Assessing the potential of nature-based solutions in European cities for addressing climate change challenges

Clara Veerkamp, Martijn Spoon, Frank van Rijn, Milan Loreti, Ton Dassen, Aafke Schipper (PBL), Niklas Boke-Olén, Chiara Cortinovis, Katarina Hedlund and Peter Olsson (ULUND)

Deliverable 3.7

October, 2020

This project has been funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 730243

Table of Contents

Summary

European citizens are facing a broad range of challenges. Over 70% of Europe's population reside in cities, with an expected growth to more than 80% by the middle of this century (UN 2018, Eurostat, 2020). Next to the ongoing urbanisation process, Europe's cities are expected to face major challenges related to biodiversity loss and climate change, which also exacerbate the negative effects of urbanisation already experienced, including environmental, economic and social consequences. Consequently, cities seek new strategies to deal with these challenges and sustainable development has become a strategic issue for cities in Europe. The implementation of nature-based solutions (NBS) is such a strategy, as NBS are seen to hold significant promise in enabling the urban transition towards sustainability. NBS are defined as solutions that are inspired and supported by nature, are cost-effective, simultaneously provide environmental, social and economic benefits to society, and help to build resilience (EC 2015). Compared to single-purpose, grey infrastructure, NBS typically offer multiple benefits and thus have the potential to address multiple challenges simultaneously (Bulkeley, 2017).

Assessing the value and potential of NBS requires approaches that account for the multiple benefits. Therefore, the NATURVATION project developed the Urban Nature Navigator (UNN) (Dammers et al., 2019), an assessment framework that brings together different kinds of knowledge, integrates the contributions of multiple NBS and assesses the potential of NBS in relation to the goals of urban sustainability. It provides a first glance of possible benefits, trade-offs and synergies using NBS to increase cities' sustainability, as well as provides a database of available methods and indicators to quantify the environmental, social-cultural and economic benefits provided by urban NBS. Among these methods, spatial modeling is a relevant approach to assess the spatial distribution of urban NBS benefits as well potential changes of benefits when NBS are mainstreamed into future urban planning.

In this report, we applied a spatially explicit scenario-based modelling approach to test and assess future spatial explicit implementations of NBS and their benefits provided. Among the many urban sustainability challenges that NBS help to tackle, we focus on challenges related to climate change. More specifically, we aimed to assess the full potential of urban NBS for supporting cities to adapt to and mitigate climate change. We thereby used two different scales: i) European-scale assessment, including all major European urban core areas and their associated hinterlands (i.e. 775 Functional Urban Areas (FUAs); Part A) and ii) more fine-grained city-scale assessment, including three selected case studies (i.e. Malmö, Barcelona, Utrecht; Part B).

In both assessments, we mapped the current situation of the cities and developed several scenarios, differing in their amount and location of urban NBS (e.g., placing additional green roofs on buildings, planting additional trees along streets or creating new green areas). To that end, the European-scale assessment developed a reference scenario, representing the current situation, a green scenario, where additional trees and green

areas are placed, and a grey scenario, where trees and urban green spaces are removed from the city. At the city scale, we develop six more detailed scenarios, including the current condition, the implementation of four different NBS (i.e., green roofs, parks, street trees, permeable parking areas), and a combination of them.

To assess the contribution of urban NBS to address climate change under these different scenarios, we quantified NBS' potential to i) mitigate heat during a heatwave, ii) store carbon, and to iii) retain water runoff during a rainfall event (Bolund and Hunhammar, 1999, Gómez-Baggethun and Barton, 2013, Haase et al., 2014). To that end we used the InVEST modelling framework (Sharp et al., 2020). Moreover, we quantified additional benefits of urban NBS, including iv) recreation opportunities, v) availability of green space to support health and well-being, and vi) biodiversity potential (Table 1). This provides additional insights into co-benefits of NBS for climate change adaptation and mitigation. The city-scale assessment quantified additional benefits of urban NBS by developing and applying additional GIS-based models (Table 1).

Table 1: Overview of the modelled NBS benefits and assessment tools used by the two assessments. For details on the NBS benefits and methods applied, see Part A (European-scale assessment) and Part B (city-scale assessment).

NBS benefits	Assessment tools	Scale(s)	Indicator (unit)
Heat mitigation	InVEST Urban Cooling Model	Europe: 775 FUA Case studies: Barcelona, Malmö, Utrecht	Heat mitigation index (0 - 1)
Carbon storage	InVEST Carbon Storage and Sequestration model	Europe: 775 FUA Case studies: Barcelona, Malmö, Utrecht	Carbon storage potential (ton C/ha)
Runoff retention	InVEST Urban Flood Risk Mitigation model	Case studies: Barcelona, Malmö, Utrecht	Water infiltration capability (% of a 20, mm rain event)
Biodiversity potential	Shannon-Weaver biodiversity model of habitat complexity and area	Case studies: Barcelona, Malmö, Utrecht	Biodiversity Index (0 - 1)
Recreation opportunities	GIS / network analysis	Case studies: Barcelona, Malmö, Utrecht	Residents' accessibility to parks (meters)
Health and well-being benefits	GIS buffer and area content analysis	Case studies: Barcelona, Malmö, Utrecht	Fraction of green within a 500 meter radius (%)

Model outcomes include high-resolution spatial maps for the 775 Functional Urban Areas (FUAs) representing urban core areas and their associated hinterlands; and three selected cities, which can be downloaded from the NATURVATION website (see Figure 1 and Figure 2 for an example). The maps show the spatial distribution of the NBS benefits per FUA/city, under different scenarios. By comparing the different outcomes between FUAs/cities or/and scenarios, possible changes in benefit provision as well as synergies and trade-offs between benefits and/or NBS types implemented can be explored.

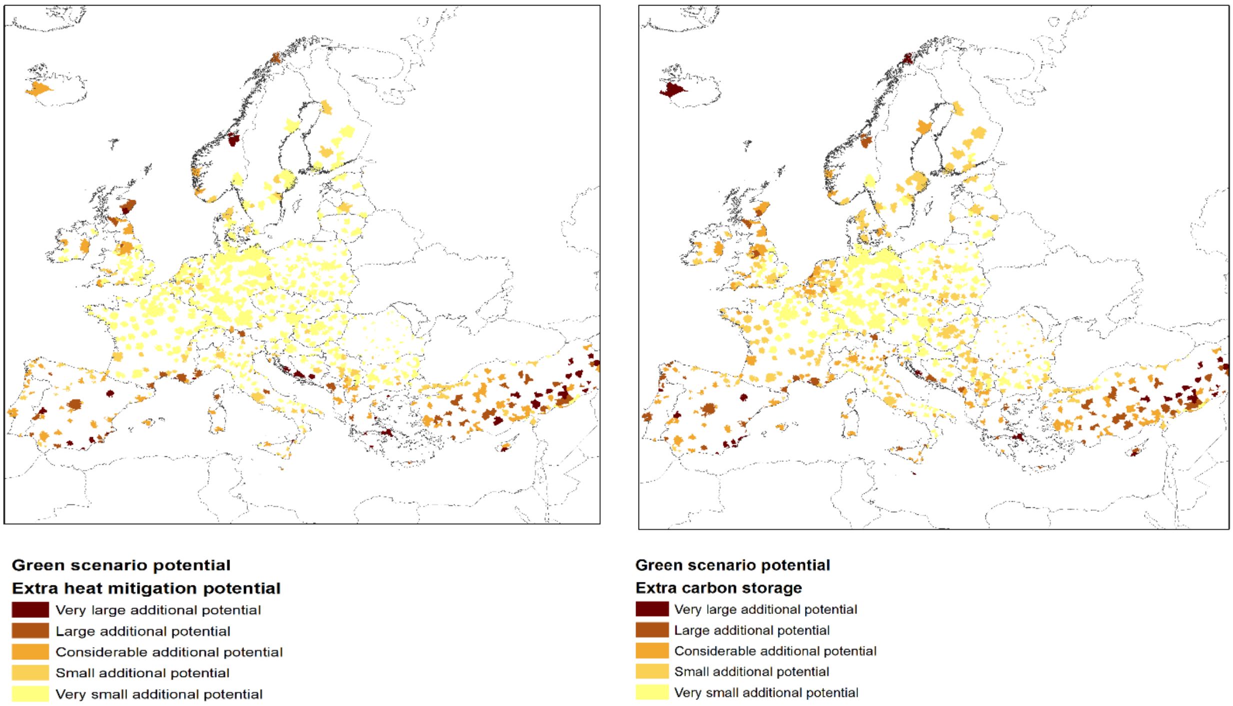

Figure 1: Change in heat mitigation (left figure) and carbon storage (right figure) potential when implement additional urban NBS in the 775 FUAs, compared to the current situation (as presented in Part A of this report). (Legend: very low additional potential: 5%; small additional potential: 5-10%, considerable additional potential: 10-20%, large additional potential: 20-30%, very large additional potential: >30%).

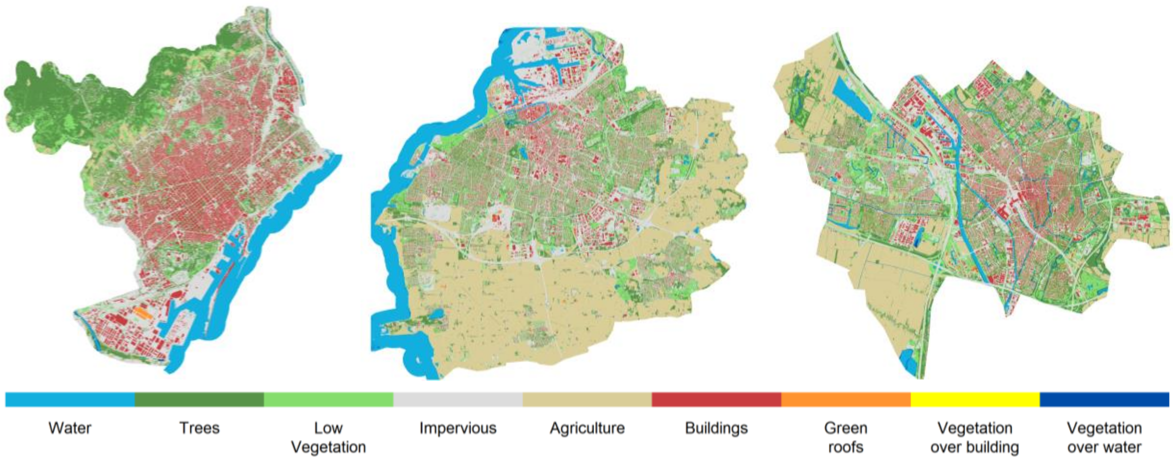

Figure 2: High-resolution current land cover of the three case study cities (as presented in Part B of this report). ***left:*** *Barcelona,* ***centre:*** *Malmö,* ***right:*** *Utrecht.*

Based on the results of the two assessments, we conclude the following:

- The average heat mitigation (HM) index across the 775 FUAs is 0.37 which corresponds with an average reduction of the Urban Heat Island (UHI) effect by 0.94°C during the hottest day in July 2016.
- On average, 8,759 Mg carbon per km^2 is currently stored across the 775 European FUAs.
- Removing most trees and larger green areas from the 775 cities would reduce the heat mitigation by 46% and carbon storage by 45%. In contrast, planting additional trees and creating new green areas would increase the HM potential by 22% and carbon storage potential by 9% on average.
- The implementation of additional urban NBS has greatest potential in Southern Europe, Northern UK, West Balkan and Turkey, while we estimated the lowest additional potential of NBS implementation in central Europe (Figure 1).
- For the three selected cities, compared to the current condition, the full NBS implementation scenario increases the average heat mitigation index by 0.2 on a hot summer day (corresponding to an average temperature reduction of around 0.2 °C), increases carbon storage potential in a range between 2.8 and 7.4 tons/ha, and prevents an additional 5% of a 20 mm rain event to become runoff on average for all three cities (e.g., runoff retention increases from around 50% to 56% in Barcelona).
- Co-benefits related to biodiversity potential, access to urban parks, and overall greenness are also consistently observed at the city scale, with only trade-offs between climate change-related benefits and co-benefits emerging at the local level (single blocks).
- Overall, the city-scale analysis reveals synergies among the three climate-related benefits, and in most cases also with the considered co-benefits. No trade-offs emerge between the overall benefits at the city scale.
- The single most effective NBS type at the city scale varies depending on the considered benefit and city. Adding green roofs provides the greatest benefits in terms of runoff reduction in all three cities, while the highest impact on heat mitigation and carbon storage is achieved either by enhancing urban parks, by planting street trees, or by implementing green roofs (see Part B for details on the scenarios).
- The results reveal that the full potential of NBS at the city scale depends on two factors: 1) the existing possibilities of integrating NBS in the urban fabric of the cities, and 2) the capacity of the solution itself to deliver the selected benefits in certain conditions.
- 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, accessibility to urban parks, and greenness).
- The different effectiveness of NBS types in providing different benefits suggests that, when addressing climate change adaptation and mitigation in urban contexts, trade-offs tend to emerge not among

benefits, but among priorities at the decision-making level. Prioritising a specific NBS type above another implies providing a specific set of benefits and co-benefits.

- Assessing the impacts of NBS implementation at the local scale, based on high-resolution local data, provides valuable information to urban planners and decision-makers to understand what NBS types and locations should be prioritised to gain the desired benefits.
- Assessments at the city scale that shows how the benefits and co-benefits of NBS implementation are distributed within the city can help to prevent undesired local effects and support a fair and equitable distribution of NBS benefits among the urban population.

References

BOLUND, P. & HUNHAMMAR, S. 1999. Ecosystem services in urban areas. *Ecological Economics,* 29**,** 293-301.

BULKELEY, H. 2017. State of the Art Review - NATURVATION Deliverable 1.3

DAMMERS, E., VEERKAMP, C., RUIJS, A., HEDLUND, K., OLSSON, P., ALSTERBERG, C., HANSON, H., LUNDMARK, L., OLSSON, J., PINTER, L., ALMASSY, D., ROCHA, S., WERNER , A., BOCKARJOVA, M. & BULKELEY, H. 2019. Working paper: Set up, applicability and use of the Naturvation Index. *Report to the European commission, deliverable 3.4 of the Naturvation project,* *https://www.naturvation.eu/result/urban-nature-navigator.*

EC (EUROPEAN COMMISSION) 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions and Re-naturing Cities. Final report of the Horizon 2020 Expert Group on ´Nature-Based Solutions and Re-Naturing Cities' (full version). In: EUROPEAN COMMISSION, D.-G. F. R. A. I. D. I. C. A., ENVIONMENT, RESOURCE EFFICIENCY AND RAW MATERIALS (ed.). Luxembourg: Publication Office of the European Union.

EUROSTAT. 2020. *Population and poputlation change statistics* [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics#EU-27_population_continues_to_grow [Accessed 10/15/2020 2020]

GÓMEZ-BAGGETHUN, E. & BARTON, D. N. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics,* 86**,** 235-245.

HAASE, D., LARONDELLE, N., ANDERSSON, E., ARTMANN, M., BORGSTRÖM, S., BREUSTE, J., GOMEZ-BAGGETHUN, E., GREN, Å., HAMSTEAD, Z. & HANSEN, R. 2014. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. *Ambio,* 43**,** 413-433.

SHARP, R., DOUGLASS, J., WOLNY, S., ARKEMA, K., BERNHARDT, J., BIERBOWER, W., CHAUMONT, N., DENU, D., FISHER, D., GLOWINSKI, K., GRIFFIN, R., GUANNEL, G., GUERRY, A., JOHNSON, J., HAMEL, P., KENNEDY, C., KIM, C. K., LACAYO, M., LONSDORF, E., MANDLE, L., ROGERS, L., SILVER, J., TOFT, J., VERUTES, G., VOGL, A. L., WOOD, S. & WYATT, K. 2020. InVEST 3.8.7 User's Guide.

UN (UNITED NATIONS) 2018. World Urbanization Prospects: The 2018 Revision. New York, USA: United Nations, Department of Economic and Social Affairs, Population Division

Part A: Assessing the potential of nature-based solution in European cities to address climate change

Clara Veerkamp, Martijn Spoon, Frank van Rijn, Milan Loreti, Ton Dassen and Aafke Schipper

Deliverable 3.7

October, 2020

This project has been funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 730243

PBL Netherlands Environmental Assessment Agency

List of figures

List of tables

Abbreviations

CC – Cooling capacity

ET – Evapotranspiration

FUA – Functional urban area

HM – Heat mitigation

InVEST - Integrated Valuation of Ecosystem Services and Trade-offs

LULC – Land use and land cover

NBS – Nature-based solutions

TCD – Tree cover density

UHI – Urban heat island

1. Introduction

Climate change presents one of the greatest challenges to society today, with urban areas being most vulnerable to extreme weather conditions when compared to surrounding rural areas (Kovats et al., 2014). Impacts of climate change on urban societies include socio-economic impacts (e.g. health-related effects and damage to building infrastructure) induced by an increased number and intensity of heatwaves, droughts and flooding events (EEA 2020b). For example, a severe heatwave in 2003 led to 70,000 reported heat-attributable deaths across Europe, and since then Europe faced several more heatwaves with new temperature records causing substantial increases in heat-related deaths (Holtanová et al., 2015, Hoy et al., 2017, EEA 2020a). As climate continues to change, the occurrence of extreme weather events will increase in the coming decades (Kovats et al., 2014, Smid et al., 2019, Russo et al., 2015). This calls for adaptation strategies to reduce the adverse impacts of severe weather conditions.

