities, spatial data to model land cover transitions in the NBS implementation scenarios were retrieved from the Urban Atlas and from Open Street Map (Open Street Map Contributors, 2020). Operationally, we defined a set of rules to identify suitable areas for NBS implementation and translated them into GIS models that modify the current land cover maps, thus obtaining scenario maps at 1 m resolution. The changes involve only the urbanized part of the cities. We restricted the simulation to the administrative boundaries of the three cities, to capture the effects of policies that could be implemented by local administrations. Furthermore, we maintained all the current land uses and functions unchanged, to simulate strategies that do not require drastic interventions on the urban structure. Table 1 summarizes the rules applied to develop the scenarios. Justifications for the rules, additional methodological details, and exemplary maps showing the effects of land cover changes in the different scenarios are available in Section 2 of the Supplementary Material.

2.2. *Assessing benefits and co-benefits of NBS implementation*

To assess the performance of NBS implementation scenarios, we selected two benefits related to climate change adaptation and three additional co-benefits. The former focus on NBS contributions to reduce two climate change-related challenges that are common across the three cities, and across many urban areas in Europe, i.e. heat waves and stormwater runoff. The latter cover aspects related to three additional socio-environmental urban challenges: carbon storage, linked to climate change mitigation; biodiversity potential, linked to biodiversity conservation; and overall greenness, linked to the health benefits of a green environment for the resident population.

2.2.1. *Heat mitigation*

The potential of NBS to lower high (summer) temperatures in the city was assessed using the heat mitigation index as calculated through the InVest - Urban cooling model v 3.8.7 (Sharp et al., 2020), a spatially-explicit proxy-based model. First, the model computes a heat mitigation index using average values of albedo, crop coefficient (evapotranspiration), and canopy coverage (shading) for each land use class, and accounting for the cooling effect generated by large green areas on their surroundings. Then, it calculates air temperature based on the heat mitigation index, a rural reference temperature, the intensity of the urban heat island for the analyzed city, and a distance for air mixing. Considering our purpose of comparing alternative scenarios, we focused on the heat mitigation index. We set the green area maximum cooling distance to the conservative value of 100 m (Aram et al., 2019; Hamel et al., 2021) and used the standard weights suggested by the model developers for shading, albedo, and evapotranspiration (respectively 0.6, 0.2, and 0.2). We conducted some tests to analyze the sensitivity of the results to the variation of these parameters; the results are shown in Section 6 of the Supplementary Material.

We used the classified land cover maps to calculate canopy coverage, while crop coefficient and albedo were retrieved from the Landsat-based EEFLUX (https://eeflux-level1.appspot.com/), a version of the METRIC model that operates on Google Earth Engine (Allen et al., 2015). We selected summer days with no cloud cover, warm temperature, and low wind (Table 3.1 in the Supplementary Material). As the model operates on land use classes, we analyzed the distribution of the values of albedo, crop coefficient, and canopy coverage in each Urban Atlas land use class. Since in some cases we found a higher within-class than between-class variance (data not shown), we decided to run the model considering each block (as defined in Section 2.3) as a separate land use class.

To model heat mitigation in the NBS implementation scenarios, we needed to adjust the values of crop coefficient and albedo in the areas affected by land cover changes. To do this, we identified in the original Landsat-derived raster maps at 30 m resolution the "pure" cells corresponding to a single land cover and, based only on those cells, we calculated median values for each land cover class in each city (see Table 3.2 in the Supplementary Material). The difference between the medians were used to update the maps in the areas affected by NBS interventions. To update values for the green roofs, since only few "pure" cells existed in the cities, we searched in the literature and adopted a value of 0.1 higher than conventional roofs in the same city for crop coefficient and a value of 0.02 lower than low vegetation for albedo. Reinforced lawns in the *ParkingAreas* scenarios were assumed to be composed of 50 % impervious and 50 % low vegetation, and the values of albedo and crop coefficient were adjusted accordingly. Since values in the 30-by-30 m cells in the Landsat-derived raster maps reflect the mixture of land covers within each cell, the calculated differences were applied considering the share of the cell involved in each land cover change.

2.2.2. *Runoff reduction*

The potential of NBS to reduce stormwater runoff was assessed through the runoff retention index, i.e. the share of stormwater that is retained in the analysed area, calculated by the InVest - Urban flood risk mitigation model v.3.8.7 (Sharp et al., 2020). The model applies the Curve Number method developed by the USDA (NRCS, 1986) and widely adopted in the literature about green infrastructure and NBS for urban stormwater management (Grêt-Regamey et al., 2020; McPhearson et al., 2013; Yao et al., 2015). The inputs required by the model include a land cover map, a map of soil hydrological groups, a table with curve numbers for each combination of land cover and soil hydrological group, and rainfall depth for the simulated event.

Maps of hydrological soil groups with a resolution of 250 m were generated based on the maps of saturated hydraulic conductivity k_s in the 3D Soil Hydraulic Database of Europe (Tóth et al., 2017) combined with the maps of depth to bedrock in the soilGrids250 m database (Shangguan et al., 2017) to identify the depth of the water impermeable layer. The minimum values of ks found in the layers above the bedrock were used to classify the soil groups based on USDA tables (NRCS, 2007). Missing values along the coast due to the lower resolution of the soil maps compared our land cover maps were filled with soil type D, i.e. the soil type with the worst infiltration capacity found in every city.

Curve numbers (Table 3.3 in the Supplementary Material) were assigned to the different land cover classes based on the standard values provided by USDA (NRCS, 1986), assuming all impermeable surfaces connected to the drainage system (Tables 1 to 8 of reference). Areas covered by low vegetation are considered equivalent to urban open spaces in good conditions (>75 % grass), while trees were assigned the value of woods in fair conditions. Agricultural areas are assumed to be in the fallow state, with only crop residue cover in poor condition, i.e. the worst possible hydrologic condition for agricultural areas. Reinforced lawns in parking areas are approximated by bare soil. To account for the effect of green roofs of different slopes, we divided them into 5 classes and calculated the respective curve number by applying the relation found by (Getter et al., 2007) to the average slope of each class. A class for slope higher than 20 ° was added to account for the angle of some existing green roofs. We present here the results for a rain event of 20 mm in normal conditions. Section 7 of the Supplementary Material shows the results of a sensitivity analysis that considered different rain events and antecedent moisture conditions.

2.2.3. *Carbon storage*

Carbon storage was modeled as a function of land cover, assuming a steady state (no sequestration or decomposition). Carbon storage values per unit area of each land cover class were retrieved from the literature (Table 3.4 in the Supplementary Material and references therein). The total carbon storage was calculated as the sum of carbon stored in above and below ground vegetation, and soil organic carbon. We focused only on land cover classes affected by NBS implementation scenarios, hence agricultural land and water were not included in the analysis.

To compensate for variations in the organic carbon content of urban soils depending on latitude (Vasenev and Kuzyakov, 2018) and to account for local effects, we adjusted the results on soil organic carbon from the literature review using the values of a world map of soil organic carbon (Hiederer and Köchy, 2012). We extracted the total soil carbon per unit area both within the boundaries of the three analyzed cities and in a radius of 5000 m around the locations of the case studies included in the literature review. The ratios between these values were used to calculate the final values of soil organic carbon for the three cities.