Nature-based solutions (NBS) are increasingly recognised for their potential to address challenges related to climate change (Kabisch et al., 2017, Hobbie and Grimm, 2020, Demuzere et al., 2014). NBS are defined as solutions that are inspired and supported by nature, are cost-effective, simultaneously provide environmental, social and economic benefits to society, and help to build resilience (EC 2015). These benefits can be achieved by the implementation of urban green (e.g. parks, allotment gardens, green roofs) and blue (e.g. ponds, lakes) infrastructures within the urban environment (Veerkamp et al., submitted). Within cities, benefits include, for example, the reduction of temperature during a heatwave, the retention of stormwater during a heavy rainfall event, or the provision of recreation possibilities. Global and European policy frameworks on sustainable development support the uptake and implementation of NBS, which is promoted as an explicit strategy to solve societal challenges such as those related to climate change (e.g. New Urban Agenda – Habitat III, EU Green Deal, EU Biodiversity Strategy; EU Adaptation Strategy) (Davis et al., 2018). Integrating NBS into urban planning and decision-making requires quantitative assessments which quantify the extent to which urban nature provides a solution to relevant challenges. Although, there is a growing body of such assessments (Veerkamp et al., submitted), these typically estimate the effectiveness of urban NBS within a specific location (e.g. city, street). Large-scale quantitative assessments are currently limited (but see Larondelle et al. (2014)).

The aim of this study is to assess the potential of urban NBS in Europe to address two challenges related to climate change, i.e., the need to counteract increased heat stress and the need to mitigate increased atmospheric carbon concentrations. We focus heat stress because it pose severe health risks to people in cities, driven by the local urban heat island (UHI) effect in combination with global warming. Cities frequently experience higher temperature than the surrounding non-urban region because of the UHI effect, which is exacerbated by global warming (EEA 2020b). Urban nature can help to reduce the UHI by providing shade, enhancing cooling through evapotranspiration, and increasing the albedo, thus reducing air temperatures (Bolund and Hunhammar, 1999). In addition, vegetation can lower atmospheric carbon dioxide (CO_2) concentration, by fixing carbon during photosynthesis and storing excess carbon as biomass (e.g. wood) (Nowak and Crane, 2002, Pataki et al., 2006), and thus contributing to reducing global warming. Although urban vegetation is expected to provide only a small contribution to carbon storage compared to total city-based carbon emissions, we include it nevertheless to cover not only adaptation but also mitigation to climate change (Baro et al., 2014, Kabisch et al., 2017). To assess the full potential of NBS in European cities to address climate change, we quantified the heat mitigation potential and carbon storage potential of 775 European cities by applying a scenario-based modelling approach. We used the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) tool (version 3.8.7) (Sharp et al., 2020), which is a leading open-source GIS-based modelling tool for quantifying various ecosystem services. We applied the modules for heat mitigation and carbon storage to three different scenarios that differ in the amount and location of urban nature i.e. i) *reference,* which represents the current situation; ii) *green scenario*, where additional trees and green space are being placed; iii) *grey scenario*, where the amount of green space is reduced and very limited in the cities. This comparative approach enabled us to estimate the actual and potential contribution of urban nature to heat mitigation and carbon storage.

2. Methods and data

2.1 Model description

2.1.1. InVEST urban cooling model

The InVEST urban cooling model is designed to quantify the potential of urban nature to mitigate the UHI by providing shade, increasing cooling through evapotranspiration, and modifying the thermal properties of the urban fabric (albedo effect) (Sharp et al. 2020). The model works with an index of **heat mitigation (HM)**, which is a value between 0-1, representing a low (0) and high (1) mitigation potential.

The HM with a given grid cell *i* is estimated by computing the cooling capacity of the green within that grid cell as well as the additional cooling effect of surrounding larger green areas (>2ha):

$$HM_i = \{CC_i \; if \; CC_i \; \geq CC_{parki} \; or \; GA_i < 2ha; CC_{parki} \; otherwise \qquad \text{[Eq. 1]}$$

Where CC_i is the cooling capacity of grid cell *i* (dimensionless), CC_{parki} is the cooling capacity of surrounding larger green areas on grid cell *i* (dimensionless) and GA_i is the area of green space surrounding grid cell *i* (ha).

Thus, HM equals CC if a grid cell is assumed not to be cooled by surrounding larger green space (i.e. GA_i<2 ha). When the grid cell is part of a larger green area (GA_i >2 ha), HM is set to a distance-weighted average of the CC value of the larger green areas (CC_{park_i}).

The **cooling capacity (CC)** of each grid cell is calculated based on shade, albedo and evapotranspiration (ET):

$$CC_i = 0.6 * shade + 0.2 * albedo + 0.2 * ET \qquad \text{[Eq. 2]}$$

Shade is a value between 0-1, representing the proportion of tree cover of the land use and land cover (LULC) types (0 for no tree; 1 for full tree cover). *Albedo* is a value between 0 and 1, representing the proportion of sunlight directly reflected by the LULC type. The brighter the surface, the more sunlight is reflected and less heat absorbed (e.g. snow has a high albedo value). In the city, dark surfaces such as concrete and pavement generally have a lower albedo than bare or vegetation covered ground, reflecting less and absorbing more sunlight, which results in higher temperatures. *Evapotranspiration (ET)* represents a normalised value of actual evapotranspiration. ET is calculated for each grid cell by multiplying the reference/potential evapotranspiration (ET_0) with a so-called crop coefficient (K_c) which is associated with the LULC type, and dividing by the maximum evapotranspiration value (ET_{max}) of the city to obtain a value between 0 and 1:

$$ET_i = \frac{K_c * ET_0}{ET_{max}} \qquad \text{[Eq. 3]}$$

Then the cooling capacity of larger green areas on each grid cell is assessed by estimating the number (Eq. 4) and area (Eq. 5) of green grid cells within the cooling distance and correcting the cooling capacity of those grid cells that have >2ha of green space around them. Note that the green grid cells do not have to be contiguous; it is the total of green area within the radius that is being summed.

$$CC_{park,i} = \sum_{j\epsilon\, radius\, from\, i} g(j) * CC_j * \exp\left(-\frac{d(i,j)}{d_{cool}}\right) \qquad \text{[Eq. 4]}$$

$$GA_i = cell_{area} * \sum_{j\in d\, radius\, from\, i} g(j) \qquad \text{[Eq. 5]}$$

Where $CC_{park,I}$ is the distance weighted average of the cooling capacity caused by surrounding green grid cells (dimensionless), g(j) is the grid cell *j*, 1 if grid cell is green area, otherwise 0 (dimensionless), CC_j is the cooling capacity of surrounding grid cell (dimensionless), d(i,j) is the distance between grid cell *i* and *j* (meter) (i.e. air blending distance), d_{cool} is the distance over which a green grid cell has a cooling effect (meter) (i.e. cooling distance), GAj is the area of green space surrounding each grid cell (hectares) and $cell_{area}$ is the area of grid cell (hectares). The model summarises heat mitigation potential into raster output maps (HM per grid cell).

2.1.2. InVEST carbon model

Vegetation, such as trees, acts as a sink for CO_2 fixing carbon during photosynthesis and storing excess carbon as biomass (e.g. as wood, roots) (Tang et al., 2016, Nowak and Crane, 2002). But also (urban) soils may hold considerable amounts of organic carbon (Lal, 2008, Edmondson et al., 2014). The InVEST carbon storage model is designed to capture these carbon pools and estimates the amount of carbon stored in the landscape (Mg C/ha), depending on the size of four carbon pools for different land cover types: aboveground biomass, belowground biomass, soil and dead organic matter. The model requires an estimate of the amount of carbon in at least one of these four fundamental carbon pools for each LULC type. The model summarises the total amount of carbon stored into raster output maps (Mg C per grid cell) as well as aggregate totals (Mg C) per area of interest.

2.2. Model parameterisation

2.2.1. Study area and spatially explicit input data

We applied the InVEST modules for heat mitigation and carbon storage to each of the 775 Functional Urban Areas (FUAs), using spatially explicit input data on relevant input variables. A FUA represents a city with more than 100.000 inhabitants including its commuting zone. The 775 FUAs cover the EU28, EFTA countries (i.e. Iceland, Liechtenstein, Norway and Switzerland), West Balkans and Turkey. The basic data requirements per FUA are a map of its extent, a LULC raster map, an excel file containing information on shade, evapotranspiration, albedo, presence of green areas, and carbon pools per each LULC class (i.e. biophysical tables – see section 2.2.2), evapotranspiration and temperature raster maps and tree density cover data (Table A-1 and Figure A-1).

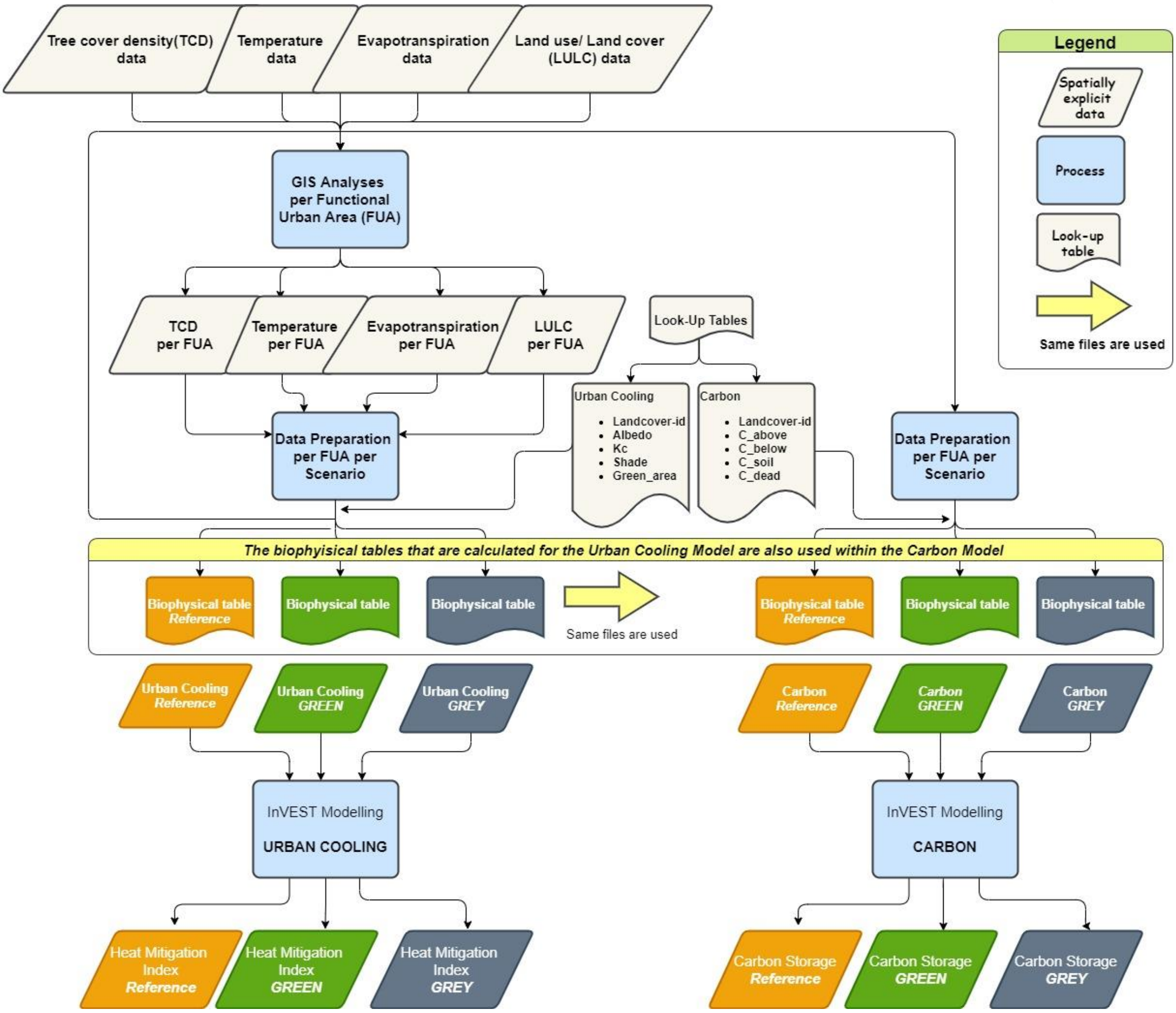

Figure A-1: Overview of GIS-based modelling approach applied in the Europe-wide NBS assessment.

We obtained high-resolution LULC data for the 775 FUAs from the European Urban Atlas. This dataset distinguishes among 27 different LULC classes. We retrieved a raster map of evapotranspiration (ET_0; mm) for the month July 2016 from the Global Aridity Index and Potential Evapotranspiration Climate Database from CGIAR and a raster map for temperature (°C) for the month of July 2016 from the ER15-land dataset from ECMWF (European Centre for Medium-Range Weather Forecasts). We used the evapotranspiration raster also to retrieve the maximum evapotranspiration per FUA (Eq. 3). We obtained tree cover density (TDC) data from the EU Copernicus Land Monitoring Service Portal, representing tree cover in a range from 0-100% per grid cell (Table A-1).

Table A-1: Input data

Data Name	Spatial and temporal resolution	Source
European Urban Atlas LULC	20m x 20m; reference year 2012	https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012?tab=download
Global Aridity Index and Potential Evapotranspiration Climate Database	30 arc-seconds/ 1km at the equator; reference year 2016	https://doi.org/10.6084/m9.figshare.7504448.v1
ERA5-Land dataset	9km x 9km; reference year 2016	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview
Tree Cover Density (TDC)	20m x 20m; reference year 2015	https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/2015?tab=download

2.2.2. Biophysical input tables

The urban cooling model requires values for shade, albedo, crop coefficient, and green areas per LULC type (Table A-1 in Appendix). To estimate the shade value per LULC, we estimated the average tree cover density (TDC, see section 2.2.1) per LULC class per city using zonal statistics of the geographical information system software ArcGIS. Because albedo value of urban fabric tend to vary only little (Trlica et al., 2017, Stewart and Oke, 2012, Taha, 1997), we applied a generic albedo value of 0.15 to all LULC, expect for water, which has generally a much lower albedo (i.e. 0.06) (Stewart and Oke, 2012). We calculated a crop coefficient (Kc) per LULC type as an area-weighted average value based on the composition of each LULC type (i.e. tree, grass, build-up) (Table A-1 in Appendix). To that end, we used the FUA specific proportion of canopy cover (i.e. shade value) and baseline Kc values for certain crops (e.g. trees, turf grass, grass and shrubs) or the soil coefficient for bare soils (Nistor, 2016, Nistor and Porumb, 2015, Allen et al., 1998). In case of agricultural land, water and wetlands, we adopted average Kc values from Allen et al. (1998). To assess the cooling effect of the surrounding larger green areas (Eq. 4), LULC types have to be classified as green area (value of '1') or not (value of '0'),. We counted 'green urban areas' and 'forests' as green areas (Table A-1 in Appendix). We set the cooling distance over which a larger green area (>2ha) may have a cooling effect to 230m (i.e. medium value of Aram et al. (2019)).

The carbon model requires the carbon density of each LULC type, which we retrieved from Bouwer et al. (2018) (Table A-2 in Appendix). Bouwer et al. (2018) provide average carbon pools for various LULC (e.g. agricultural land, grasslands and forests) based on several European studies. To account for the differences in vegetation cover between the various urban LULC types in our study, we assumed no carbon storage in urban fabric (Bouwer et al., 2018) and calculated the carbon pool based on the tree cover (i.e. shade value) per LULC and an assumption on remaining land coverage (e.g. built-up, grassland). For example, if an urban LULC has a shade value of 30%, we calculated the carbon density as 0.3 times the carbon pool value of forest plus 0.7 times the baseline values for the remaining coverage, e.g. in case of an urban fabric class (e.g. 'Continuous urban fabric') we assumed this would be build-up areas (and thus the baseline value is zero), or in case of a urban park ('green urban areas') we assumed the remaining area is covered by grass.

2.3. Scenario implementation

In addition to the current situation, we applied the model to two scenarios that differ in the amount and location of urban nature when compared to the reference situation (see section 2.2.2.): i) *green scenario*, where additional NBS are placed; ii) *grey scenario*, where green spaces are removed from the city. To implement the scenarios, we changed a number of parameters used in the models were relative to the reference situation (Table A-3 to A-6 in Appendix).

2.3.1. Green scenario

In the green scenario, we assumed a large-scale implementation of additional urban nature, including planting extra trees where possible (e.g. within residential areas, along streets, industrial areas), transforming current construction sites into green residential areas and extraction sites into parks (brownfield redevelopment), and placing additional green areas within the cities where possible (e.g. transform unused land into parks). To implement this scenario, we changed the LULC properties compared to the reference (i.e. shade, crop coefficient, green area values) (Table A-3 and Table A-4 in Appendix). We simulated the implementation of additional trees within the city by increasing the shade values per LULC to the 95th percentile of the LULC-specific shade values across all cities. We used the 95th percentile to represent an ambitious but realistic increase in trees. If the reference value of a specific LULC type was higher than the scenario value of that specific LULC, we kept the reference value. In addition, we changed selected LULC classes into 'greener' LULC classes (resulting in changes in shade values, evapotranspiration (via Kc) and carbon densities). We converted 'construction sites' into 'very low urban fabrics' (assuming new green residential areas) and 'land without current use' and 'herbaceous vegetation' into new forest areas, and 'mineral extraction sites' and 'sport fields' into new green urban areas, representing a higher shade values and counted as green area. We assumed agricultural land, wetlands and water areas to remain unchanged. With regard to the albedo effect, we assume no change due to the minimal change in albedo when the canopy cover increases (Trlica et al., 2017).

2.3.2. Grey scenario

In the grey scenario, we assumed that trees, parks and larger green areas are removed from the city, which we implemented by changing relevant LULC properties (i.e. shade, crop coefficient, green area values) compared to the reference (Table A-5 and Table A-6 in Appendix). We translated the removal of trees into decreases of shade values per LULC class. We applied city-specific shade values of 'land without current use' (i.e. areas in the vicinity of artificial surface waiting to be used or re-used, like wasteland) to all green LULC (i.e. green urban areas, forest, sport and leisure facilities) and to all residential and non-residential LULC (e.g. continuous urban fabric, discontinuous urban fabric, isolated structures, industrial, commercial, roads, railway etc). If the reference shade value was lower than the shade value of 'land use without current use' we kept the reference value. Agricultural land, open space and water remained unchanged. The crop coefficient (Kc) and the carbon densities changed in line with the change of the shade values. There are no 'green areas' in this scenario.

2.4. Analysis of the results

Based on the heat mitigation index per grid cell, we estimated an average heat mitigation index per FUA and categorised each FUA based on the average heat mitigation index as i) very low potential (HM < 0.2), ii) low potential (HM 0.2 - 0.4), iii) medium potential (HM 0.4 - 0.6), iv) high potential (HM 0.6 - 0.8) or v) or very high potential (HM ≥ 0.8). In addition, we estimated the potential cooling (°C) of the UHI. To that end, we estimated the UHI for each FUA during the summer heatwave in 2016, when cooling demands are highest, based on the hottest day in July. UHI magnitude is typically measured by the urban – rural temperature difference, but often poorly represent site characteristics (Stewart, 2011), measuring the UHI magnitude as a difference in temperature between different zones within a city have been shown to be more accurate (Stewart and Oke, 2012). Therefore, we estimated the UHI magnitude as the difference between the maximum temperature (presented by the highest value measured within a FUA) and minimum temperature (which represent the lowest value within the FUA). We then estimated the potential cooling (°C) by multiplying the UHI with the HM. For carbon storage, we aggregate the output raster maps with the carbon storage potential (Mg C) per grid cell into the total amount of carbon stored per FUA (Mg C), as well as average carbon densities (Mg C/km^2) per FUA. We then categorised each FUA based on its average carbon density as i) very low (<6,000 Mg C/km^2), ii) low (6,000 – 8,000 Mg C/km^2), iii) medium (8,000 - 10,000 Mg C/km^2), iv) high (10,000 - 12,000 Mg C/km^2) or v) very high (≥12,000 Mg C/km^2).

To assess the additional potential contribution of urban nature, we compared the relative changes in heat mitigation and carbon storage between the reference and green scenario, where very small additional potential (Δ < 5%), small additional potential (Δ 5-10%), medium additional potential (Δ 10-20%), large additional potential (Δ 20-30%) and very large additional potential (Δ >30%).

3. Results

3.1. Heat mitigation potential

The average heat mitigation (HM) index across the 775 FUAs is 0.37, with the highest HM estimated in Umeå (Sweden; HM: 0.80), Savona (Italy; HM: 0.79) and Karabük (Turkey; HM 0.79). Reykjavík (Island), Alicante and Torrevieja (both Spain) have the lowest HM (i.e. 0.10, 0.15 and 0.16 respectively). Overall, 6% of the FUAs have a high HM (>0.8), mainly in Scandinavian cities. The majority of FUAs (57%) have a low HM (<0.2). Especially cities in Western Europe and in Turkey have a rather low HM, while cities in the Baltic countries and in central Europe as well as cities in the western Balkan have a slightly higher index (Figure A-2). An overview of the spatial distribution of HM values per FUA is provided on the NATURVATION website.

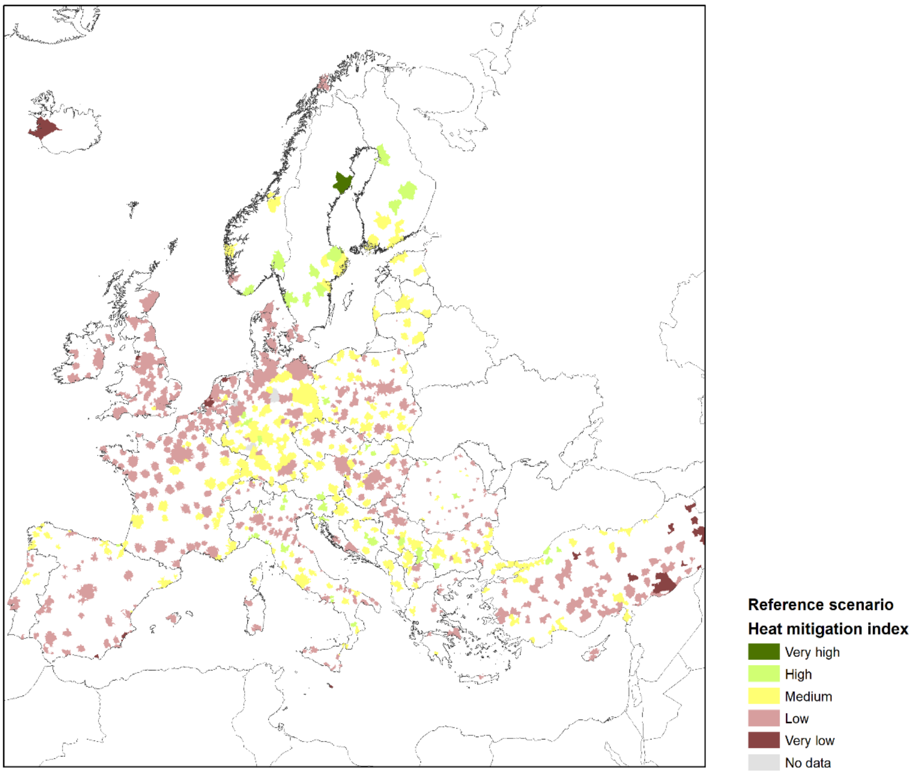

Figure A-2: Heat mitigation index across the 775 FUAs under the reference scenario (i.e. very low (HM < 0.2), ii) low (HM 0.2 - 0.4), iii) medium (HM 0.4 - 0.6), iv) high (HM 0.6 - 0.8) or v) or very high (HM ≥ 0.8)).

Removing trees within the city and thereby decreasing the shade (i.e. the grey scenario), decreases the HM (Figure A-3). Compared to the current situation, the average HM decrease by 46% (i.e. to an average HM of 0.20 across all FUAs) (Figure A-5). In contrast, adding green areas and trees (i.e. the green scenario), increases the HM, and 18% of the FUAs have a high to very high HM index, and 42% of all FUA have a medium HM potential (Figure A-4). Compared to the current situation, the average HM increase by 22% in the green scenario (i.e. to average HM of 0.46 across all FUAs) (Figure A-5). Most prominent increases in additional potentials for heat mitigation are observed in Southern Europe, West Balkan, North England and Turkey (Figure A-6).

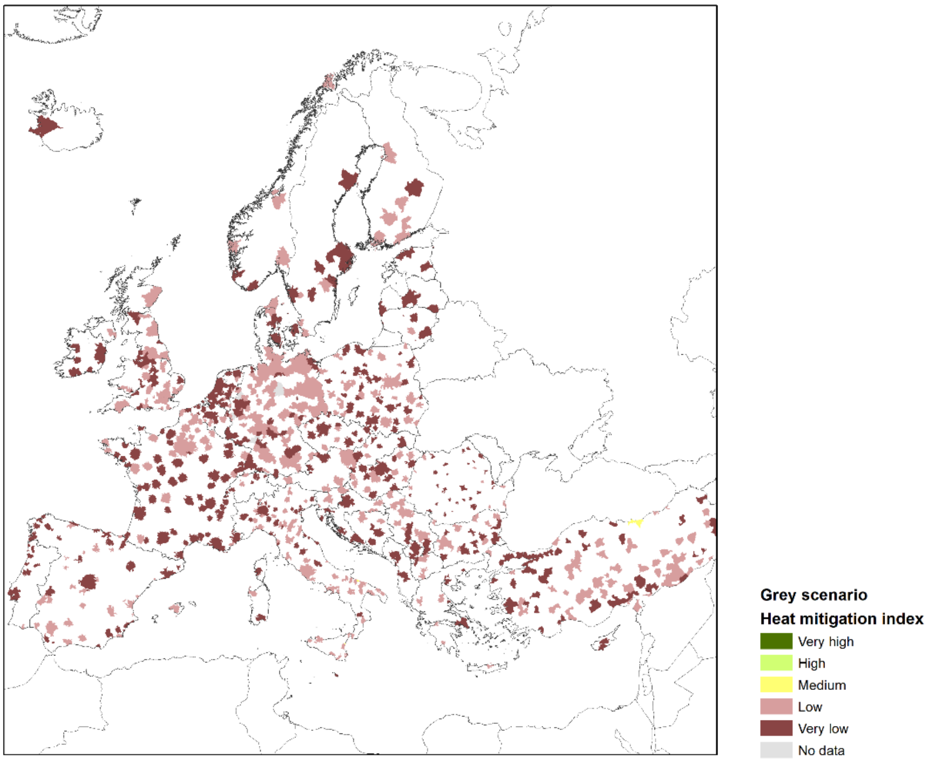

Figure A-3: Heat mitigation index across the 775 FUAs under the grey scenario (i.e. very low (HM < 0.2), ii) low (HM 0.2 - 0.4), iii) medium (HM 0.4 - 0.6), iv) high (HM 0.6 - 0.8) or v) or very high (HM ≥ 0.8)).

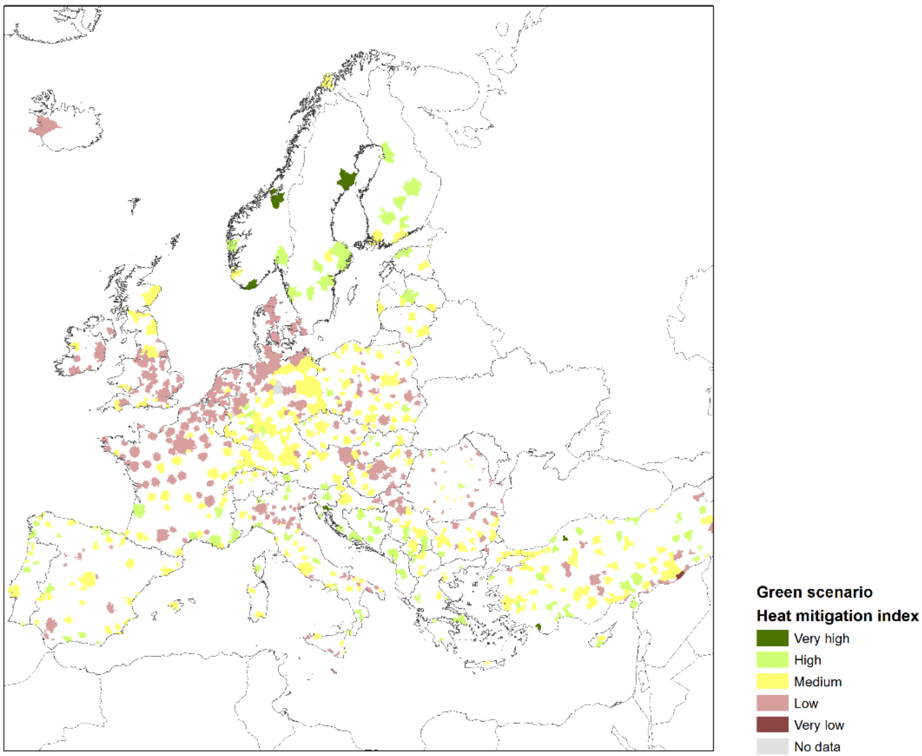

Figure A-4: Heat mitigation index across the 775 FUAs under the green scenario (i.e. very low (HM < 0.2), ii) low (HM 0.2 - 0.4), iii) medium (HM 0.4 - 0.6), iv) high (HM 0.6 - 0.8) or v) or very high (HM ≥ 0.8)).

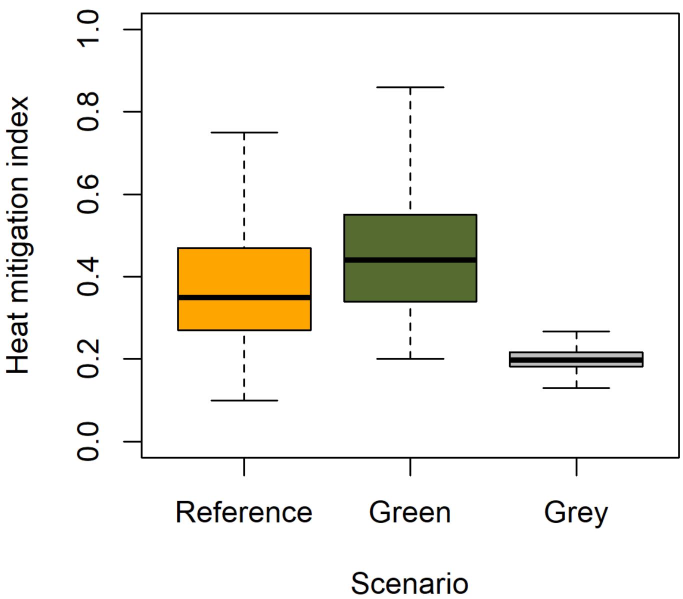

Figure A-5: Heat mitigation across the 775 FUAs under the three different scenarios. Boxplots represent median (black line), interquartile range (boxes) and range (minimum – maximum; whiskers represent the minimum and maximum values within 1.5 times the interquartile range).

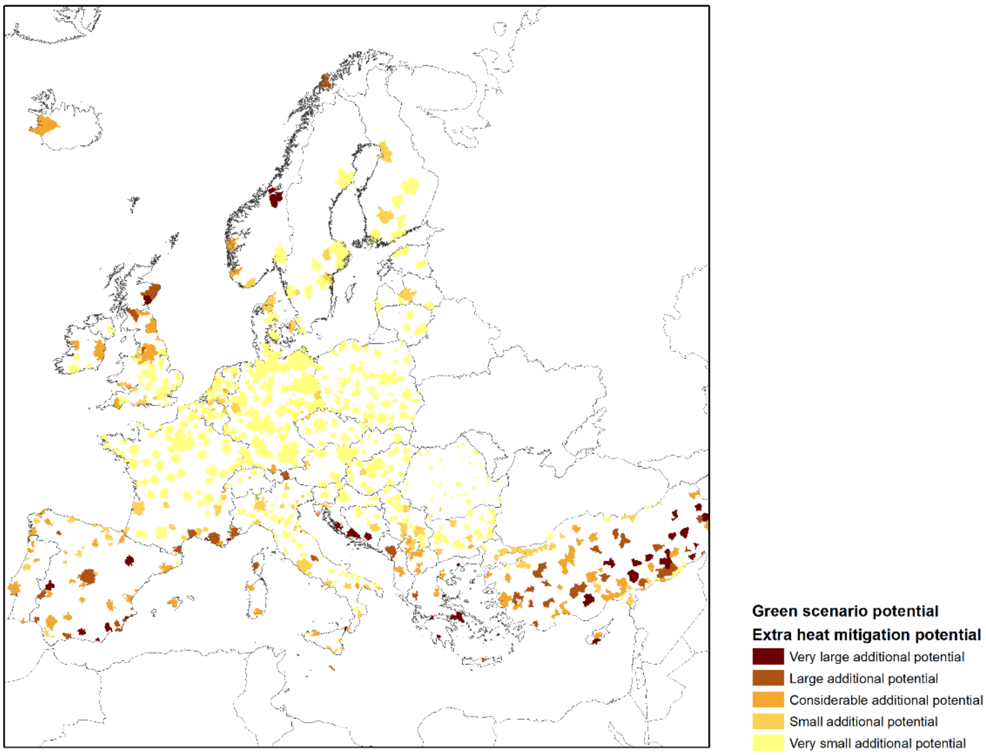

Figure A-6: Change in heat mitigation potential when implement additional urban NBS, compared to the reference (i.e. very low additional potential: 5%; small additional potential: 5-10%, considerable additional potential: 10-20%, large additional potential: 20-30%, very large additional potential: >30%).

The average UHI across the different European cities was 2.59°C for the hottest day in July 2016. With the current amount and location of urban NBS across European cities, this means that the UHI can be reduced by an average of 0.94°C. In the grey scenario, European cities would have been 0.42°C warmer when compared to the current situation (i.e. average cooling of UHI: 0.52°C), while when implementing additional green areas, European cities would have been 0.25°C cooler when compared to current situation (i.e., green scenario, average cooling of UHI: 1.20°C).

3.2. Carbon storage potential

On average across the 775 FUAs we found a carbon storage of 8,759 Mg C/km^2. The highest carbon density is estimated for Savona (Italy, 13,693 Mg C/ km^2), Karabük (Turkey, 13,533 Mg C/km^2) and Banská Bystrica (Slovakia, 13,270 Mg C/km^2). The lowest amount of carbon is stored in Reykjavik (Island, 2,472 Mg C/ km^2), Lelystad (Netherlands, 3,839 Mg C/ km^2) and Torrevieja (Spain, 4,031 Mg C/km^2). The majority of FUAs have a medium (41%) or low (30%) carbon storage. Carbon storage is generally higher in Northern and Eastern Europe when compared to the rest of Europe (Figure A-7).