2.2.4. *Biodiversity potential*

The biodiversity potential was calculated for each block using the method by Radford and James (2013) and Pauleit et al. (2005). Biodiversity potential is a function of land cover (structural) diversity and share of green area. The former is measured by computing a Shannon-Weaver index (Eq. 1). The index is then multiplied by the fraction of green area in each block, calculated by summing the area of all the "green" land cover classes (i.e., low vegetation, trees, green roof, agriculture, and vegetation over water).

$$D = -\sum_{i=1}^{9} p_i log_2 p_i \tag{1}$$

Where p_{1-9} represent the share of city area covered by each land cover class.

2.2.5. *Overall greenness*

We used the greenness index as an overall indicator of health and wellbeing benefits provided by NBS (Amoly et al., 2014; Dadvand et al., 2015; Krekel et al., 2016). The greenness index, ranging from 0 to 1, measures the amount of green (and blue) spaces surrounding each point of observation, thus providing an indicator of how "green" an area of the city is. Significant correlations have been found in the literature between this simple index and a number of health and wellbeing aspects including mortality (Villeneuve et al., 2012), mental health (Triguero-Mas et al., 2015), life satisfaction (Krekel et al., 2016), and children cognitive (Dadvand et al., 2015) and behavioral development (Amoly et al., 2014). Here, we specifically focus on benefits in terms of restoration and mental health, related to the amount of natural and semi-natural areas that people experience in their surroundings, either by seeing or by directly accessing them.

Coherently with previous studies (Amoly et al., 2014; Fuertes et al., 2014; Triguero-Mas et al., 2015; Villeneuve et al., 2012), we used a buffer of 500 m around each point and calculated the share of area covered by water, trees (including vegetation over water), low vegetation, and agriculture. We excluded green roofs, since in most cases they are not visible by people in the streets or inside buildings, and permeable parking areas, since they cannot be perceived as green spaces when in use, i.e. filled with cars. Operationally, land cover maps of the current conditions and of the scenarios were reclassified into binary maps of green vs non-green land covers (Maas et al., 2009) and the index was computed for points randomly placed at a minimum distance of 10 m from each other (N = 999,740 in Malmö, N = 668,880 in Barcelona, N = 658,765 in Utrecht). The final value of the indicator is the average value of the points within the analyzed area.

2.3. Exploring the relation between NBS, benefits and co-benefits, and urban structure

The results of the assessment of NBS benefits and co-benefits were analysed at three levels of aggregation: i) urban block, ii) land use class, iii) whole city. We identified urban blocks starting from the Urban Atlas polygons, which distinguish patches of land separated by streets or characterised by different land uses. We removed roads and railroads (classes 12210, 12220, 12230) keeping only larger areas that correspond e.g. to large intersections or railway yards, and expanded the neighbouring polygons to cover the gaps. By using these polygons as a basis instead of city-specific census tracts, we could associate each block to the corresponding Urban Atlas land use class and population, defined homogeneously over the three cities. Exemplary maps at the block level are shown in Section 5 of the Supplementary Material.

To understand how the NBS potential varies depending on the urban structure, we analysed the distribution of the changes simulated in the scenarios across the different Urban Atlas land use classes. Then, for every city, we calculated the average value of the benefit and co-benefit indicators per land use class, and analysed the results considering the specific potential for NBS implementation observed for each class. The Urban Atlas land use maps of the three cities are available in Section 4 of the Supplementary Material.

2.4. Case study cities

The three case study cities are three partners of the H2020 project Naturvation: Barcelona (Spain), Malmö (Sweden), and Utrecht (the Netherlands). They are located in a latitudinal gradient that covers a large part of Europe (Fig. 2) and are characterized by different urban structures.

Barcelona (41 ° 22′ 57″N; 2 ° 10′ 38″E) is the capital of Catalunia and the second largest city in Spain. With more than 1,600,000 inhabitants, it is one of the densest urban centers in Europe. The population is expected to remain stable in the next decade (Adjuntament the Barcelona, 2020). Located on the northeastern coast of the Iberian peninsula, Barcelona is characterized by a Mediterranean hot summer climate (Köppen-Geiger: Csa) characterized by approximately 600 mm of annual rainfall and typical monthly average temperatures ranging between 9 °C and 24 °C (AEMet, 2021).

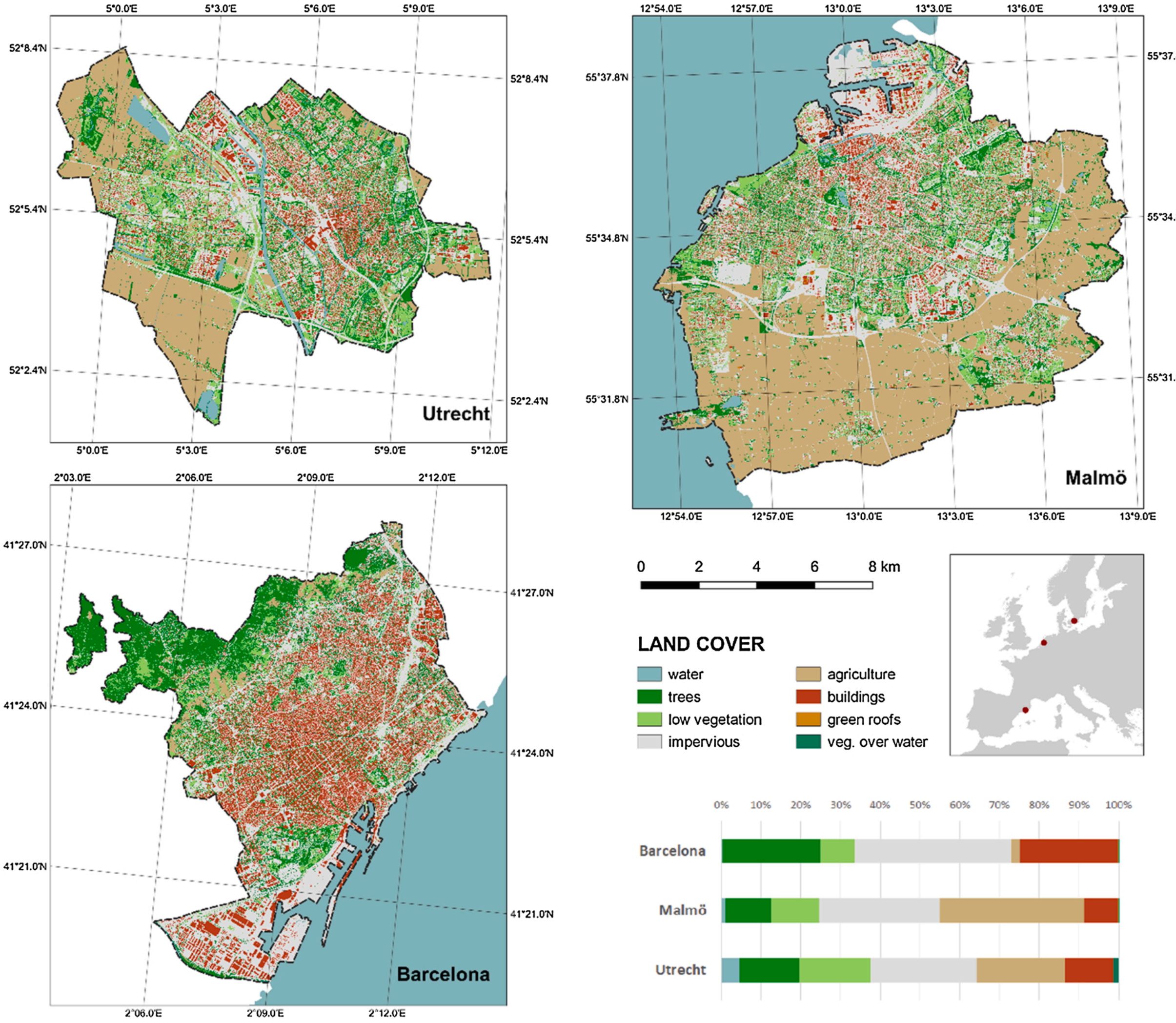

Fig. 2. Current distribution of land covers in the three case study cities.