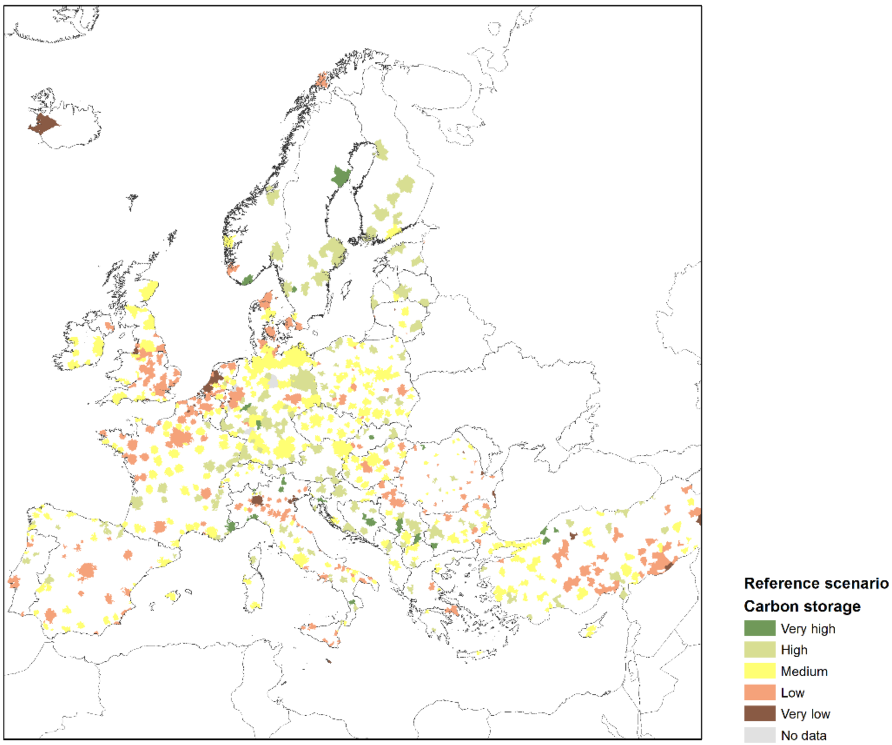

Figure A-7: Average carbon storage across the 775 FUAs under the reference scenario (i.e. very low (<6,000 Mg C/km^2), ii) low (6,000 – 8,000 Mg C/km^2), iii) medium (8,000 - 10,000 Mg C/km^2), iv) high (10,000 - 12,000 Mg C/km^2) or v) very high (≥12,000 Mg C/km^2)).

When removing trees and larger green areas (i.e. grey scenario) the majority of FUAs would have a low (16% of all FUAs) or very low carbon storage (84% of all FUAs) (Figure A-8). On average, the carbon storage is reduced by 45% when compared to the reference situation (i.e. to 4,825 Mg C/ km^2) (Figure A-10).

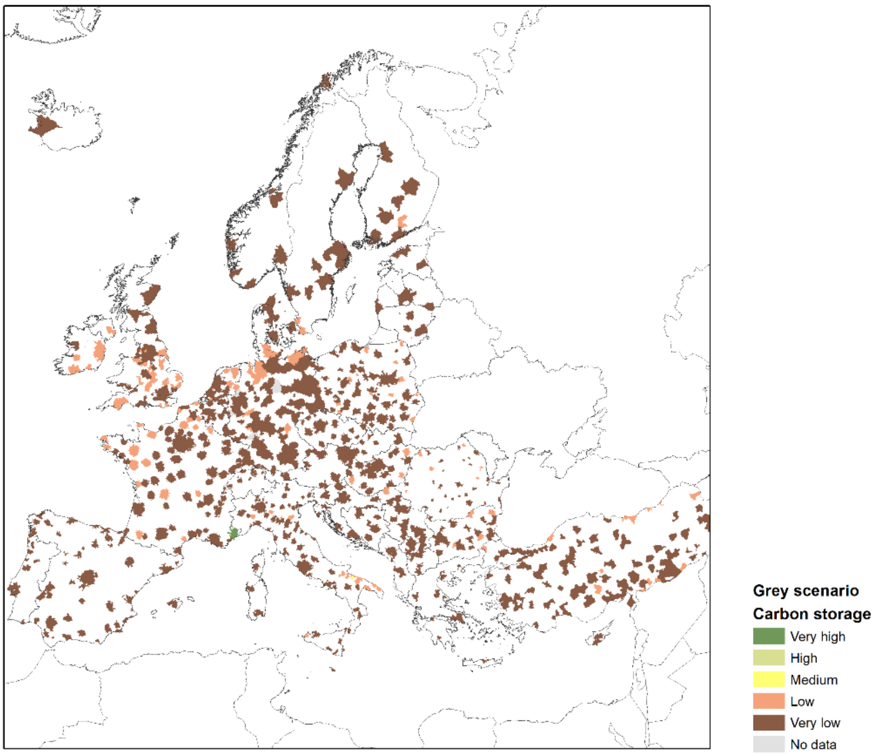

Figure A-8: Average carbon storage across the 775 FUAs under the grey scenario (i.e. very low (<6,000 Mg C/km^2), ii) low (6,000 – 8,000 Mg C/km^2), iii) medium (8,000 - 10,000 Mg C/km^2), iv) high (10,000 - 12,000 Mg C/km^2) or v) very high (≥12,000 Mg C/km^2)).

In contrast, planting additional trees and creating new green areas increase the carbon storage and 42% of the FUAs have a high to very high carbon storage, while only 17% are classified as having a low to very carbon storage potentials (Figure A-9). Compared to the reference scenario, this would mean an increase in carbon storage by 9% (i.e. to 9,635 Mg C/ km^2) (Figure A-10). Most prominent increases in additional potentials for carbon storage are observed in Southern Europe, Croatia, Island and Turkey (Figure A-11).

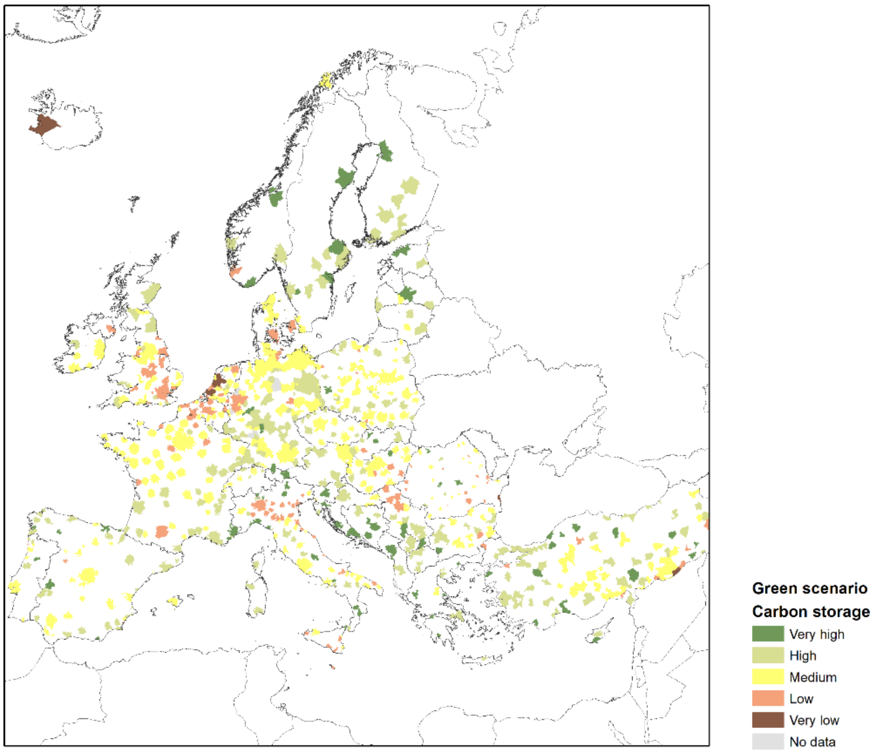

Figure A-9: Average carbon storage across the 775 FUAs under the green scenario (i.e. very low (<6,000 Mg C/km^2), ii) low (6,000 – 8,000 Mg C/km^2), iii) medium (8,000 - 10,000 Mg C/km^2), iv) high (10,000 - 12,000 Mg C/km^2) or v) very high (≥12,000 Mg C/km^2)).

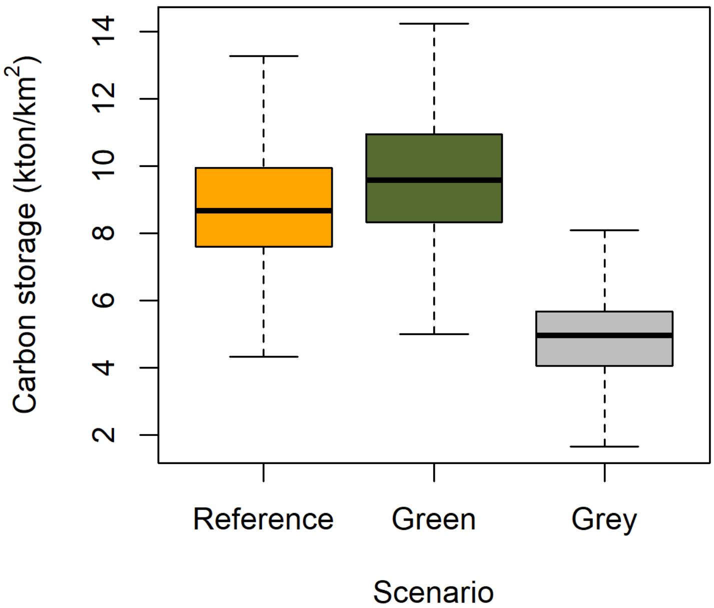

Figure A-10: Carbon storage (kton/km2) across the 775 FUAs under the three different scenarios. Boxplots represent median (black line), interquartile range (boxes) and range (minimum – maximum; whiskers represent the minimum and maximum values within 1.5 times the interquartile range).

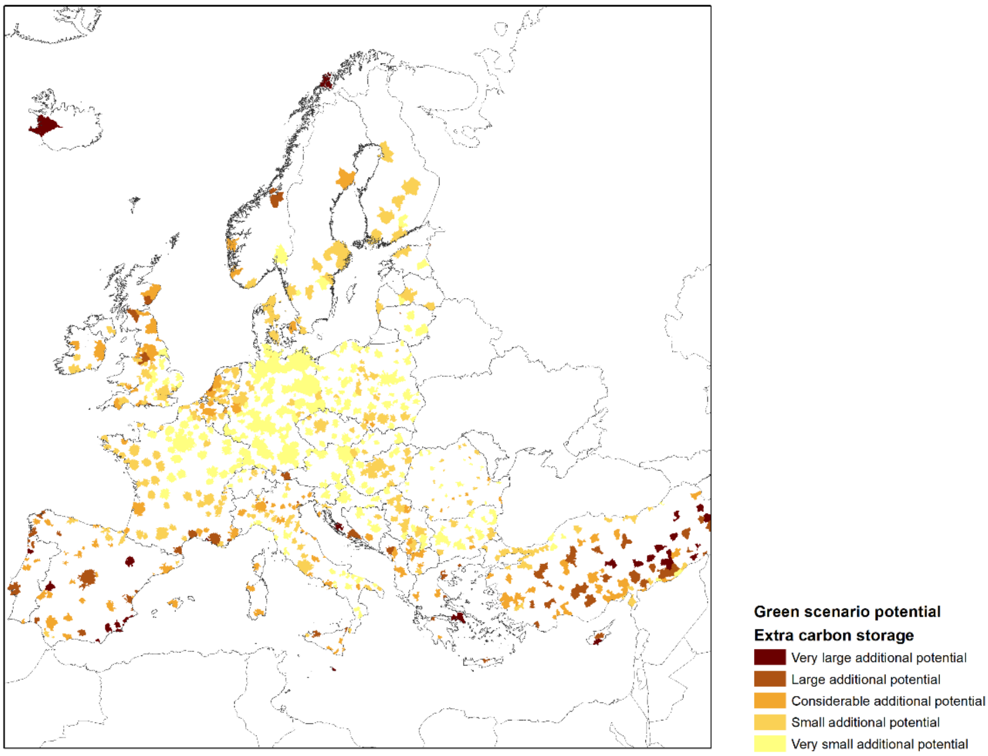

Figure A-11: Change in carbon storage when implement additional urban NBS, compared to the reference (i.e. very low additional potential: 5%; small additional potential: 5-10%, considerable additional potential: 10-20%, large additional potential: 20-30%, very large additional potential: >30%).

4. Discussion and Conclusion

This study represents a European-scale assessment of the actual and potential contribution of urban NBS to address climate related challenges. We applied the InVEST modelling framework because it is open access and relatively easy to parameterise, while accounting for key ecosystem processes. The model provides standard quantitative relationships and values based on latest available empirical studies; however, users can also tailor key parameters to the area of interest (e.g. considering data availability, context). Because of the scope of our study (i.e., 775 FUAs) we parameterised the model based on generalised values (e.g. for albedo, cooling distance of green areas) across all cities, which is a simplification of the reality.

Another simplification of our approach is the selection of NBS. Here we focused on trees, parks, and urban forests. Although these urban NBS are shown to play a major role in UHI reductions, the potential of green roofs on lowering the UHI effect has been excluded in our assessments due to the lack of data (e.g. proportion of buildings suitable for placing green roofs). However, green roofs are expected to reduce air temperatures because of the higher albedo of the vegetated as opposed to non-vegetated roofs, and because of the evapotranspiration effect (Francis and Jensen, 2017, Santamouris, 2014). In addition, we have also not included the potential contribution of other urban NBS such as urban gardens and water areas, which have also been shown to contribute to heat mitigation strategies within cities (Fung and Jim, 2020, Lin et al., 2020, Tsilini et al., 2015). This indicates that higher heat mitigation potentials could be achieved than estimated in this study, particular for the green scenario.

For the development of the carbon density values, we ignored species composition, age structure and other regional characteristics that can affect carbon storage (Huang et al., 2014). Moreover, we assumed carbon storage estimates for non-urban carbon pools would be applicable to the urban context, however, it might result in uncertainties in our estimated carbon storage potential. For example, we used non-urban forest carbon densities while it has been suggested that urban trees store only one third to one half of the carbon stored in non-urban forest due to generally younger trees within the city and more limiting growth conditions (Tang et al., 2016). Others however, argue that by-products of urbanisation (e.g. higher temperature, carbon concertation and nitrogen deposition when compared to rural areas) are likely to promote urban tree growth thus enhancing carbon storage potentials (Carreiro and Tripler, 2005). Also, urban below-ground carbon storage potentials might be very different from the non-urban areas. Urban soils are much more heterogeneous when compared to non-urban soils (e.g. as a result of human residential activities, settlement history), and carbon stocks might be even higher in urban soils when compared to non-urban soils (Vasenev et al., 2013).

For the development of the scenarios, we applied the generic change rules to all FUAs, and did not tailored the scenarios more closer to the local context. To verify the assumptions as well as to develop more ambitious as well as realistic narratives for urban NBS developments, existing visions, policies and local planning documents as well as the involvement of stakeholders (e.g. policy makers, urban planners) should be considered.

Given these simplifications and uncertainties, our study provides a first and tentative estimate of the contribution of urban NBS to address two climate change challenges in cities across Europe. We have shown that urban NBS in European cities have a positive impact on reducing heat and lowering atmospheric carbon, and that enhancing the amount of urban NBS represents a great potential for cities to mitigate and adapt to climate change. As NBS holds the promise to address multiple challenges simultaneously, future efforts should be directed to assess the contribution of urban NBS to various urban sustainability challenges (e.g. human health and well-being). Moreover, we recommend to refine the scenarios and models to account more for the local context (e.g. with more city-specific inputs; see e.g. Part B and Bosch et al. (2020)), as well as to identify associated uncertainties more systematically (e.g. sensitivity analysis due to generalised values, comparing multiple models to identify sources and magnitude of uncertainty).

Acknowledgement

We would like to thank Dr. Roy Remme from the Natural Capital Project at Stanford University who supported us applying the urban InVEST modelling framework and providing valuable feedback on our assessment and report. Also, we would like to thank Dr. Francesc Baró (UAB) for giving valuable suggestions to further improve the report.

References

ALLEN, R. G., PEREIRA, L. S., RAES, D. & SMITH, M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome,* 300**,** D05109.

ARAM, F., GARCÍA, E. H., SOLGI, E. & MANSOURNIA, S. 2019. Urban green space cooling effect in cities. *Heliyon,* 5**,** e01339.

BARO, F., CHAPARRO, L., GOMEZ-BAGGETHUN, E., LANGEMEYER, J., NOWAK, D. J. & TERRADAS, J. 2014. Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain. *Ambio,* 43**,** 466-479.

BOLUND, P. & HUNHAMMAR, S. 1999. Ecosystem services in urban areas. *Ecological Economics,* 29**,** 293-301.

BOSCH, M., LOCATELLI, M., HAMEL, P., REMME, R. P., CHENAL, J. & JOOST, S. 2020. A spatially-explicit approach to simulate urban heat islands in complex urban landscapes. *Geoscientific Model Development Discussions***,** 1-22.

BOUWER, L., CAPRIOLO, A., CHIABAI, A., FOUDI, S., GARROTE, L., HARMÁČKOVÁ, Z. V., IGLESIAS, A., JEUKEN, A., OLAZABAL, M. & SPADARO, J. 2018. Upscaling the Impacts of Climate Change in Different Sectors and Adaptation Strategies. *Adapting to Climate Change in Europe.* Elsevier.

BULKELEY, H. 2017. State of the Art Review - NATURVATION Deliverable 1.3.

CARREIRO, M. M. & TRIPLER, C. E. 2005. Forest remnants along urban-rural gradients: examining their potential for global change research. *Ecosystems,* 8**,** 568-582.

DAMMERS, E., VEERKAMP, C., RUIJS, A., HEDLUND, K., OLSSON, P., ALSTERBERG, C., HANSON, H., LUNDMARK, L., OLSSON, J., PINTER, L., ALMASSY, D., ROCHA, S., WERNER , A., BOCKARJOVA, M. & BULKELEY, H. 2019. Working paper: Set up, applicability and use of the Naturvation Index. *Report to the European commission, deliverable 3.4 of the Naturvation project,* https://www.naturvation.eu/result/urban-nature-navigator.

DAVIS, M., ABHOLD, K., MEDERAKE, L. & KNOBLAUCH, D. 2018. Nature-based solutions in European and national policy frameworks. Deliverable 1.5 NATURVATION. Horizon 2020 Grant Agreement No 730243, European Commission.

DEMUZERE, M., ORRU, K., HEIDRICH, O., OLAZABAL, E., GENELETTI, D., ORRU, H., BHAVE, A., MITTAL, N., FELIU, E. & FAEHNLE, M. 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management,* 146**,** 107-115.

EC (EUROPEAN COMMISSION) 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions and Re-naturing Cities. Final report of the Horizon 2020 Expert Group on ´Nature-Based Solutions and Re-Naturing Cities' (full version). *In:* EUROPEAN COMMISSION, D.-G. F. R. A. I. D. I. C. A., ENVIONMENT, RESOURCE EFFICIENCY AND RAW MATERIALS (ed.). Luxembourg: Publication Office of the European Union.

.

EDMONDSON, J. L., DAVIES, Z. G., MCCORMACK, S. A., GASTON, K. J. & LEAKE, J. R. 2014. Land-cover effects on soil organic carbon stocks in a European city. *Science of the total Environment,* 472**,** 444-453.

EEA (EUROPEAN ENVIRONMENT AGENCY). 2020a. *Indicator Assessment - Extreme temperatures and health* [Online]. Available: https://www.eea.europa.eu/data-and-maps/indicators/heat-and-health-2/assessment/#_edn2 [Accessed 10/15/2020 2020].

EEA (EUROPEAN ENVIRONMENT AGENCY) 2020b. Urban adaptation in Europe: How cities and towns responds to climate change Luxembourg: Publications Office of the European Union: European Environment Agency (EEA).

EUROSTAT. 2020. *Population and poputlation change statistics* [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics#EU-27_population_continues_to_grow [Accessed 10/15/2020 2020].

FRANCIS, L. F. M. & JENSEN, M. B. 2017. Benefits of green roofs: A systematic review of the evidence for three ecosystem services. *Urban Forestry & Urban Greening*.

FUNG, C. K. & JIM, C. Y. 2020. Influence of blue infrastructure on lawn thermal microclimate in a subtropical green space. *Sustainable Cities and Society,* 52**,** 101858.

GÓMEZ-BAGGETHUN, E. & BARTON, D. N. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics,* 86**,** 235-245.

HAASE, D., LARONDELLE, N., ANDERSSON, E., ARTMANN, M., BORGSTRÖM, S., BREUSTE, J., GOMEZ-BAGGETHUN, E., GREN, Å., HAMSTEAD, Z. & HANSEN, R. 2014. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. *Ambio,* 43**,** 413-433.

HOBBIE, S. E. & GRIMM, N. B. 2020. Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B,* 375**,** 20190124.

HOLTANOVÁ, E., VALERIÁNOVÁ, A., CRHOVÁ, L. & RACKO, S. 2015. Heat wave of August 2012 in the Czech Republic: comparison of two approaches to assess high temperature event. *Studia Geophysica et Geodaetica,* 59**,** 159-172.

HOY, A., HAENSEL, S., SKALAK, P., USTRNUL, Z. & BOCHNÍČEK, O. 2017. The extreme European summer of 2015 in a long-term perspective. *International Journal of Climatology,* 37**,** 943-962.

HUANG, Q., ROBINSON, D. T. & PARKER, D. C. 2014. Quantifying spatial–temporal change in land-cover and carbon storage among exurban residential parcels. *Landscape ecology,* 29**,** 275-291.

KABISCH, N., KORN, H., STADLER, J. & BONN, A. 2017. *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice*, Springer Nature.

KOVATS, R. S., R. VALENTINI, L.M. BOUWER, E. GEORGOPOULOU, D. JACOB, E. MARTIN & M. ROUNSEVELL, A. J.-F. S. 2014. Europe. *In:* BARROS, V. R., C.B. FIELD, D.J. DOKKEN, M.D. MASTRANDREA, K.J. MACH, T.E. BILIR,

M. CHATTERJEE, K.L. EBI, Y .O. ESTRADA, R.C. GENOVA, B. GIRMA, E.S. KISSEL, A.N. LEVY, S. MACCRACKEN, P .R. MASTRANDREA, AND L.L. WHITE (ed.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge, United Kingdom and New York, NY , USA, : Cambridge University Press.

LAL, R. 2008. Carbon sequestration. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 363**,** 815-830.

LARONDELLE, N., HAASE, D. & KABISCH, N. 2014. Mapping the diversity of regulating ecosystem services in European cities. *Global Environmental Change,* 26**,** 119-129.

LIN, Y., WANG, Z., JIM, C. Y., LI, J., DENG, J. & LIU, J. 2020. Water as an urban heat sink: Blue infrastructure alleviates urban heat island effect in mega-city agglomeration. *Journal of Cleaner Production***,** 121411.

NISTOR, M.-M. 2016. Mapping evapotranspiration coefficients in the Paris metropolitan area. *GEOREVIEW Scientific Annals of Ştefan cel Mare University of Suceava, Geography Series,* 26**,** 138-153.

NISTOR, M.-M. & PORUMB, G. C. G. 2015. How to compute the land cover evapotranspiration at regional scale? A spatial approach of Emilia-Romagna region. *GEOREVIEW: Scientific Annals of Stefan cel Mare University of Suceava. Geography Series,* 25**,** 38-53.

NOWAK, D. J. & CRANE, D. E. 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental pollution,* 116**,** 381-389.

PATAKI, D. E., ALIG, R., FUNG, A., GOLUBIEWSKI, N., KENNEDY, C., MCPHERSON, E., NOWAK, D., POUYAT, R. & ROMERO LANKAO, P. 2006. Urban ecosystems and the North American carbon cycle. *Global Change Biology,* 12**,** 2092-2102.

RUSSO, S., SILLMANN, J. & FISCHER, E. M. 2015. Top ten European heatwaves since 1950 and their occurrence in the coming decades. *Environmental Research Letters,* 10**,** 124003.

SANTAMOURIS, M. 2014. Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar energy,* 103**,** 682-703.

SHARP, R., DOUGLASS, J., WOLNY, S., ARKEMA, K., BERNHARDT, J., BIERBOWER, W., CHAUMONT, N., DENU, D., FISHER, D., GLOWINSKI, K., GRIFFIN, R., GUANNEL, G., GUERRY, A., JOHNSON, J., HAMEL, P., KENNEDY, C., KIM, C. K., LACAYO, M., LONSDORF, E., MANDLE, L., ROGERS, L., SILVER, J., TOFT, J., VERUTES, G., VOGL, A. L., WOOD, S. & WYATT, K. 2020. InVEST 3.8.7 User's Guide.

SMID, M., RUSSO, S., COSTA, A. C., GRANELL, C. & PEBESMA, E. 2019. Ranking European capitals by exposure to heat waves and cold waves. *Urban Climate,* 27**,** 388-402.

STEWART, I. D. 2011. A systematic review and scientific critique of methodology in modern urban heat island literature. *International Journal of Climatology,* 31**,** 200-217.

STEWART, I. D. & OKE, T. R. 2012. Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society,* 93**,** 1879-1900.

TAHA, H. 1997. Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and buildings,* 25**,** 99-103.

TANG, Y., CHEN, A. & ZHAO, S. 2016. Carbon storage and sequestration of urban street trees in Beijing, China. *Frontiers in Ecology and Evolution,* 4**,** 53.

TRLICA, A., HUTYRA, L., SCHAAF, C., ERB, A. & WANG, J. 2017. Albedo, land cover, and daytime surface temperature variation across an urbanized landscape. *Earth's Future,* 5**,** 1084-1101.

TSILINI, V., PAPANTONIOU, S., KOLOKOTSA, D.-D. & MARIA, E.-A. 2015. Urban gardens as a solution to energy poverty and urban heat island. *Sustainable cities and society,* 14**,** 323-333.

UN (UNITED NATIONS) 2018. World Urbanization Prospects: The 2018 Revision. New York, USA: United Nations, Department of Economic and Social Affairs, Population Division.

VASENEV, V., STOORVOGEL, J. & VASENEV, I. 2013. Urban soil organic carbon and its spatial heterogeneity in comparison with natural and agricultural areas in the Moscow region. *Catena,* 107**,** 96-102.

VEERKAMP, C., SCHIPPER, A., HEDLUND, K., LAZAROVA, T., NORDIN, A. & HANSON, H. submitted. Ecosystem services provided by urban green and blue infrastructure.

Appendix Part A

1. *Reference parameters*

Table A-1: Reference values for the cooling model

Code	Urban Atlas LULC classes	Shade (0-1)	Albedo	Kc	Green area (0/1)
11100	Continuous Urban Fabric (Soil sealing >80%)	Estimated per city based on city specific tree densities	0.15	(shade * 1.37[1])	0
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)		0.15	(shade * 1.37)	0
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)		0.15	(shade * 1.37)	0
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)		0.15	(shade * 1.37)	0
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)		0.15	(shade * 1.37)	0
11300	Isolated structures		0.15	(shade * 1.37)	0
12100	Industrial, commercial, public military and private units		0.15	(shade * 1.37)	0
12210	Fast transit roads and associated land		0.15	(shade * 1.37)	0
12220	Other roads and associated land		0.15	(shade * 1.37)	0
12230	Railway and associated land		0.15	(shade * 1.37)	0
12300	Port areas		0.15	(shade * 1.37)	0
12400	Airports		0.15	(shade * 1.37) + ((1-shade)*0.85[2])	0
13100	Mineral extraction and dump sites		0.15	(shade * 1.37) + ((1-shade)*0.3[3])	0
13300	Construction sites		0.15	(shade * 1.37) + ((1-shade)*0.3[7])	0
13400	Land without current use		0.15	(shade * 1.37)	0
14100	Green urban areas		0.15	(shade * 1.37) + ((1-shade) * 0.85[6])	1
14200	Sports and leisure facilities		0.15	(shade * 1.37) + ((1-shade) * 0.85[6])	0
21000	Arable land (annual crops)		0.15	1.08[4]	0
22000	Permanent crops		0.15	0.89[5]	0
23000	Pastures		0.15	0.85[6]	0
24000	Complex and mixed cultivation patterns		0.15	1.11[6]	0
25000	Orchards		0.15	0.85[7]	0
31000	Forest		0.15	(Shade *1.37)	1
32000	Herbaceous vegetation associations		0.15	(shade * 1.37) + ((1-shade) * 0.75)	0
33000	Open spaces with little or no vegetation		0.15	0.3[7]	0
40000	Wetlands		0.15	1.20[8]	0
50000	Water		0.06	0.65[9]	0

[1] Average Kc of different forest types assuming 100% tree coverage (i.e. coniferous forest, broad-leaved forest, mix forest) (Allen et al. 1998 Nistor et al 2015 and 2016)
[2] Average Kc for different grass types (i.e. turf grass, extensive grazing, rotated grazing) (Allen et al. 1998)
[3] Average Kc for bare soil (Allen et al. 1998)
[4] Average Kc for various annual crop types (i.e. wheat, barely, oats, maize, hay, clover, rye grass) (Allen et al. 1998)
[5] Average Kc for various permanent crop types (i.e. apple trees, olive, berries, grapes, hops) (Allen et al. 1998)
[6] Average Kc for arable land, permanent crops and trees
[7] Average Kc for fruit trees (i.e. apple, cherries, pear, olive, berries, grapes) (Allen et al. 1998)
[8] Average Kc for wetland in temperate climate (Allen et al. 1998)
[9] Average kc for water (Allen et al. 1998)

Table A-2: Reference carbon densities for the carbon model

Code	Urban Atlas LULC classes	**Above ground biomass** (Mg C/ha)	**Below ground biomass** (Mg C/ha)	**Soil organic matter** (Mg C/ha)	**Dead organic matter** (Mg C/ha)
11100	Continuous Urban Fabric (Soil sealing >80%)	Shade * 50	Shade * 13	Shade * 90	Shade * 15
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)	Shade * 50	Shade * 13	Shade * 90	Shade * 15
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)	Shade * 50	Shade * 13	Shade * 90	Shade * 15
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)	Shade * 50	Shade * 13	Shade * 90	Shade * 15
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)	Shade * 50	Shade * 13	Shade * 90	Shade * 15
11300	Isolated structures	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12100	Industrial, commercial, public military and private units	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12210	Fast transit roads and associated land	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12220	Other roads and associated land	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12230	Railway and associated land	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12300	Port areas	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12400	Airports	Shade * 50	Shade * 13	Shade * 90	Shade * 15
13100	Mineral extraction and dump sites	Shade * 50	Shade * 13	Shade * 90	Shade * 15
13300	Construction sites	Shade * 50	Shade * 13	Shade * 90	Shade * 15
13400	Land without current use	Shade * 50	Shade * 13	Shade * 90	Shade * 15
14100	Green urban areas	Shade * 50 + ((1-shade) * 2) [Forest + grass]	Shade * 13 + ((1-shade) * 4)	Shade 90 + ((1-shade) * 90)	1 Shade 15 + ((1-shade) * 1)
14200	Sports and leisure facilities	Shade * 50 + ((1-shade) * 2) [forest + grass]	Shade * 13 + ((1-shade) * 4)	Shade 90 + ((1-shade) * 90)	1 Shade 15 + ((1-shade) * 1)
21000	Arable land (annual crops)	6	2	60	0
22000	Permanent crops	20	10	70	0
23000	Pastures	2	4	90	1
24000	Complex and mixed cultivation patterns	6	2	60	0
25000	Orchards	20	10	70	0
31000	Forest	Shade * 50 + ((1-shade) * 2)	Shade * 13 + ((1-shade) * 4)	Shade * 90 + ((1-shade) * 90)	Shade * 15 + ((1-shade) * 1)
32000	Herbaceous vegetation associations	Shade * 50 + ((1-shade) * 2)	Shade * 13 + ((1-shade) * 4)	Shade * 90 + ((1-shade) * 90)	Shade * 15 + ((1-shade) * 1)
33000	Open spaces with little or no vegetation	1	1	2	0
40000	Wetlands[1]	10	5	87	0
50000	Water	0	0	0	0

2. Green scenario parameters

Table A-3: Green scenario values for the cooling model

Code	Urban Atlas LULC classes	shade	albedo	Kc	green area
11100	Continuous Urban Fabric (Soil sealing >80%)	9% (if std value is <9% otherwise keep std value)	No change in albedo from baseline	Shade * 1.37	
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)	20% (if std value is <20% otherwise keep std value)		Shade * 1.37	
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)	25% (if std value is <25% otherwise keep std value)		Shade * 1.37	
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)	30% (if std value is <30% otherwise keep std value)		Shade * 1.37	
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)	32% (if std value is <55% otherwise keep std value)		Shade * 1.37	
11300	Isolated structures	28% (if std value is <28% otherwise keep std value)		Shade * 1.37	
12100	Industrial, commercial, public military and private units	12% (if std value is <12% otherwise keep std value)		Shade * 1.37	
12210	Fast transit roads and associated land	20% (if std value is <20% otherwise keep std value)		Shade * 1.37	
12220	Other roads and associated land	25% (if std value is <25% otherwise keep std value)		Shade * 1.37	
12230	Railway and associated land				
12300	Port areas				
12400	Airports				
13100	Mineral extraction and dump sites	50% (if std value is <50% otherwise keep std value) [value of urban green areas]		(shade * 1.37) + ((1-shade)*0.85)	1
13300	Construction sites	32% (if std value is <32% otherwise keep std value) [value of low urban fabric]		shade * 1.37	
13400	Land without current use	82% [value of forest]		shade * 1.37	Change to '1'
14100	Green urban areas	50% (if std value is <50% otherwise keep std value)		(Shade * 1.37) + ((1-shade)*0.85)	
14200	Sports and leisure facilities	31% (if std value is <31% otherwise keep std value)		(shade * 1.37) + ((1-shade)*0.85)	Change to '1'
21000	Arable land (annual crops)				
22000	Permanent crops				

23000	Pastures				
24000	Complex and mixed cultivation patterns				
25000	Orchards				
31000	Forest	82% (if std value is <82% otherwise keep std value)		shade * 1.37	
32000	Herbaceous vegetation associations	82% (if std value is <82% otherwise keep std value) [value forest]		shade * 1.37	Change to '1'
33000	Open spaces with little or no vegetation				
40000	Wetlands				
50000	Water				

Table A-4: Carbon pools for the green scenario (green shade = 95 percentile Shade)

Code	Urban Atlas LULC classes	Above ground biomass (Mg C/ha)	Below ground biomass (Mg C/ha)	Soil organic matter (Mg C/ha)	Dead organic matter (Mg C/ha)
11100	Continuous Urban Fabric (Soil sealing >80%)	Green shade * 50	Green Shade * 13	Green Shade * 90	Green Shade * 15
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)				
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)				
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)				
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)				
11300	Isolated structures				
12100	Industrial, commercial, public military and private units				
12210	Fast transit roads and associated land				
12220	Other roads and associated land				
12230	Railway and associated land	Shade * 50	Shade * 13	Shade * 90	Shade * 15
12300	Port areas				
12400	Airports	[no shade change]	[no shade change]	[no shade change]	[no shade change]
13100	Mineral extraction and dump sites	Green Shade of 'urban green areas'* 50	Green Shade of 'urban green areas' * 13	Green Shade of 'urban green areas' * 90	Green Shade of 'urban green areas' * 15
13300	Construction sites	Green Shade of 'very low urban fabric'* 50	Green Shade of 'very low urban fabric' * 13	Green Shade of 'very low urban fabric' * 90	Green Shade of 'very low urban fabric' * 15
13400	Land without current use	Green Shade of 'forest'* 50	Green Shade of 'forest' * 13	Green Shade of 'forest' * 90	Green Shade of 'forest' * 15
14100	Green urban areas	Green Shade * 50 + ((1-shade) * 2) [Forest + grass]	Green Shade * 13 + ((1-shade) * 4)	Green Shade * 90 + ((1-shade) * 90)	Green Shade 15 + ((1-shade) * 1)