With a population of around 350,000 inhabitants, expected to rise to 500,000 within 30 years, and a density of 2200 in./km^2 (SCB, 2020), Malmö (55 ° 36′ 23″N; 13 ° 00′ 06″E) is the third largest city in Sweden and the main urban center in the southern part of the country, also thanks to its strategic connection to Copenhagen. Malmö is characterized by a warm summer humid continental climate (Köppen-Geiger according to Beck et al. (2018): Dfb), with monthly average temperature ranging between 1 and 18 °C and average annual rainfall of 610 mm (SMHI, 2021).

Utrecht (52 ° 05′ 30″N; 5 ° 7′ 10″E), a center of medieval origins, is the fourth largest and the fastest growing city in the Netherlands. It has a population of around 350,000 inhabitants, expected to grow to 410,000 by 2030, and a population density above 3700 in./km^2 (CSB, 2020). The climate is oceanic (Köppen-Geiger: Cfb), characterized by monthly average temperatures ranging from 3 to 18 °C and average annual rainfall of around 830 mm (KNMI, 2021).

Despite the differences in location and climate, all the three cities suffer from extreme weather events that are expected to become more frequent due to climate change. Summer heat waves, with temperatures occasionally above 30 °C occur in all three cities, with negative consequences for citizens' wellbeing and public health (Rocklöv and Forsberg, 2009; Tobías et al., 2014; van Loenhout et al., 2018). Moreover, all the three case studies have already experienced urban flooding caused by intense rainfalls (Dai et al., 2018; Russo et al., 2020; Sörensen and Emilsson, 2019).

3. Results

3.1. *What is the potential to scale up the use of NBS?*

The three case study cities are characterized by a different current distribution of land covers (Fig. 2). The "green" classes - including water, trees, low vegetation, and agriculture - sum up to less than half of the total city area in Barcelona (around 35 %) and more than 60 % in both Utrecht and Malmö. Malmö shows the greatest share of agricultural areas within the city boundary (36 %), followed by Utrecht (22 %), while in Barcelona the areas surrounding the city core are mostly covered by forests (classified as "trees"). Even accounting for these differences in extra-urban areas, the share of buildings and impervious surfaces is greater in Barcelona compared to the other case study cities, which points to a denser urban form. On the other hand of the spectrum is Malmö, with a lower building density and the diffused presence of low-density neighborhoods surrounding the city core. However, each 1 m^2 of building footprint corresponds to 1.6 m^2 of impervious area in Barcelona, 2.2 m^2 in Utrecht, and more than 3.5 m^2 in Malmö.

These different starting conditions affect the potential for NBS implementation simulated in the scenarios. The land cover changes amount to different shares of the city area, ranging from around 1% of the *ParkingAreas* and *StreetTrees* scenarios, to more than 10 % of the *GreenDream* (Table 2). Due to its density, Barcelona outclasses the other case study cities in the *GreenRoofs* scenario, which simulates the conversion of more than 10 % of the city area, even if the share of built-up area involved is the smallest across the cities. On the contrary, the changes induced by the de-sealing in the *ParkingAreas* scenario are the greatest in Malmö (around 160 ha), even if the percentage change is higher in Utrecht (1.16 % of the city area). Enhancing vegetation in existing urban parks – as simulated in the *Parks* scenario - leads to a land cover change involving from around 2%–2.5% of the city area in all three cities. The increase in tree cover and the decrease in the share of impervious surfaces over the city are the greatest in Malmö: +16 % and -4% respectively. In both Malmö and Utrecht, the *Parks* scenario produces a reduction in the share of low vegetation in favor of tree cover, while in Barcelona the area of low vegetation increases too, but the increase in tree cover is less pronounced. Malmö also shows the highest potential for street trees: here the *StreetTrees* scenario resulted in the addition of more than 52,000 new trees, around double of those simulated in Utrecht, leading to an increase in tree coverage of more than 12 % compared to the current condition.

Table 2

Key characteristics of the NBS implementation scenarios in the three case study cities. * Trees are the sum of the land cover classes "trees" and "vegetation over water". Change areas for the planting of new trees are calculated considering the canopy cover, since changes on the ground are not visible in the land cover maps.

		City		
Scenario	Indicator	Barcelona	Malmö	Utrecht
–	*City area (ha)*	10,067	15,864	9911
Baseline	tree area (% city area)*	24.7 %	11.7 %	16.2 %
	low vegetation area (% city area)	8.5 %	12.0 %	18.0 %
	impervious area (% city area)	39.6 %	30.4 %	26.7 %
	green roofs (ha; % building area)	9 (0.4 %)	18 (1.3 %)	3 (0.3 %)
GreenRoofs	change area (ha; % city area)	1077 (10.7 %)	816 (5.2 %)	625 (6.3 %)
	green roof (% building area)	43.4 %	61.1 %	52.1 %
ParkingAreas	change area (ha; % city area)	68 (0.7 %)	159 (1.0 %)	115 (1.2 %)
	impervious area change (% existing)	−1.7%	−3.2%	−3.8%
Parks	change area (ha; % city area)	210 (2.1 %)	399 (2.5 %)	229 (2.3 %)
	tree area change (% existing)*	+5.2 %	+16.1 %	+12.1 %
	low vegetation area change (% existing)	+2.4 %	−5.5%	−6.8%
	impervious area change (% existing)	−3.8%	−4.0%	−2.7%
StreetTrees	change area (ha; % city area)	84 (0.8 %)	224 (1.4 %)	113 (1.1 %)
	new street trees (n)	20,170	52,923	26,852
	tree area change (% existing)*	+3.4 %	+12.1 %	+7.1 %
	impervious area change (% existing)	−2.1%	−4.5%	−4.0%
GreenDream	change area (ha; % city area)	1433 (14.2 %)	1588 (10.0 %)	1075 (10.9 %)
	tree area change (% existing)*	+8.5 %	+27.9 %	+19.0 %
	low vegetation area change (% existing)	+1.6 %	−6.4%	−7.9%
	impervious area change (% existing)	−7.3%	−11.5%	−10.3%
	green roof (% building area)	43.4 %	61.1 %	52.1 %

3.2. *What are the expected benefits and co-benefits of NBS implementation?*

The aggregated results per city (Table 3) provide an overview of the benefits and co-benefits of NBS implementation in the different scenarios. Not surprisingly, the *GreenDream* scenario, which combines multiple NBS interventions, is always the best performing. On the contrary, the second-best scenario varies depending on the benefits or co-benefits and, sometimes, on the city. Among the scenarios considering a single NBS type, the *Parks* scenario outclasses the others in enhancing heat mitigation in all three cities, while the *GreenRoofs* scenario provides the best performance in terms of runoff reduction and biodiversity potential.

The same pattern does not emerge for the other co-benefits, for which the second most favourable scenario depends on the city. In Barcelona, the greatest increase in carbon storage compared to the *Baseline* scenario is realized by implementing the *GreenRoofs* scenario, while in Utrecht the greatest improvements are obtained from the *Parks*

Table 3
Overview of the benefits and co-benefits of the six NBS implementation scenarios across the three case study cities (average values of the indicator across the city and standard deviation).

City	Scenario	NBS benefits and co-benefits – average values and standard deviation				
		Heat mitigation (-)	Runoff reduction (%)	Carbon storage (ton/ha)	Biodiversity potential (-)	Overall greenness (-)
Barcelona	*Baseline*	0.309 (± 0.257)	50.18 (± 33.71)	87 (± 107.8)	0.36 (± 0.33)	35.48 (± 28.81)
	GreenRoofs	0.309 (± 0.257)	55.67 (± 33.47)	93 (± 104.6)	0.55 (± 0.35)	35.48 (± 28.81)
	ParkingAreas	0.309 (± 0.257)	50.39 (± 33.65)	87 (± 107.8)	0.36 (± 0.33)	35.46 (± 28.81)
	Parks	0.319 (± 0.260)	51.24 (± 34.07)	91 (± 108.3)	0.38 (± 0.35)	36.98 (± 28.54)
	StreetTrees	0.314 (± 0.254)	50.76 (± 33.90)	90 (± 107.7)	0.37 (± 0.33)	36.29 (± 28.54)
	GreenDream	0.324 (± 0.257)	57.49 (± 33.61)	98 (± 105.9)	0.59 (± 0.36)	37.72 (± 28.26)
Malmö	*Baseline*	0.185 (± 0.131)	58.34 (± 29.24)	67 (± 99.9)	0.60 (± 0.36)	60.91 (± 27.57)
	GreenRoofs	0.186 (± 0.131)	61.18 (± 28.62)	70 (± 98.7)	0.72 (± 0.36)	60.91 (± 27.57)
	ParkingAreas	0.185 (± 0.131)	58.71 (± 29.06)	67 (± 99.8)	0.61 (± 0.36)	60.88 (± 27.58)
	Parks	0.198 (± 0.150)	59.23 (± 29.34)	70 (± 104.9)	0.62 (± 0.38)	62.11 (± 27.04)
	StreetTrees	0.196 (± 0.130)	59.32 (± 29.34)	70 (± 103.6)	0.65 (± 0.35)	62.26 (± 26.33)
	GreenDream	0.210 (± 0.146)	63.37 (± 28.37)	77 (± 107.6)	0.80 (± 0.36)	63.40 (± 25.84)
Utrecht	*Baseline*	0.247 (± 0.144)	58.53 (± 32.14)	113 (± 131.2)	0.63 (± 0.38)	61.02 (± 23.69)
	GreenRoofs	0.249 (± 0.143)	62.02 (± 31.42)	116 (± 129.1)	0.79 (± 0.38)	61.02 (± 23.69)
	ParkingAreas	0.247 (± 0.144)	58.91 (± 31.95)	113 (± 131.2)	0.63 (± 0.38)	60.88 (± 23.72)
	Parks	0.259 (± 0.157)	59.06 (± 32.20)	117 (± 134.8)	0.64 (± 0.39)	61.74 (± 23.60)
	StreetTrees	0.255 (± 0.140)	59.31 (± 32.22)	116 (± 133.1)	0.66 (± 0.37)	62.10 (± 22.90)
	GreenDream	0.269 (± 0.151)	63.70 (± 31.16)	124 (± 135.1)	0.85 (± 0.37)	62.65 (± 22.82)

scenario. *GreenRoofs* and *Parks* scenarios produce almost equal results in Malmö, and very similar to those produced by the *StreetTrees* scenario. Regarding overall greenness, the maximum increase from the implementation of a single NBS type is generated by the *StreetTrees* scenario in Utrecht and Malmö, and by the *Parks* scenario in Barcelona.

The comparison also reveals aspects in which certain scenarios are ineffective. For example, the *ParkingAreas* scenario generates only little benefits in terms of runoff reduction, a small reduction in the overall greenness (due to the fact that existing patches of grass and roadside vegetation inside the parking areas are overridden by the new land use), and negligible improvements in all the other indicators. The *GreenRoofs* scenario affects neither heat mitigation nor overall greenness. Instead, the positive effects of *Parks* and *StreetTrees* scenarios are evident across the whole range of analysed benefits and co-benefits.

3.3. How does the urban form affect potential and benefits of NBS?

By breaking down the results by land use class, we can gain some insights on the effect of the urban structure on the variables considered in the study. The changes simulated in the scenarios are not equally distributed across land use classes, i.e. different land use classes show a different potential to integrate NBS (Fig. 3). In all the three cities, that of industrial and commercial areas is the land use class contributing the most to the *GreenRoof* and the *ParkingAreas* scenarios. Even though this land use class covers just around 20 % of the urbanized areas, more than half of the surfaces that can be converted to green roofs and permeable parking areas are located there (with the only exception of potential green roofs in Barcelona, where industrial and commercial areas contribute for slightly more than 40 %). Other land use classes with a significant potential to integrate green roofs are residential areas, particularly continuous and discontinuous high density urban fabric in Barcelona and Utrecht, and discontinuous medium and low density urban fabric in Malmö.

The *Parks* scenario involves mostly the land use class of urban green areas and partly (less than 10 % of the changes) sport and leisure facilities. Only in Barcelona there is a non-negligible potential of residential as well as industrial and commercial areas, due to the diffused presence of “pocket parks”, too small to be classified in a separate Urban Atlas land use class. The *StreetTrees* scenario is the one producing the most distributed changes, which affect mainly residential areas. Among them, in Utrecht there is a predominant role of continuous urban fabric, while in Barcelona the discontinuous high density urban fabric has a more relevant role compared to the share of urban area that it covers. Industrial and commercial areas also show a certain potential to integrate new street trees (more than 25 % in Malmö and Utrecht, and more than 35 % in Barcelona).

By looking at how the benefits and co-benefits from existing green infrastructure (Fig. 4) and the improvements produced by the NBS implementation scenarios (Figs. 5–7) are distributed across the different land use classes, it is possible to draw some reflections about their capacity to meet the existing needs. The greatest improvements compared to the *Baseline* not always correspond to land use classes where the current benefits are comparatively lower. Focusing on residential classes and on the *GreenDream* scenario, this is true for example for runoff reduction and biodiversity potential in Barcelona (Fig. 5), and for carbon storage and overall greenness in Malmö (Fig. 6). However, in most cases, the improvements do not match with the differences in the current levels of benefits that characterize the different land use classes.