14200	Sports and leisure facilities	Green Shade * 50 + ((1-shade) * 2) [forest + grass]	Green Shade * 13 + ((1-shade) * 4)	Green Shade * 90 + ((1-shade) * 90)	Green Shade * 15 + ((1-shade) * 1)
21000	Arable land (annual crops)	6	2	60	0
22000	Permanent crops	20	10	70	0
23000	Pastures	2	4	90	1
24000	Complex and mixed cultivation patterns	6	2	60	0
25000	Orchards	20	10	70	0
31000	Forest	Green Shade * 50 + ((1-shade) * 2)	Green Shade * 13 + ((1-shade) * 4)	Green Shade * 90 + ((1-shade) * 90)	Green Shade 15 + ((1-shade) * 1)
32000	Herbaceous vegetation associations	Green Shade * 50 + ((1-shade) * 2)	Green Shade * 13 + ((1-shade) * 4)	Green Shade * 90 + ((1-shade) * 90)	Green Shade 15 + ((1-shade) * 1)
33000	Open spaces with little or no vegetation	1	1	2	0
40000	Wetlands[1]	10	5	87	0
50000	Water	0	0	0	0

3. *Grey scenario parameters*

Table A-5: Grey scenario values for the cooling model

Code	Urban Atlas LULC classes	Shade	albedo	Kc	Green area
11100	Continuous Urban Fabric (Soil sealing >80%)	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value	No change in albedo from baseline	(shade * 1.37)	
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
11300	Isolated structures	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
12100	Industrial, commercial, public military and private units	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
12210	Fast transit roads and associated land	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
12220	Other roads and associated land	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	

12230	Railway and associated land	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
12300	Port areas	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
12400	Airports	Change to value of 'Land without current use' (threshold value) if current value is higher than threshold		(shade * 1.37)	
13100	Mineral extraction and dump sites	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
13300	Construction sites	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
13400	Land without current use	Use as threshold value (low shade value)		(shade * 1.37)	
14100	Green urban areas	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	Change to 0
14200	Sports and leisure facilities	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
21000	Arable land (annual crops)				
22000	Permanent crops				
23000	Pastures				
24000	Complex and mixed cultivation patterns				
25000	Orchards				
31000	Forest	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	Change to 0
32000	Herbaceous vegetation associations	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
33000	Open spaces with little or no vegetation				
40000	Wetlands	Change to value of 'Land without current use' (threshold value); if current value is lower keep baseline value		(shade * 1.37)	
50000	Water				

Table A-6: Carbon pools for the grey scenario [if shade value is lower than 'land without current use' keep baseline value]

Code	Urban Atlas LULC classes	Above ground biomass (Mg C/ha)	Below ground biomass (Mg C/ha)	Soil organic matter (Mg C/ha)	Dead organic matter (Mg C/ha)
11100	Continuous Urban Fabric (Soil sealing >80%)	Shade 'land without current use' * 50 [if shade value is lower than 'land without current use' keep baseline value]	Shade 'land without current use' * 13 [if shade value is lower than 'land without current use' keep baseline value]	Shade 'land without current use' * 90 [if shade value is lower than 'land without current use' keep baseline value]	Shade 'land without current use' * 15 [if shade value is lower than 'land without current use' keep baseline value]
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)				
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)				
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)				
11240	Discontinuous Very Low Density Urban Fabric (S.L. <10%)				
11300	Isolated structures				
12100	Industrial, commercial, public military and private units				
12210	Fast transit roads and associated land				
12220	Other roads and associated land				
12230	Railway and associated land				
12300	Port areas				
12400	Airports				
13100	Mineral extraction and dump sites				
13300	Construction sites				
13400	Land without current use				
14100	Green urban areas				
14200	Sports and leisure facilities				
21000	Arable land (annual crops)	6	2	60	0
22000	Permanent crops	20	10	70	0
23000	Pastures	2	4	90	1
24000	Complex and mixed cultivation patterns	6	2	60	0
25000	Orchards	20	10	70	0
31000	Forest	Shade 'land without current use'* 50	Shade 'land without current use'* 13	Shade 'land without current use'* 90	Shade 'land without current use' * 15
32000	Herbaceous vegetation associations	Shade 'land without current use'* 50	Shade 'land without current use' * 13	Shade 'land without current use' * 90	Shade 'land without current use' * 15
33000	Open spaces with little or no vegetation	1	1	2	0
40000	Wetlands[1]	Shade 'land without current use'* 50	Shade 'land without current use'* 13	Shade 'land without current use'* 90	Shade 'land without current use' * 15
50000	Water	0	0	0	0

References

ALLEN, R. G., PEREIRA, L. S., RAES, D. & SMITH, M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome,* 300**,** D05109

NISTOR, M.-M. 2016. Mapping evapotranspiration coefficients in the Paris metropolitan area. *GEOREVIEW Scientific Annals of Ştefan cel Mare University of Suceava, Geography Series,* 26**,** 138-153.

NISTOR, M.-M. & PORUMB, G. C. G. 2015. How to compute the land cover evapotranspiration at regional scale? A spatial approach of Emilia-Romagna region. *GEOREVIEW: Scientific Annals of Stefan cel Mare University of Suceava. Geography Series,* 25**,** 38-5

Part B: Assessing the potential of nature-based solution in European cities to address climate change: the city-scale assessment

Niklas Boke Olén, Chiara Cortinovis, Katarina Hedlund and Peter Olsson (ULUND)

Deliverable 3.7

October, 2020

This project has been funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 730243

List of figures

List of tables

Abbreviations

DSM – Digital Surface Model

DTM – Digital Terrain Model

InVEST – Integrated Valuation of Ecosystem Services and Trade-offs

IR – Infra-red

NBS – Nature-based solutions

NDSM – Normalised Digital Surface Model

NDVI – Normalised Difference Vegetation Index

OSM – Open Street Map

RMSD – Root Mean Square Deviation

SVM – Support Vector Machine

UA – Urban Atlas

UNN – Urban Nature Navigator

UHI – Urban Heat Island

USDA - United States Department of Agriculture

1. Introduction

1.1. Aim and approach

This part of the report describes the methods and results of the detailed analysis of NBS potential in three case study cities, i.e. Barcelona, Malmö, and Utrecht. The overall aim - assessing the full potential of NBS implementation to mitigate and adapt to climate change in European cities - is here addressed by taking a close look at the effects of NBS implementation scenarios in the selected cities. This detailed assessment at the local scale complements the results of chapter 2 on the European-scale assessment and provides additional insights on the expected impacts of NBS implementation from three perspectives.

First, by focusing on the three case studies, we can use more detailed data, hence apply more refined models to analyse the expected benefits of NBS. This allows capturing the effects of NBS implementation at the local scale, providing a more shaded picture of how they vary across the city. The different resolution of the analyses reveals which specific areas in the city are expected to benefit the most from the simulated interventions, and what areas do not experience any change.

Second, by reducing the scale of analysis, we can consider more benefits that NBS produce, including co-benefits not strictly related to climate change. Co-benefits are, indeed, one of the main reasons why NBS are considered more cost-effective than grey solutions in the long run (Raymond et al., 2017, European Commission, 2015). However, assessing some co-benefits, such as those related to cultural ecosystem services, requires detailed data that can be analysed only at a detailed scale. Compared to the European-scale analysis, we include here runoff retention as an additional benefit for climate change adaptation, and three co-benefits: biodiversity potential, recreation opportunities, and health and wellbeing benefits.

Third, by working at the city scale, we can model more detailed scenarios that account for the on-the-ground factors that affect NBS implementation. Coherently with the approach for the European-scale, we use scenarios to simulate the implementation of different NBS and assess the expected impacts. Following EEA (2009), scenarios are defined as “a consistent and plausible picture of a possible future reality”. At the city scale, we develop six detailed scenarios, including the current condition, the implementation of four different NBS, and a combination of them. Compared to the European-scale analysis (Part A), we do not simulate the removal of existing green infrastructure: an unlikely scenario despite the threats posed by climate change to urban vegetation (e.g., drought and extreme events). Instead, we compare the five NBS implementation scenarios to the current condition, which is considered as a reference “grey” scenario.

Each scenario is a spatially explicit representation of the *full potential* for implementing the analysed NBS in the city, which considers the constraints determined by space availability and technical feasibility. Additional economic, social, and institutional aspects potentially affecting the process of NBS implementation (Kabisch et al., 2016, Wihlborg et al., 2019) are not considered. In this sense, our scenarios can be seen as *explorative*

(Börjeson et al., 2006), but the future reality that they depict is plausible, hence they are used in this chapter in a *predictive* perspective to quantify the potential benefits produced by NBS implementation.

1.2. Case study cities

The six European NATURVATION partner cities (Barcelona, Győr, Leipzig, Malmö, Newcastle, and Utrecht) were initially considered as case study cities. After checking for data availability (e.g. high-resolution remote sensing data), we restricted the sample to the three cities of Barcelona (Spain), Malmö (Sweden), and Utrecht (the Netherlands). For these three cities, comparable data of sufficient quality and resolution were available to allow for the assessment and comparison of the full potential of NBS within the cities.

The three cities represent a South-North gradient within the EU, and are representative of different sizes, climates, and urban forms. The 2019 population was: 1,636,800 in Barcelona (Instituto Nacional de Estadística, 2020), 344 200 in Malmö (Statistics Sweden, 2020) and 357 700 in Utrecht (Royal Netherlands Meteorological Institute, 2020), with an average population density of respectively 16 060, 4 480, and 3 610 inhabitants per km^2. Two of the cities - Barcelona and Malmö - are situated by the sea. Barcelona is characterised by the warmest climate, with an average low/average/average high temperature of 11.1 / 15.6 / 20.0 °C, followed by Utrecht 6.0 / 10.1 / 14.1 °C and Malmö 4.9 / 8.2 / 11.4 °C (Royal Netherlands Meteorological Institute, 2020, Climate-data.org, 2020). However, all cities suffer from summer heat waves, with temperatures occasionally above 30 °C. The highest average total annual rainfall is in Utrecht (832 mm) followed by Barcelona (628 mm) and Malmö (552 mm) (Climate-data.org, 2020, Royal Netherlands Meteorological Institute, 2020).

2. Material and Methods

2.1. Modelling scenarios of NBS implementation

Operationally, the simulation of NBS implementation was based on land cover transitions, i.e. NBS were implemented through changes in land cover. Additionally, two scenarios involved modifying the boundaries of publicly accessible green areas to add new urban parks. For each city, we developed six scenarios, including one showing the current condition (Table B-1). Four scenarios focus on a single NBS (green roofs, parks, street trees, permeable parking areas), thus simulating the effects of policies implementing a specific climate change adaptation and mitigation strategy; while the last scenario, named *GreenDream*, simulates the combined implementation of the four strategies.

Table B-1. Summary of scenarios considered in the analysis.

Name	NBS	UNN types	Actions
Current	Existing green infrastructure	All	-
GreenRoofs	Green roofs	External building greens	Conversion of suitable roofs into green roofs.
ParkingAreas	Permeable parking areas	Infrastructure with green features / Green areas for water management	De-sealing of existing parking areas and conversion into permeable surfaces.
Parks	Parks	Parks and green areas	Enhancement of vegetation in existing parks and creation of new ones.
StreetTrees	Street trees	Infrastructure with green features	Planting of trees along streets.
GreenDream	All the above	All the above	A combination of the above

The NBS simulated in the scenarios were selected from the Urban Nature Navigator (UNN) (Dammers et al., 2019) to be representative of different NBS types (Table B-1). Among the six level-1 types listed in the UNN, the scenarios do not consider the creation of new blue areas, since the latter require different methods than those suitable to assess the expected impacts of green solutions (EEA, 2010).

The current land cover was classified by combining Normalised Difference Vegetation Index (NDVI), lidar data, and derived products available for each city with information from the Urban Atlas (UA) (https://land.copernicus.eu/local/urban-atlas). Lidar data is laser scans from above normally used to estimate the structure and heights of objects on the ground. Spatial data to model land cover changes in the NBS implementation scenarios were retrieved for all cities from the UA and from OpenStreetMap (OSM) (Open Street Map, 2020), to ensure a homogeneous approach in the analysis of the full potential of NBS implementation. Since the 2018 release of the UA was not available for all three cities, we used the most updated version of the 2012 dataset (version 021 for Barcelona and Utrecht and version 013 for Malmö). The city boundaries used are based on the administrative boundaries of the three municipalities as obtained from

GADM v3.6 (https://gadm.org/), adjusted based on data availability. The extent of the lidar data and NDVI limited the area included in the analysis for Malmö and Barcelona, respectively. For Utrecht, only a small portion (25 ha) of the east part of the city was not covered by data, hence it is not included in the analysis. A sea area of around 700 meters from the shoreline was added in Barcelona and Malmö to account for possible cooling effects by the sea in the parameterisation of the cooling model.

2.1.1. Current scenario

The data used to classify the land cover of the three cities were rescaled to a common 1 m resolution (if raster data, Table B-2) and geographical projection (WGS84). The data used to classify the land cover were Normalised Difference Vegetation Index (NDVI), Normalised Digital Surface Model (NDSM), UA data on water and agriculture, building outlines, and coastline data (Table B-2).

For Malmö and Utrecht, NDVI maps were calculated from an infrared (IR) orthophoto, while for Barcelona it was downloaded as a premade product (Table B-2).For Malmö, the acquisition date of the latest orthophoto was before tree budburst, which made it impossible to identify the greenness of deciduous trees. Therefore, we complemented it with an additional orthophoto to detect the missing trees.

To calculate the height of objects in the cities (NDSM) we used the differences between the elevation of objects above sea level (digital surface model, DSM) and the height of the surface (digital terrain model, DTM). DSM and DTM were, for Malmö and Barcelona, calculated from the lidar (light detection and ranging) data, and for Utrecht downloaded as a ready-made DTM and DSM from processed lidar data (Table B-2).

Table B-2. Input data for land cover classification of the three cities.

Data (year of data)		**Source**
Barcelona	NDVI (2017)	https://opendata-ajuntament.barcelona.cat/data/en/dataset/cobertura-vegetal-ndvi
	NDSM (2016)	Calculated from LIDAR 0.5pts/m² http://centrodedescargas.cnig.es/CentroDescargas/locale?request_locale=en
	Building polygons (2019)	http://www.catastro.minhap.es/INSPIRE/Buildings/08/08900-BARCELONA/A.ES.SDGC.BU.08900.zip
Malmö	NDVI (2018+2012)	Calculated from IR orthophoto 25cm resolution. *Source: Swedish cadastral surveying, Lantmäteriet*
	NDSM (2017)	Calculated from LIDAR 25 pts/m2 *Source: City of Malmö*
	Building polygons (2018)	*Source: Swedish cadastral surveying, Lantmäteriet*
Utrecht	NDVI (2019)	Calculated from IR orthophoto 25cm resolution. https://www.pdok.nl/-/nieuw-luchtfoto-2019-beschikbaar-bij-pdok
	NDSM (2015)	Calculated from DSM and DTM 50cm resolution https://downloads.pdok.nl/ahn3-downloadpage/
	Building polygons (2020)	http://3dbag.bk.tudelft.nl/data/gpkg/bag3d_2020-01-25.gpkg
Urban Atlas (2012)		https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012/
Coastlines		https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-2

For each city, we applied a threshold value on the NDVI to separate vegetation from non-vegetation (Table B-3). Once this was done, the NDVI and NDSM were rescaled between 1 and 255, where non-vegetated areas were set to 1 to allow the segmentation algorithm to only detect vegetation and treat other areas as one homogenous segment. A segmentation was then performed on the NDVI-NDSM rescaled images using the mean shift segmentation framework in the Orfeo-toolbox (Grizonnet et al., 2017). The parameters of the segmentation were trained stepwise for each city in a small area using training polygons (manually digitised for a smaller area) and evaluated using ranking. Ranking selection was based on the lowest combined rank of: i) number of extra polygons, ii) total overlap, and iii) extra segments, to get the combination that gives the highest resemblance to the training polygons. The best sets of parameters were then applied to the segmentation of the entire city.

The result of the segmentation is a polygon layer covering the entire city with attributes on the average NDVI and NDSM. Non-vegetated polygons were removed using the NDVI threshold on the average value (Table B-3). The polygons were then matched to the training points (minimum 150 pts per city manually added) data to create a training polygon dataset, which was trained using a support vector machine (SVM) classification following the method by Abdi (2020). The SVM classification was then applied to the entire polygon dataset.

Table B-3. Parameters used for land cover classification.

Parameters	Barcelona	Malmö	Utrecht
NDVI threshold	0.2	0	0.05
NDVI threshold green roof	0.3	0	0.2
Spatial r (segmentation)	5	5	5
Range r (segmentation)	20	10	10
Min size (segmentation)	5	3	4

Polygon maps of buildings (Table B-2) were used to add a building land cover class and to separate out green roofs. When information was available, we used only buildings for which the construction year was before the year of NDSM and NDVI data and that had height above one meter (to remove underground buildings). For each building left in, we extracted average slope statistics and calculated an approximation of the roof slope. We first calculated the slope for each pixel on the NDSM maps (1 x 1 m). Then, we extracted the values for each building, calculating a median of all slopes below 60 degrees. We excluded slope values above 60 degrees since most of them are assumed to be representative for abrupt changes in the roofs (chimneys or areas on the edges).