Another aspect that emerges by comparing the improvements produced by different scenarios in the same land use class (Figs. 5–7) is that, while for most of the classes and benefits the best scenario is the same identified for the whole city (Table 2), this is not always the case. For example, both heat mitigation and overall greenness in Utrecht’s denser residential areas (classes 11100 and 11210) show a greater increase in the *StreetTrees* than in the *Parks* scenario, but for the less dense classes (11220, 11230, and 11240) it is the other way round (Fig. 7).

4. Discussion

In this study, we developed scenarios to simulate a full-scale implementation of NBS for climate-change adaptation and to assess the expected benefits and co-benefits in three selected European cities. Scenarios are useful tools to visualize possible futures and to assess the associated trade-offs (EEA, 2009). Our scenarios are spatially explicit representations of hypothetical strategies to scale up NBS. As such, they can be defined as *explorative*(Börjeson et al., 2006). However, they consider the constraints to NBS implementation determined by space availability and technical feasibility, and do not involve any modification of current land uses, existing buildings, and transport infrastructures. A comparison with existing policies demonstrates that our scenarios can be considered extreme, but not unfeasible. For example, the almost 53,000 new street trees simulated in Malmö are comparable with the 220,000 street trees included in the MillionTrees Initiative in New York City (Lin and Wang, 2021). The *ParkingAreas* scenario resulting in depaving almost 4 % of the current sealed surfaces in Utrecht is well below the target of a 10 % reduction of impervious

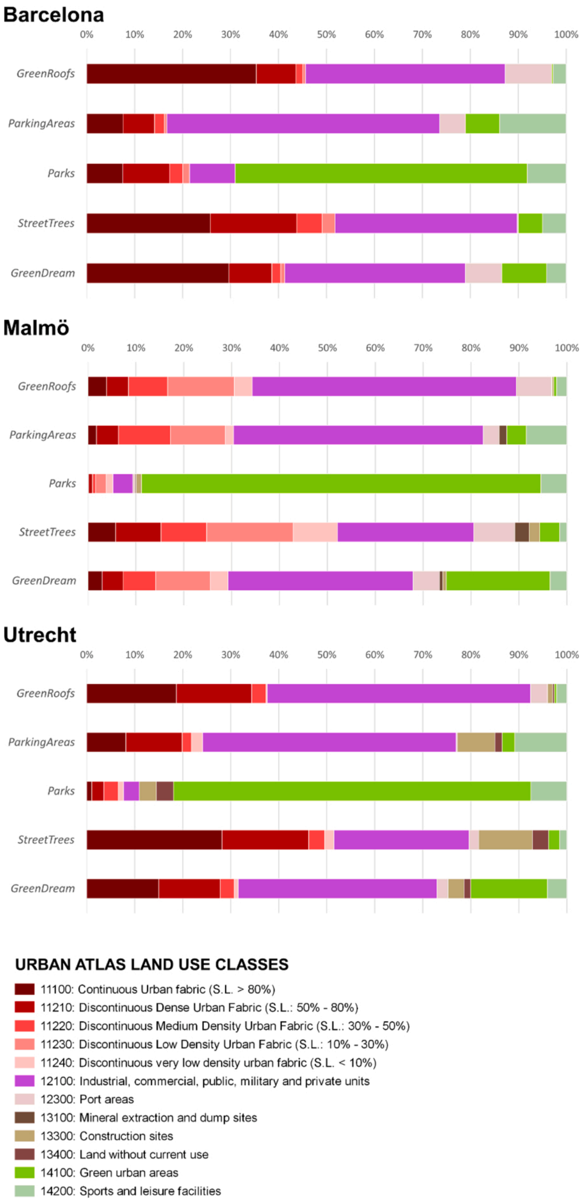

Fig. 3. Share of the total land cover changes simulated in the scenarios corresponding to each Urban Atlas land use class. Land use classes corresponding to less than 2% to the changes in all scenarios are not shown.

surfaces recently set by the Dutch city of Arnhem (The Guardian, 2020a). The share of roofs converted to green and the resulting per-capita area of green roof are, for all cities, much higher than the one recorded so far in the literature (Dong et al., 2020), but in line with what is being discussed in Utrecht where, under the motto “no roof unused”, the city wants to convert every roof either to green or to solar panels (The Guardian, 2020b). Based on these comparisons, we considered the scenarios to be credible simulations of the potential effects of strategies to scale up NBS, hence we used them in a *predictive* perspective (Börjeson et al., 2006) to assess the benefits produced.

Overall, the results of the assessment reveal that most NBS provide multiple benefits. Only the *ParkingAreas* scenario produces, among the analyzed benefits and considering the results at the city scale, improvements limited to runoff reduction. This result is coherent with the literature on NBS in urban contexts (Kabisch et al., 2016; Raymond et al., 2017) and justifies policies supporting NBS implementation to exploit synergies in the provision of urban ecosystem services (European Commission, 2015). Furthermore, the results at the city scale do not show any trade-offs among the analyzed benefits and co-benefits, i.e. cases in which the increase in one benefit produces a reduction in another one. Negative effects on biodiversity potential and greenness were observed only in few cases, at the level of single blocks. This is coherent with a view of NBS as win-win strategies and, more in general, with the scientific literature, which shows limited trade-offs among ecosystem services in cities (Howe et al., 2014). Rather, trade-offs emerge at the decision-making level (Shoemaker et al., 2019), where critical decisions are to be made about which NBS should be prioritized and where. These critical decisions involve both the use of economic resources (through direct investments or incentives) and the use of urban land (Mathey et al., 2015). For example, certain NBS that provide less benefits but coexist with current land uses, as is the case of permeable parking areas, street trees, and green roofs, might be preferred to NBS that provide greater benefits but require a change in land use, such as creating new parks. The latter have been voluntarily excluded from our scenarios.

Looking at the aggregated results, different scenarios show a different potential to address different challenges. Among the scenarios simulating the implementation of a single NBS type, installing green roofs has the greatest potential to reduce runoff and increase biodiversity, while planting more trees -either along streets or in existing urban parks– produces the greatest impact on heat mitigation and greenness. These results are coherent with previous findings indicating the potential role of green roofs in providing multiple ecosystem services, especially in dense urban contexts (Grunwald et al., 2017; Langemeyer et al., 2020), and highlighting the importance of shading as the main component of heat mitigation (Zardo et al., 2017), hence the key role of trees in controlling the urban microclimate (Norton et al., 2015; Pataki et al., 2021). However, to fully understand the implications of these aggregated results, it must be considered that they are the combination of two factors: i) the amount of changes simulated in each scenario, i.e. the potential for scaling up the selected NBS type in the specific context; and ii) the efficiency of each solution, i.e. its capacity to deliver the wanted benefits under specific conditions.