Whole buildings were then assigned to the green roof class if they satisfied all of the following conditions: more than 90% (50% for Malmö) vegetated pixels, an area larger than 100 m^2 (75 for Malmö), an area smaller than 50,000 m^2, an average NDVI value above the NDVI threshold for green roofs (Table B-3). The percent vegetated pixels criterion was set to exclude partial vegetated roofs (which were taken care of in the next step) and the values were selected iteratively for the three cities based on visual interpretations of the result that accounts for differences in building and vegetation structure. The size criterion was chosen to exclude small buildings where there was a risk of entire roofs being underneath a tree canopy (also iteratively chosen). However, to make sure that we also included partial green roofs, we classified as green roof also all vegetation areas covering a building deemed suitable for the placement of a green roof *GreenRoofs* (size above 40 m^2 and slope below 20 degrees – see section 3.2.1.2 for more information). The remaining vegetation areas overlapping with building footprints mostly correspond to cases where a tree partially covers a roof and were classified as “vegetation over building”.

Water was classified using the UA class 5000 “water” together with the coastlines (Table B-2) for Barcelona and Malmö. Furthermore, we classified as water the missing values in the DSM, since it is common that the lidar detection fails over water. Vegetation areas overlapping with water, corresponding e.g. to a tree hanging over a pond, were classified as “vegetation over water”.

The areas not classified after we had added the classes: tree, low vegetation, water, building, and green roofs, were classified as impervious surfaces. The agricultural classes of the UA (21000, 22000, 23000, 24000) were used to convert low vegetation and impervious areas within those polygons to agricultural areas. This was done to account for bare soil on agricultural areas, which would have been otherwise misclassified as impervious. The final land cover maps had the following classes: water, trees, low vegetation, impervious, agriculture, buildings (without green roof), green roofs, vegetation over building, and vegetation over water.

The current scenario is complemented by a vector map of the existing urban parks. The boundaries of existing parks were identified by combining UA data (class 14100 "green urban areas") and OSM data (tag: leisure = park). The latter served as a complement to identify small parks and public green areas in peri-urban zones, not included in the UA database. To obtain the final map, we removed the overlaps between the two datasets and with the streets. To this purpose, the latter were identified by buffering the OSM street network using different distances depending on the type of street. We set a buffer distance of 3 m for residential and other small roads (OSM tag: highway = residential OR unclassified) and a distance of 6 m for bigger roads (OSM tag: highway = primary OR motorway OR secondary OR tertiary).

2.1.2. GreenRoofs scenario

The scenario simulates the implementation of green roofs on all roofs – currently non-green – considered suitable for the installation of this technology. Several criteria can be applied to assess the suitability of a roof to be converted into a green roof, including size, slope, orientation and shading of the roof, and building structure and use (Karteris et al., 2016, Santos et al., 2016, Grunwald et al., 2017). However, most of these aspects do not represent feasibility constraints, and green roofs can be installed on almost any type of roof, as far as appropriate technology and type of vegetation are selected (see e.g., Langemeyer et al. (2020)).

In our simulation, we considered extensive green roofs with a substrate of around 10-15 cm, which are the lightest and the easiest to maintain (Friedman, 2015). These roofs are not walkable and the substrate depth limits the species of plants that can be grown (Santos et al., 2016), but they can be installed on the widest range of roofs. We selected the roofs based on two criteria: size above 40 m^2 and slope below 20 degrees. The size criterion excludes small buildings with no continue presence of people (i.e., presumably neither houses nor work places) and those for which the calculation of slope is less reliable (the smaller the size, the greater the effect of cells falling on the boundary of the building). The slope criterion limits the selection to cases in which no special technologies are required (Kwok and Grondzik, 2007).

2.1.3. ParkingAreas scenario

The scenario simulates the de-sealing of all existing parking areas (polygons) identified in the OSM database (tag: amenity = parking) and their conversion into permeable surfaces as reinforced lawns. Patches of low vegetation within existing parking areas were overridden by the land cover change, but existing trees have been maintained.

2.1.4. Parks scenario

The scenario simulates the effect of policies directed to enhancing urban parks by: i) improving vegetation in existing parks, and ii) creating new parks. The enhancement of vegetation in existing parks consists in: i) converting part of the areas currently sealed into low vegetation, and ii) increasing the tree coverage. We used OSM data to exclude from land cover changes all areas corresponding to existing paths (tag: highway), sport fields (tag: leisure = pitch), cemeteries (tag: landuse = cemetery), and community gardens (tag: landuse = allotments). Residual sealed areas were converted into low vegetation. The increase in tree coverage was modelled by adding new trees to plantable areas. Plantable areas were defined as the areas not occupied by current canopies and buildings, including a buffer distance of 4 m from them. We added a tree every 100 m^2 of plantable area and distributed them randomly at a minimum distance of 2 m between the stems. Crowns were approximated by a circular shape with radius varying randomly from 3.0 to 6.0 m.

Areas for new parks were identified based on UA land uses. The scenario simulates the creation of new parks on derelict sites (class 13400 "land without current use") and patches of herbaceous vegetation (class 32000) completely interclosed, i.e. surrounded exclusively by artificial land uses. The latter normally correspond to areas not used for agriculture, often targeted for infill development. A preliminary check was conducted to ensure that no construction had been built in the selected areas between the UA survey and the image used to develop the land cover map. Overlaps with the street network and with existing parks were removed, as for the vector map of existing parks in the *Current* scenario (Section 2.1.1).

Within the new parks, we modelled impervious areas, low vegetation, and trees. Existing trees, low vegetation, and water areas (as in the classified land cover) - as well as existing paths, sport fields, cemeteries, and community gardens (as in the OSM database) - were preserved. We added new impervious areas corresponding to a hypothetical 4-meter wide path running parallel to the boundary of the park at a distance of 10 m. The distribution of new trees followed the same rules applied to the enhancement of vegetation in existing parks.

2.1.5. StreetTrees scenario

The scenario simulates tree planting along streets, where enough space is available. We used OSM street network and selected urban streets (tag: highway = residential OR tertiary OR unclassified), excluding high-speed roads and motorways. We assume that "residential" and "unclassified" roads have (or can be restricted to) one lane for each direction, i.e. 6 m in total, while tertiary roads have (or can be restricted to) two lanes for each direction, i.e. 12 m in total. Whenever additional space, currently sealed, is available next to the road, it is considered a potential area for planting. Adopting the same parameters used by Trlica et al. (2020) to assess the potential increase in street trees in Boston, new trees were located at a minimum distance of 8 m between the stems and 4 m from existing canopies and building facades, to allow enough space for growth.

Crowns were approximated by a circular shape with radius varying randomly from 3.0 to 4.2 m, which is consistent with the size of existing street trees in the three cities as measured on sample street trees on the land cover map of the *Current* scenario.

2.1.6 GreenDream scenario

The scenario combines all interventions simulated in the other four scenarios:

- green roofs are installed on all roofs larger than 40 m^2 and with a slope lower than 20 degrees.
- parking areas are converted into permeable surfaces.
- the vegetation in existing parks is enhanced and new parks are created.
- street trees are planted along urban streets, wherever sufficient space is available.

Since land cover changes simulated in the four scenarios did not overlap, we obtained the map for the *GreenDream* scenario by merging the changes modelled in each scenario.

2.2 Assessing climate change adaptation and mitigation benefits

The scenarios were assessed in terms of climate change adaptation and mitigation benefits of NBS, considering three main aspects: heat mitigation, carbon storage, and runoff reduction. We applied three spatially explicit models based on land cover to assess the three benefits and then analysed the results at three scales: i) UA block, ii) UA class, iii) whole city.

The identification of blocks was based on UA polygons, which distinguish patches of land separated by streets or characterised by different land uses. We removed roads and railroads (class 12210, 12220, 12230) and expanded the neighbouring polygons to cover the gaps. Larger road/railroad areas, corresponding e.g. to large intersections or railway yards, were kept if, after applying a negative buffer (distance equal to 30 m, 20 m, and 35 m for the three classes, respectively), their area exceeded 400 m^2. By using the UA polygons as a basis instead of city-specific census data, we could associate to each block a UA land use class and an estimation of population calculated homogenously over the three cities. Population data were then used to model accessibility to urban parks as one of the co-benefits of NBS implementation.

2.2.1. Heat mitigation

We used the InVEST - Urban cooling model v 3.8.7 (Sharp et al., 2020) to assess the heat mitigation benefit of urban nature-based solutions, i.e. their potential to lower high (summer) temperatures in the city. The model is a proxy-based method, associating cooling with albedo, evapotranspiration, and canopy shade. The model also accounts for cooling effects generated by large green areas on their surroundings. The model applies a two-step procedure: first, it computes an index of heat mitigation, secondly, it calculates air temperature using a minimum reference temperature, an intensity of the urban heat island, and a distance for air mixing.

The model requires as input a land use map with the following data associated to each class: canopy cover, albedo, crop coefficient (Kc) for evapotranspiration, and a true/false classification of the classes to be considered as green areas. Other input include a map of reference evapotranspiration for the analysed period, and seven parameters to be set by the user: reference rural temperature, intensity of the urban heat island, weights of the three factors (shade, albedo, and evapotranspiration) to calculate the heat mitigation index, cooling distance of large green areas, and air mixing distance.

As reference areas, we used the blocks modified after by the UA polygons, which were rasterised to 10 by 10 meter resolution and aligned with the land cover map (see section 3.2.1.1). Data for Kc (fraction of alfalfa reference grass), reference evapotranspiration (for alfalfa reference grass) and albedo were obtained from the Landsat based EEFLUX (https://eeflux-level1.appspot.com/), a version of METRIC (Mapping Evapotranspiration at high Resolution with Internalised Calibration) that operates on the Google Earth Engine (Allen et al., 2015)**.** We selected data with low cloud cover (<10% for the whole image according to the tool as well as nearly cloud free over our target area, which was inspected visually in the tool) between 1 of June and 30 of Aug during the years 2015 to 2019. Additionally, we checked for meteorological conditions characterised by low wind (<3 m/s), low water availability (assessed by comparing Kc rasters across several dates), and warm temperature (above 28 °C in Barcelona and Utrecht and above 25 °C in Malmö). Meteorological data at 11 local time to match Landsat-derived data were obtained from official sources (Swedish Meteorological and Hydrological Institute, Malmö city and Barcelona harbour), complemented by citizens' data (https://temperatur.nu/ and https://www.wunderground.com/) to get enough points for calibration.

Based on land cover data, we calculated the canopy cover (as percentage of surface covered by trees) and total green area (including trees and low vegetation) for each block. We tested the correlation between canopy cover, shade, Kc, and albedo with UA land use classes and found for many land use classes a higher within class than between class variation (data not shown). Thus, instead of using UA classes, we decided to consider each block as a single class in the model. Blocks to be considered as green areas were automatically identified based on the total green area of trees and low vegetation, using a cut-off of 75%. Average values of Kc and albedo for each date were calculated for each block by weighting Kc and albedo raster values by the fraction of cell within the area.

The model was calibrated to each data set to measured air temperatures using Simulated Annealing Optimisation in R / optim function with 900 iterations. The RMSD (root-mean-square deviation) between predicted and measured air temperatures were minimised. The model was calibrated allowing the albedo, shade, and evapotranspiration parameters to vary between 0 and 1, green area maximum cooling distance between 0 and 500 m, and the air temperature maximum blending distance between 0 and 2000 m. The baseline air temperature was allowed to vary between 2 °C less than the lowest measured temperature and the lowest measured temperature. The magnitude of the Urban Heat Island (UHI) effect was allowed to vary ± 2 °C around the difference between maximum and minimum measured temperature.

As several data sets from each city were independently calibrated, we selected data sets that had no parameters on the parameter's allowed boundaries and with as a high temperature as possible. The final set of calibrated parameters used to run the analysis can be found in Table B-4.

Table B-4. Input data and calibrated parameters used to model heat mitigation through the InVEST urban cooling model.

	Barcelona	**Malmö**	**Utrecht**
Date	2018/08/04	2019/07/24	2016/07/20
Landsat/EEFlux data set	LC81970312018216LGN00	LC81950212019205LGN00	LC81980242016202LGN01
Wind (m/s)	2.2	1.4	0.3
Relative Humidity (%)	42	64	51
Air temperature (°C)	33.6 (30.6-35.6)	28.1 (25.9-30.9)	26.8 (24.9-30.3)
Albedo (index)	0.227	0.387	0.042
Evapotranspiration (index)	0.592	0.646	0.723
Shade (index)	0.133	0.384	0.124
Green area maximum cooling	94	214	88
Air temperature maximum	1422	1853	750
Baseline air temperature (°C)	28.9	25.7	23.5
Magnitude of the UHI effect (°C)	6.7	3.3	6.8
RMSD	1.731	1.489	1.647

To model heat mitigation in NBS implementation scenarios, Kc and albedo values needed to be adjusted in areas affected by land cover changes. To do this, first we identified cells in the Kc and albedo raster maps corresponding to a single land cover. Median values for albedo and Kc for each land cover class in each city were calculated using these cells (Table B-5), and the difference between the medians used to calculate new values. We used medians as the means of several land cover classes were clearly affected by outliers.

We found only few raster cells completely covered by the land use class green roofs in Barcelona and Malmö, and none in Utrecht. Therefore, literature values of Kc and albedo were used to simulate cooling by new green roofs. Most of the crop coefficients of sedum roofs in the literature have been measured on a well-watered green roof, which do not correspond to the warm and dry conditions that we are simulating to measure heat mitigation. (Lazzarin et al., 2005) report Kc values (reference crop = grass) between 0.15 and 0.3 for a water stressed sedum roof, and (Djedjig et al., 2012) confirm that evapotranspiration is reduced to its minimum by low water availability**.** (Djaman and Irmak, 2013) show that Kc for alfalfa is generally lower than for grass, hence we used for green roofs a Kc of 0.1 higher than conventional roofs in the same city. Schwarz (2015) found values of albedo for sedum roofs (0.16) significantly lower than grass (0.18), while a study from New

York (Gaffin et al., 2009) shows albedo values in July generally oscillating around or just below 0.2. Based on these findings, we set albedo for green roofs to 0.02 below that of low vegetation.

For the *ParkingAreas* scenario, we assumed the new permeable parking areas as covered by 50% impervious and 50 % low vegetation (e.g., reinforced lawn), and adjusted the albedo and Kc to 50% of the change between the median values of impervious and low vegetation (Table B-5).

Changes in Kc and albedo were applied to cells in the land cover map affected by a land cover change compared to the *Current* scenario. Since values in the Landsat/EEFLUX-derived raster in each 30 by 30 m cell correspond to a mixture of land covers, we recalculated them by applying the differences only to the share of the cell involved in each land cover change.

Table B-5. Median values used to calculate the changes in albedo and Kc produced by land cover changes in the NBS implementation scenarios.

Barcelona			
Land cover class	**N cells**	**Albedo**	**Crop coefficient**
water	11252	0.027	0.248
trees	5948	0.111	0.726
low vegetation	396	0.133	0.674
impervious	3048	0.191	0.285
agriculture	626	0.153	0.371
buildings	1126	0.202	0.191
Malmö			
Land cover class	N cells	Albedo	Crop coefficient
water	16812	0.018	0.856
trees	903	0.146	0.857
low vegetation	1245	0.172	0.111
impervious	7570	0.150	<0.001
agriculture	48744	0.154	0.583
buildings	931	0.098	<0.001
Utrecht			
Land cover class	**N cells**	**Albedo**	**Crop coefficient**
water	2205	0.031	1.258
trees	1085	0.141	0.822
low vegetation	797	0.186	0.644
impervious	2032	0.155	0.286
agriculture	14454	0.184	0.778
buildings	473	0.096	0.197

2.2.2. Carbon storage

Carbon storage was modelled as a function of land cover using the same approach applied through InVEST in Part A, assuming a steady state of carbon content (no sequestration or decomposition). Carbon storage values per land cover class (Table B-6) were retrieved from peer-reviewed literature. Publications were searched for in Web of Science. Combinations of words (“carbon stock*” or “carbon pool*” or “carbon storage*”) and urban were used. Also, additional words as review, lawn*, “green roof*”, canopy*, impervious or sealed, were used to further identify literature on carbon storage linked to specific land covers. 1

The total carbon storage per unit area of land cover class was calculated as a sum of living material above and below ground, and soil organic carbon (Table B-6). We accounted only for land cover classes affected by our NBS implementation scenarios, hence agricultural land and water were not included in the total carbon storage values over the cities.

There is evidence of organic carbon in urban soils increasing with latitude (Vasenev and Kuzyakov, 2018). To compensate for this effect and to account for local effects, we used the values in a world map of soil organic carbon (Hiederer and Köchy, 2011) to adjust the values from the literature review for the three cities. We extracted the soil carbon in the topsoil and subsoil layers within the boundaries of our three cities and the total soil carbon in the locations of the case studies included in the review (with a 5,000-meter radius circle). The ratios between these values were used to calculate the final values of soil organic carbon for the three cities.

Table B-6. Carbon pools (kg C/m^2) per land cover class used to model carbon storage. Values for water and agriculture are not included since corresponding areas are not changed in the NBS implementation scenarios. Values for soil organic carbon from the literature review are adjusted considering the values for the different locations in the world soil carbon dataset (Hiederer and Köchy, 2011).