Regarding the potential for scaling up different NBS types, the *GreenRoofs* scenario is the one involving the largest portion of the city area in all case studies. If on the one hand this highlights the role of green roofs as key opportunities to increase green spaces within urbanized areas, on the other hand it confirms that the lack of space is a critical factor for NBS implementation in cities. The fact that the other three scenarios focusing on a single NBS type generate greater changes in Malmö and Utrecht than in Barcelona suggests that less dense cities offer more opportunities for integrating NBS, especially those requiring space on the ground. Within these general trends, each city is then characterized by specific conditions that affect its potential for scaling up NBS. For example, in Malmö the greater increase of tree cover in the *Parks* scenario is due to a lower presence of trees in urban parks compared to the other cities, while the relatively scarcer possibilities to plant street trees in Barcelona are due to the already diffused presence of tree-lined streets (Baró et al., 2019), not so common in the two other cities.

In all case studies, the area converted into green roofs is twice the area of new tree cover added in existing parks and at least three times the area covered by new street trees. If these differences in the area of change are taken into account in an attempt to assess the unit-area efficiency of different NBS types, the ranking of the scenarios changes quite dramatically. It should be noted here that a simple calculation of the average efficiency as the total impact of the scenario divided by the area involved is not meaningful for some of the analyzed benefits, since their provision is characterized by non-linearities (e.g., heat mitigation depends, among others, on the cooling effect of large green areas in the surroundings (Cao et al., 2010), while the index of biodiversity potential is affected by the share of all land cover types in the analyzed areas (Radford and James, 2013)). Focusing just on those benefits that depend linearly on NBS area, street trees are more efficient than green roofs in

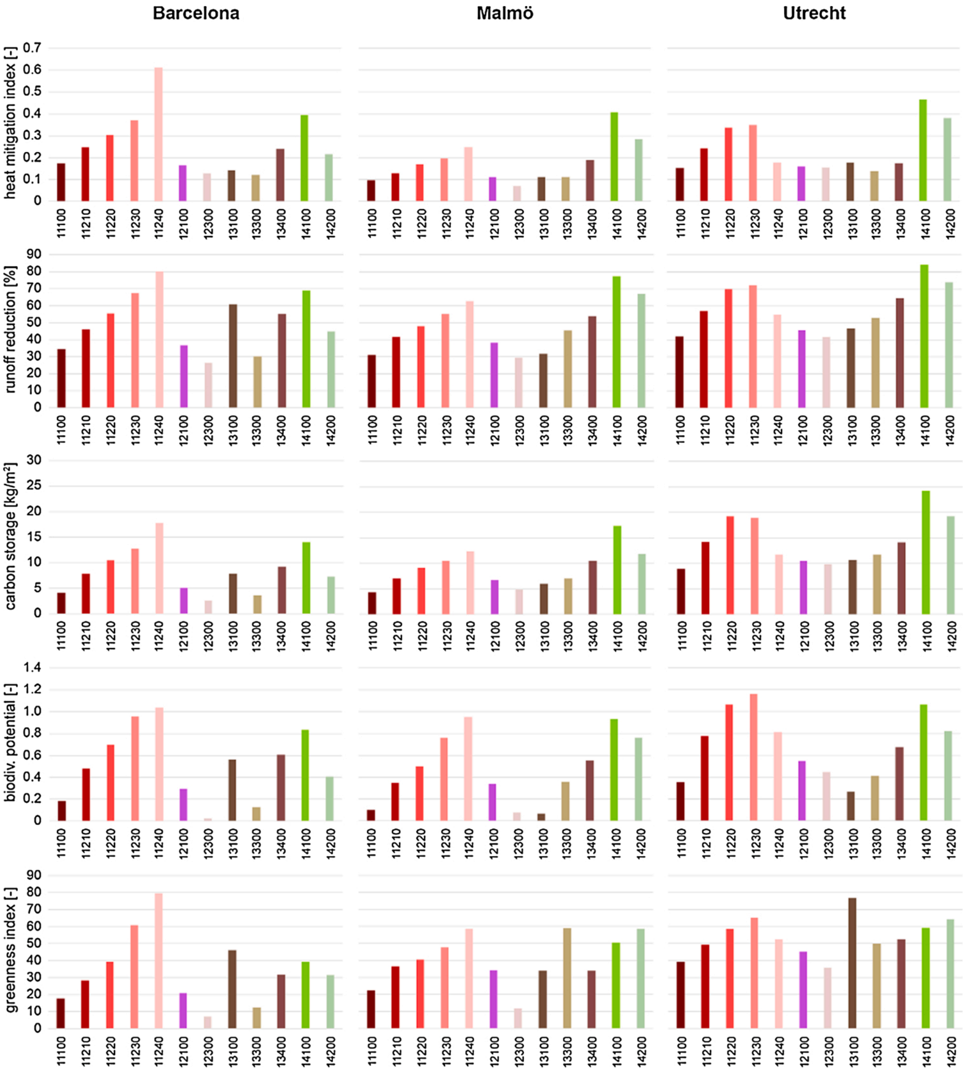

Fig. 4. Average values of the benefits and co-benefits indicators for each Urban Atlas land use class in the Baseline scenario. For the standard colour legend and codes of Urban Atlas land use classes, please refer to Fig. 3.

providing runoff reduction, and both street trees and improvements in park vegetation are more efficient in enhancing carbon storage. If we look at the aggregated results and disregard other aspects such as cost and ease of implementation, considering that green roofs have no effect on greenness and limited capacity for heat mitigation, planting trees appears as the best single strategy to provide multiple benefits.

Breaking down the results by land use classes helps to investigate how the changes simulated in the scenarios and related benefits are distributed across the city, and unveils the potential related to specific urban structures. Despite not being based on a strictly morphological characterization, the Urban Atlas land use classes differentiate between residential areas of varying density levels, and include separate classes normally characterized by different shares of built-up areas and open spaces, different building heights and volumes, and different prevalent types of green areas. Also from this perspective, the *StreetTrees* scenario is the one with the most balanced distribution of NBS that maximizes interventions in residential areas, partly compensating, at least in Malmö and Utrecht, the different benefit levels currently associated with different densities. This “redistributive role” of street trees has already been observed in Barcelona, where their presence is more widespread (Baró et al., 2019). On the other hand, commercial and industrial areas emerge as key opportunity areas for NBS implementation in all scenarios excluding *Parks*. Green roofs, street trees, and permeable surfaces can mitigate, at least partially, the environmental impacts of these areas and contribute to adapting them to climate change. While the link between urban form and environmental impacts is well-known (Alberti, 2005), only recently have some authors started to explore the link between urban form and ecosystem services (Andersson et al., 2020; Grêt-Regamey et al., 2020; Ronchi et al., 2020). The analysis of the potential for NBS implementation adds another knowledge level, which is needed to understand the possibilities to integrate green interventions in existing built-up areas, also in order to ensure the sustainability of densification strategies (Haaland and van den Bosch, 2015).

Compared to average values at the city scale, NBS show much greater impacts at the local scale of single blocks. These mostly affect the areas where NBS are implemented, but – depending on the benefits – can produce measurable effects also on the surroundings (e.g., in terms of heat mitigation and overall greenness). Our assessment grounded on a preliminary detailed classification of land cover allows mapping the distribution of the benefits across the city at high resolution, which opens to the possibility of investigating the results in a perspective of distributional equity (La Rosa and Pappalardo, 2019). By including additional socio-economic data about the distribution of population and vulnerability factors, it would be possible to identify the winners and losers of the simulated interventions (Cortinovis and Geneletti, 2019; Nesbitt et al., 2019), hence to assess the societal impacts of scaling up NBS. Assessing benefits and beneficiaries is fundamental to move from strategic objectives (e.g., planting more street trees) to actions, which

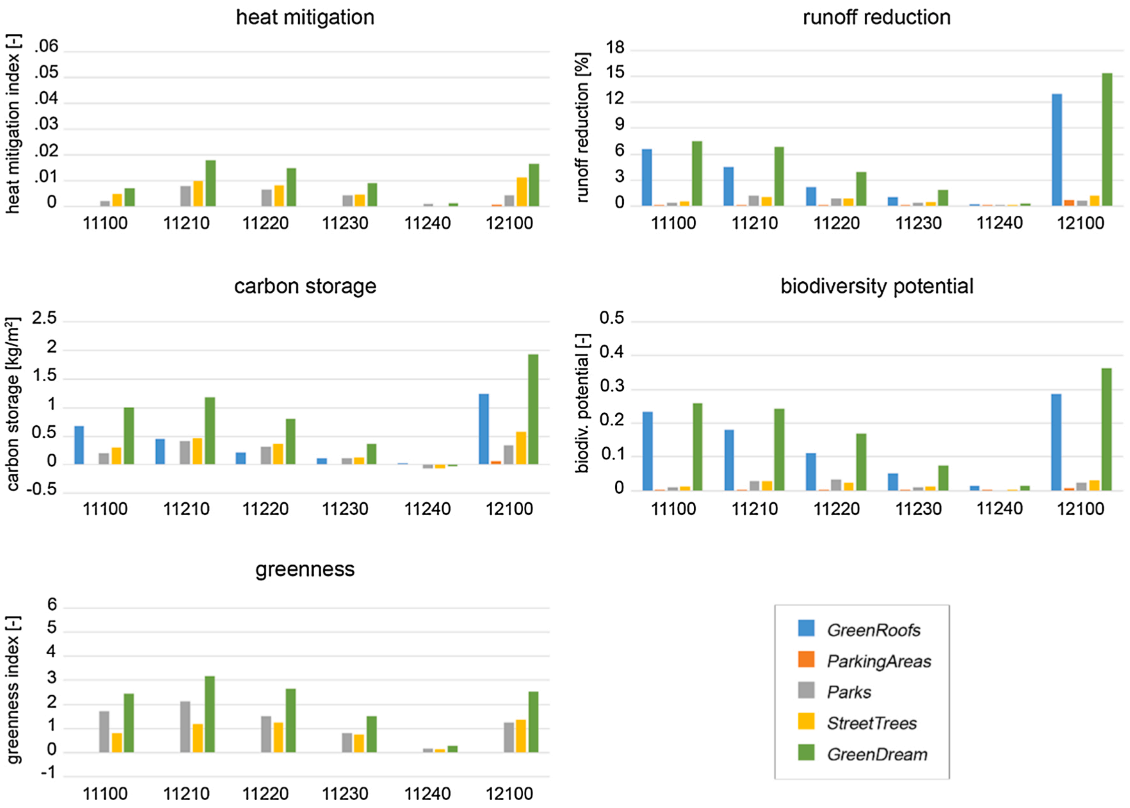

Fig. 5. Average changes in benefits and co-benefits in selected Urban Atlas land use classes (residential plus industrial and commercial) under the five NBS implementation scenarios (compared to the Baseline) in Barcelona. For the standard codes of Urban Atlas land use classes, please refer to Fig. 3. The range of values on the y-axis allows for comparison with Figs. 6 and 7, which show the results for Malmö and Utrecht, respectively.

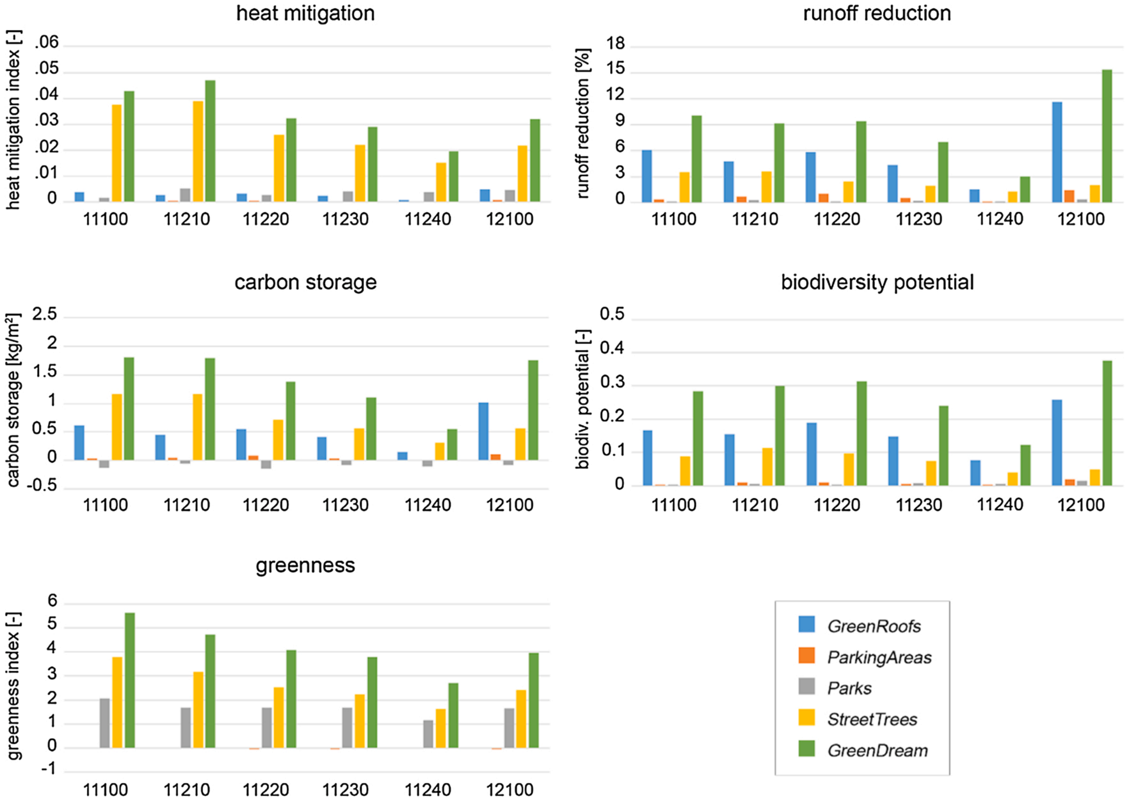

Fig. 6. Average changes in benefits and co-benefits in selected Urban Atlas land use classes (residential plus industrial and commercial) under the five NBS implementation scenarios (compared to the Baseline) in Malmö. For the standard codes of Urban Atlas land use classes, please refer to Fig. 3. The range of values on the y-axis allows for comparison with Figs. 5 and 7, which show the results for Barcelona and Utrecht, respectively.

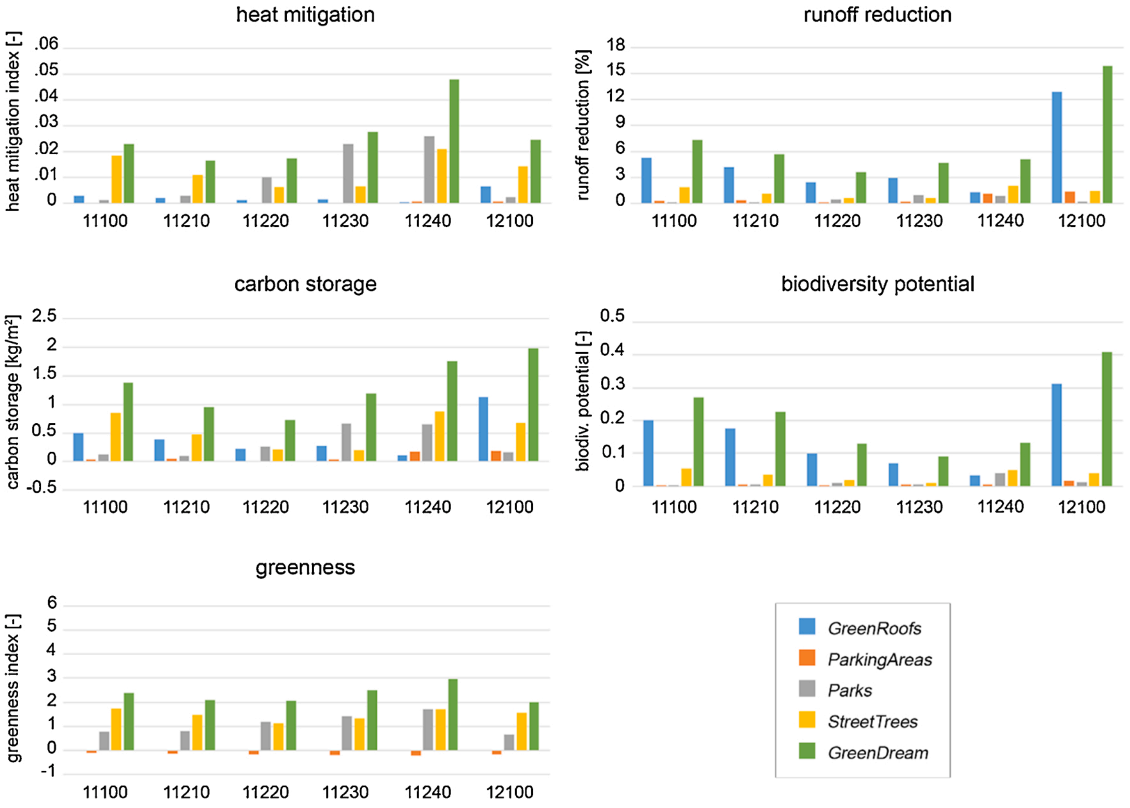

Fig. 7. Average changes in benefits and co-benefits in selected Urban Atlas land use classes (residential plus industrial and commercial) under the five NBS implementation scenarios (compared to the Baseline) in Utrecht. For the standard codes of Urban Atlas land use classes, please refer to Fig. 3. The range of values on the y-axis allows for comparison with Figs. 5 and 6, which show the results for Barcelona and Malmö, respectively.

should reflect priorities of intervention (Venter et al., 2021).

Finally, some limitations must be considered when interpreting the results of our study. It would be too long to discuss the limitations of the single methods adopted to assess benefits and co-benefits, for which we refer to the literature cited in the method section. We just mention here that benefits were modelled under conservative conditions (for example about green roofs by disregarding their water storage capacity in the assessment of runoff and assuming low water availability in the calculation of heat mitigation), hence the expected impacts of NBS implementation could be greater than in our results. The design of the scenarios was limited by both simplistic underlying assumptions and the availability of input data. Among others, we simulated an increase in vegetation only in public areas, despite private green provides valuable opportunities for the integration of NBS, in particular trees (Pincetl, 2015). Depaving was modelled only on parking areas, despite other potentially more relevant opportunities for soil unsealing in brownfields and private gardens (Stobbelaar et al., 2021; Tobias et al., 2018). Moreover, the use of Open Street Map data does not guarantee absolute completeness and homogeneity across cities. Future studies looking at single cities can integrate design parameters of NBS that make them suitable to the specific contexts, apply more refined methods based on local data, and perhaps involve local stakeholders in the identification of opportunities for NBS implementation (see e.g. Langemeyer et al., 2020).

Considering the potential use of the results for policy-making, some important limitations should also be noted. First, the assessment overlooks the temporal dimension and considers that all NBS are implemented and fully functional. Trees are considered as mature trees and vegetation on green roofs as fully developed. While this is coherent with the aim of supporting the definition of policy targets by investigating the full potential of NBS, policy-makers must be aware of the time lag before the expected benefits are experienced, which may be of several years (Kabisch et al., 2016). Second, the analysed benefits and co-benefits do not cover the whole range of potential impacts, which must be acknowledged when comparing the performance of different scenarios in a real-life decision-making context. Particularly, we overlooked ecosystem disservices (von Döhren and Haase, 2015) that could increase under some of our scenarios (e.g., allergenic potential and damage to infrastructure as results of extensive planting interventions). Methods to assess disservices are only partly available and applicable at the urban scale since, besides a more detailed description of the NBS, additional local data to estimate the vulnerability to different hazards are needed for a proper assessment (von Döhren and Haase, 2019). However, a careful design and management of the solutions (e.g., species selection, correct location, maintenance) can usually prevent most of those undesired effects (Tiwary et al., 2016).

5. Conclusions

We assessed the potential for scaling up NBS for climate change adaptation and the expected benefits and co-benefits in three European cities. Overall, the research reveals that the possible effects of scaling up NBS depend on two factors: 1) the existing opportunities to integrate NBS in the urban fabric of the cities, and 2) the capacity of each NBS type to deliver benefits in specific conditions. These two factors, combined, explain why the same scenario performs better in one city compared to another, and in certain areas compared to others with a different urban structure, and should be both considered when formulating policies for NBS implementation.

While a mix of different NBS is recommended to harness local opportunities and ensure a wide range of benefits, scenarios focusing on the implementation of single NBS types revealed strengths and weaknesses of specific NBS implementation strategies. Green roofs hold a great potential to reduce runoff and increase biodiversity in dense urban contexts. However, the results highlight the importance of planting more trees, both along streets and in public green areas, as an efficient strategy to provide a wider range of benefits in a balanced and distributed way. The analysis by land use class also showed the great potential for adapting to climate change industrial and commercial areas, where many people spend much of their daily life.

Assessing the impacts of NBS implementation at the local scale, based on high-resolution data, provides valuable information to urban planners and decision-makers to understand what NBS types and locations should be prioritized to gain the desired benefits. A spatially-explicit assessment can be combined with information about the potential beneficiaries and their vulnerability, in order to prevent undesired local effects and support a fair and equitable distribution of NBS benefits among the urban population. Further research is needed to unveil the social and economic implications of the scenarios, as well as to add to the analysis the temporal dimension, thus investigating non-linearity in the provision of benefits while the scenarios are progressively implemented.

CRediT authorship contribution statement

Chiara Cortinovis: Conceptualization, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Peter Olsson:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – review & editing. **Niklas Boke-Olén:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – review & editing. **Katarina Hedlund:** Conceptualization, Funding acquisition, Investigation, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2021.127450.

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