Land cover class	**Above ground**	**Soil organic carbon (0-100 cm)**				**Below ground (0-100 cm)**	**Total**		
		Mean of empirical value(s)	**Barcelona**	**Malmö**	**Utrecht**		**Barcelona**	**Malmö**	**Utrecht**
Trees	5.19[1]	18.50[2]	18.25	23.13	38.31	3.49[3]	26.9	31.8	36.9
Low vegetation	0.19[4]	15.34[5]	8.38	10.63	17.61	0.98[6]	9.5	11.8	18.7
Impervious	0	NA	3.49[7]	4.74[7]	7.33[7]	0	3.4	4.7	7.3
Green roofs	1.92[8]	2.42[8]				0.34[8]	4.6		
Vegetation over building	same as trees						26.9	31.8	36.9
Vegetation over water	same as trees						26.9	31.8	36.9
Permeable soil	0.09[9]	NA	5.93[9]	7.68[9]	12.47[9]	0.49[9]	6.5	8.2	13.0

1: Mean of urban canopy values from Leipzig, Germany (Strohbach and Haase, 2012);

2: Based on a study in Leicester UK, n = 43 samples (Edmondson et al., 2014);

3: Mean of algometric function based values (Nowak and Crane, 2002);

4: Other vegetation is modelled as low vegetation e.g. lawn, values from (Davies et al., 2011, Karteris et al., 2016, Nedkov et al., 2016);

5: Average from of lawns (n = 6 studies), urban meadow (1), herbaceous (1) and low perennials (1), (Edmondson et al., 2014, Pouyat et al., 2009, Lindén et al., 2020, Vasenev and Kuzyakov, 2018);

6: A mean of several values of varying low vegetation types (Whittinghill et al., 2014);

7: As carbon storage under impervious, an average of the sub soil in the case cities were used assuming that the sub soil is not affected by construction and that carbon is stable. Values were extracted from a world carbon content soil data set (Hiederer and Köchy, 2011).

8: Average of values from sedum and low grassy vegetation roofs (Getter et al., 2007, Whittinghill et al., 2014); 9: A mix of 50% impervious and 50% low vegetation.

2.2.3. Runoff reduction

We used the InVest - Urban flood risk mitigation model v.3.8.7 (Sharp et al., 2020) to calculate stormwater retention in the cities. The model applies the Curve Number method developed by the USDA (Nrcs, 1986) and widely adopted in the literature about green infrastructure and nature-based solutions for urban stormwater management (McPhearson et al., 2013, Yao et al., 2015, Grêt-Regamey et al., 2020). 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). The database provides consistent multi-layered spatial information about hydraulic soil properties across Europe at standard soil depths of 0, 5, 15, 30, 60, 100, and 200 cm. The value of saturated hydraulic conductivity k_s in the database is calculated by applying the pedotransfer function PTF16 (Tóth et al., 2015) to data on particle size distribution and organic content from SoilGrids250m maps (Hengl et al., 2017). Following the indication of USDA (Nrcs, 2007), we checked the depth to bedrock in the soilGrids250m database (Shangguan et al., 2017) to identify the depth of the water impermeable layer. The minimum values of k_s 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 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 as 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. Permeable 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). Each class is represented by its average slope (i.e. 2.5°, 7.5°, 12.5°, 17.5°, and 22.5°). A class for slope higher than 20° was added to account for the pitch of some existing green roofs (Table B-7).

Table B-7. Curve Numbers assigned to the different land cover classes.

	Hydrologic soil group			
Land cover class	**A**	**B**	**C**	**D**
Water (and vegetation over water)	98	98	98	98
Trees	36	60	73	79
Low vegetation	39	61	74	80
Impervious	98	98	98	98
Agriculture	76	85	90	93
Buildings (and vegetation over buildings)	98	98	98	98
Permeable parking areas	77	86	91	94
Green roofs - slope ≤5°	86			
Green roofs - slope 5°-10°	89			
Green roofs - slope 10°-15°	90			
Green roofs - slope 15°-20°	91			
Green roofs - slope >20°	92			

We simulated a rain event of 20 mm, which is - in all three cities - among the ones where the relative effects of NBS implementation are the greatest (data not shown). To synthesise the performance of the different cities and scenarios in a comparable way, we chose the indicator “Runoff retention index”, defined as the percentage of rainfall that is retained in each area of analysis.

2.3. Assessing co-benefits of NBS implementation

Besides climate-change related benefits, NBS also provide a wide range of co-benefits. We selected three of them that cover different aspects related to ecosystem health and human wellbeing: biodiversity potential, recreation opportunities, and health and wellbeing benefits.

2.3.1. Biodiversity potential

The biodiversity potential was calculated for each block using the method by Radford and James (2013) and Pauleit et al. (2005). The potential is a function of land cover (structural) diversity and green area. The former is measured by computing a Shannon-Weaver index (D, equation 3-1). The index is then multiplied with the fraction of green area in each block. The share of green area was calculated by summing the area of all the green land cover classes (low vegetation, trees, green roof, agriculture, vegetation over building, and vegetation over water).

$$D = -\sum_{i=1}^{9} p_i log_2 p_i \qquad \text{(Equation 3-1)}$$

Where $p_{1\text{-}9}$ are the proportions of all the land cover classes.

2.3.2. Accessibility to urban parks

We measured distance from households as a proxy for accessibility to urban parks, hence for recreation opportunities offered to the population living in the three cities (La Rosa, 2014). The indicator is defined as the shortest distance between a building and a park, measured along the street network. For walking and biking, at least in flat or almost flat areas, network distance can be assumed proportional to travel time, hence to the "cost" of reaching the destination point (Scheurer and Curtis, 2007).

We created the network based on OSM data (tag: highway), excluding high-speed roads (tag: highway = (motorway OR motorway link OR primary OR primary link OR secondary OR secondary link OR trunk OR trunk link OR corridor)). Note that, if a footpath or a cycle route runs parallel to any of these roads, it is usually marked separately in the OSM database, hence it was included in the analysis.

Since our data did not provide any consistent information about building use, we set as origin points the centroids of all buildings above a certain size. The threshold was set to 50 m^2 of floor area in Malmo, 30 m^2 in Barcelona, and 28 m^2 in Utrecht, to account for the different building typologies that characterise the three cities. The population in each building was obtained from the UA. All selected buildings within a block were assigned the same population density, calculated by dividing the number of inhabitants within the block by the sum of building areas. This approach assumes similar building typologies within each UA polygon. Due to temporal mismatches between the UA data and the building maps, buildings falling within blocks with no inhabitants had to be excluded.

Destination points were obtained by intersecting the street network with park boundaries to identify potential access points to the parks. We also added the park centroids, to ensure that small parks not crossed by any path were included in the analysis. We calculated the distance from each building to the closest park. As a final indicator for each block, land use class, and city, we used the average distance over the area calculated by weighting the values for each building by the number of residents.

2.3.3. 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. In the literature, this simple index has been adopted to investigate the correlation between the surrounding greenness and health and wellbeing aspects related to 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 focus on benefits in terms of restoration and mental health, related to the amount of natural and semi-natural areas whose presence can be experienced by people in their surroundings, either by seeing or by directly accessing them. Since the greenness index is not based on accessibility, but accounts also for the presence of private or semi-private green areas such as gardens and schoolyards, and for green components such as street trees and hedges, it complements the analysis of park accessibility, providing a more complete picture of how the urban environment is perceived by people.

Different distances have been used in the literature to compute the greenness index and analyse its relationship with health and wellbeing indicators. Coherently with previous studies (Villeneuve et al., 2012, Amoly et al., 2014, Fuertes et al., 2014, Triguero-Mas et al., 2015), we used a buffer of 500 m around each point and calculated the share of area covered by “green” land covers. The latter include water, trees (including vegetation over buildings and over water), low vegetation, and agriculture. Green roofs are excluded, since in most cases they are not visible by people in the streets or inside buildings. Permeable parking areas are also excluded due to their use, which prevents their perception as green spaces when filled with cars.

Operationally, land cover maps for the current conditions and for 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 distance of at least 10 m from each other (N = 1,000,000 in Malmo, N = 852,443 in Barcelona, N = 657,795 in Utrecht). Average values were calculated per block, land use class, and city.

3. Result

3.1. NBS implementation scenarios

The three case study cities are characterised by a different current distribution of land covers (Figure B-1 and Appendix B1). The "green" classes - including water, trees, low vegetation, and agriculture - sum up to less than half of the total city area in Barcelona (around 45%) and more than 60% in both Utrecht and Malmö. Malmö shows the greatest share of agricultural areas within the city boundary, followed by Utrecht, 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 neighbourhoods surrounding the city core. However, each 1 m^2 of building footprint corresponds to less than 2 m^2 of impervious area in Barcelona, 2.3 m^2 in Utrecht, and more than 3.6 m^2 in Malmö. Existing parks, including both those identified in the Urban Atlas and the areas designated as parks in Open Street Maps, cover 12% of the city area in Utrecht, followed by Malmö (8.2%) and Barcelona (6.8%).

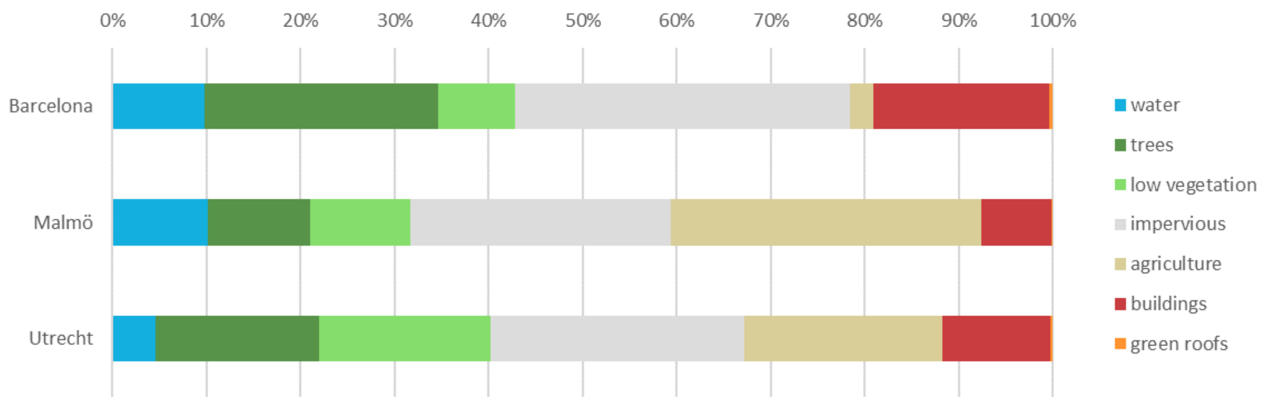

Figure B-1: Distribution of land cover in the Current scenario for the three analysed cities.

These different starting conditions affect the potential for NBS implementation simulated in the scenarios (Table B-8). By imposing rules to land cover transitions, we developed four scenarios of implementation of a specific NBS. The *GreenRoofs* scenario simulates the conversion of existing (non-green) roofs into green roofs (Figure B-2). The *ParkingAreas* scenario simulates the de-sealing of existing parking areas and their conversion into permeable surfaces (Figure B-2). The *Park* scenario involves the enhancement of vegetation in existing parks by planting more trees and converting part of the impervious areas to low vegetation, and the creation of new parks (Figure B-3). The *StreetTrees* scenario simulates planting street trees whenever sufficient space is available (Figure B-*4*). Additionally, we modelled the combined effects of the four scenarios in a fifth NBS implementation scenario called *GreenDream* (Figure B-*4*).

Table B-8: Summary of changes simulated in the NBS implementation scenarios.

	Barcelona	Malmö	Utrecht
City area (ha)	12,841	17,786	9,907
GreenRoofs			
change area (ha)	1,029	811	605
change area (% city)	8.0	4.6	6.1
building converted to green roof (% area)	41.9	60.3	51.7
ParkingAreas			
change area (ha)	78	160	118
change area (% city)	0.6	0.9	1.2
impervious area change over the city (%)	-1.7	-3.2	-3.9
Parks			
change area (ha)	248	487	272
change area (% city)	1.9	2.7	2.8
area existing parks (ha)	875	1,467	1,192
tree cover in parks - current (%)	38.7	37.5	41.6
low vegetation cover in parks – current (%)	19.8	34.6	34.4
area new parks (ha)	+37	+130	+65
tree cover in parks - scenario (%)	53.9	56.7	56.7
low vegetation cover in parks – scenario (%)	23.1	28.7	25.4
tree cover change over the city (%)	+4.7	+17.9	+12.9
impervious area change over the city (%)	-3.9	-5.4	-3.2
StreetTrees			
change area (ha)	102	229	112
change area (% city)	0.8	1.3	1.1
new street trees (n)	24,561	54,113	26,563
tree cover change over the city (%)	+3.2	+11.9	+6.5
GreenDream			
change area (ha)	1,450	1,675	1,098
change area (% city)	11.3	9.4	11.1
tree cover change over the city (%)	+7.8	+29.6	+19.2
impervious area change over the city (%)	-7.6	-12.8	-10.8

The land cover changes simulated in the scenarios amount to different shares of the city area, ranging from less than 1% of the *ParkingAreas* and *StreetTrees* scenarios in some of the analysed cities, to more than 10% of the *GreenDream* (Table B-8). The intensity of change simulated by each scenario also varies depending on the city. Due to its density, Barcelona outclass the other cities in the *GreenRoofs* scenario, which simulates the conversion of more than 8% of the city area, even if the share of built-up area involved is the smallest across the cities. The change 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 (1.2% of the city area, corresponding to a reduction of almost 4% of the area currently covered by impervious surfaces).

Utrecht and Malmö show a similar relative intensity of the total land cover change induced by the *Parks* scenario (around 2.7%), but with very different quantities involved. The area of new parks added in Malmö

(130 ha) is twice as large as the one added in Utrecht, and more than three times larger than the one added in Barcelona (35 ha). The increase in tree cover and the decrease in the share of impervious surfaces over the city are the greatest in Malmö, too: 17.9% and 5.4% respectively.

Malmö also shows the highest potential for street trees, both in absolute and relative terms. Here the *StreetTrees* scenario resulted in the addition of more than 54,000 new trees, more than double the number of those simulated in Barcelona and Utrecht, which leads to an increase in tree coverage of around 12% compared to the current condition. Overall, the combined effects of NBS implementation in the *GreenDream* scenario sum up to a value ranging between 9 and 11% in the three cities (Table B-8).

Figure B-2: A detail of the land cover maps of Barcelona in the Current (A), GreenDream (B), and ParkingAreas (C) scenarios, showing the effects of NBS implementation.

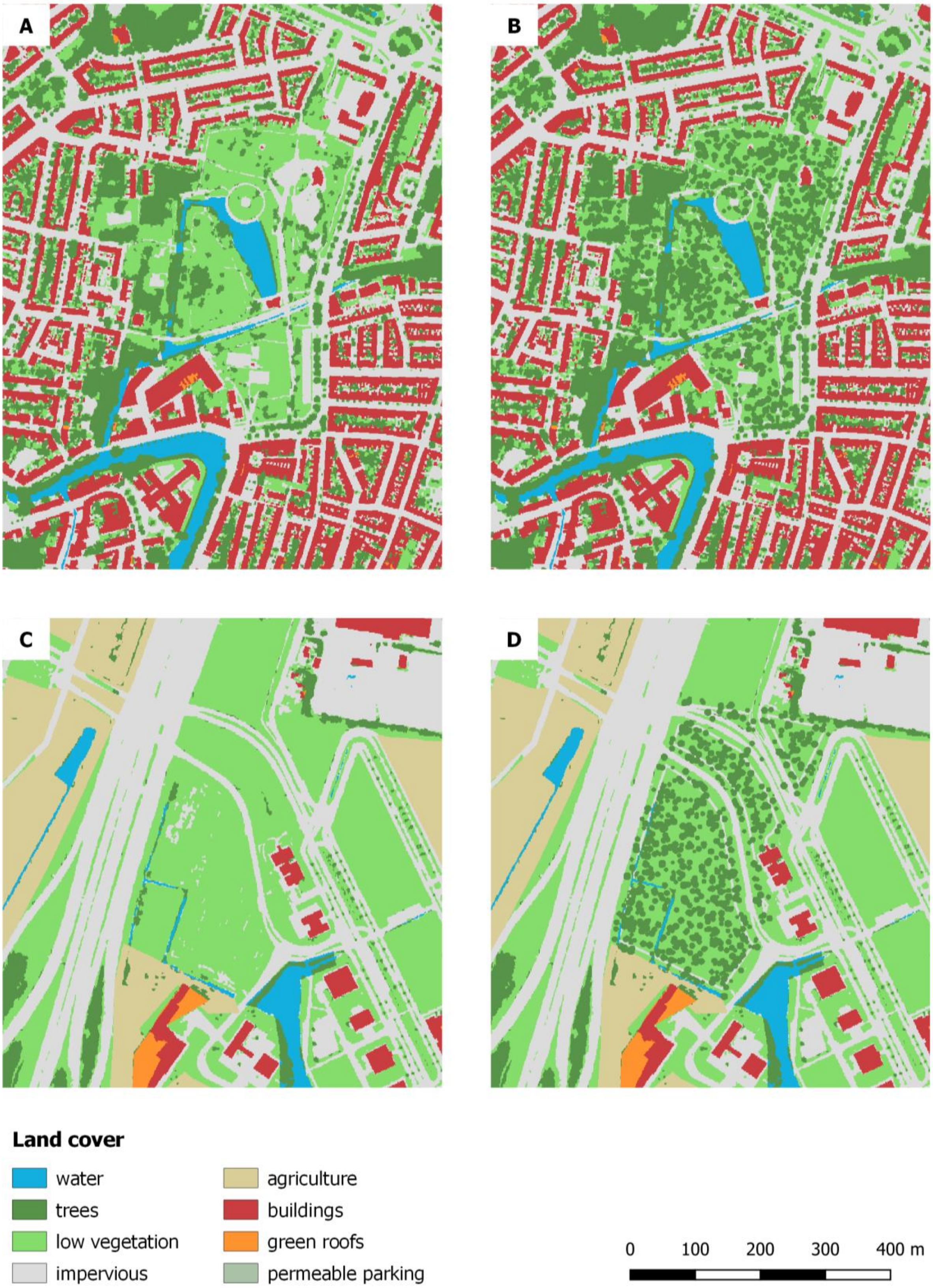

Figure B-3: A detail of the land cover maps of Utrecht in the Current (A and C), and Parks (B and D) scenarios, showing the effects of enhancing vegetation in existing parks (A and B) and creating new parks (C and D).

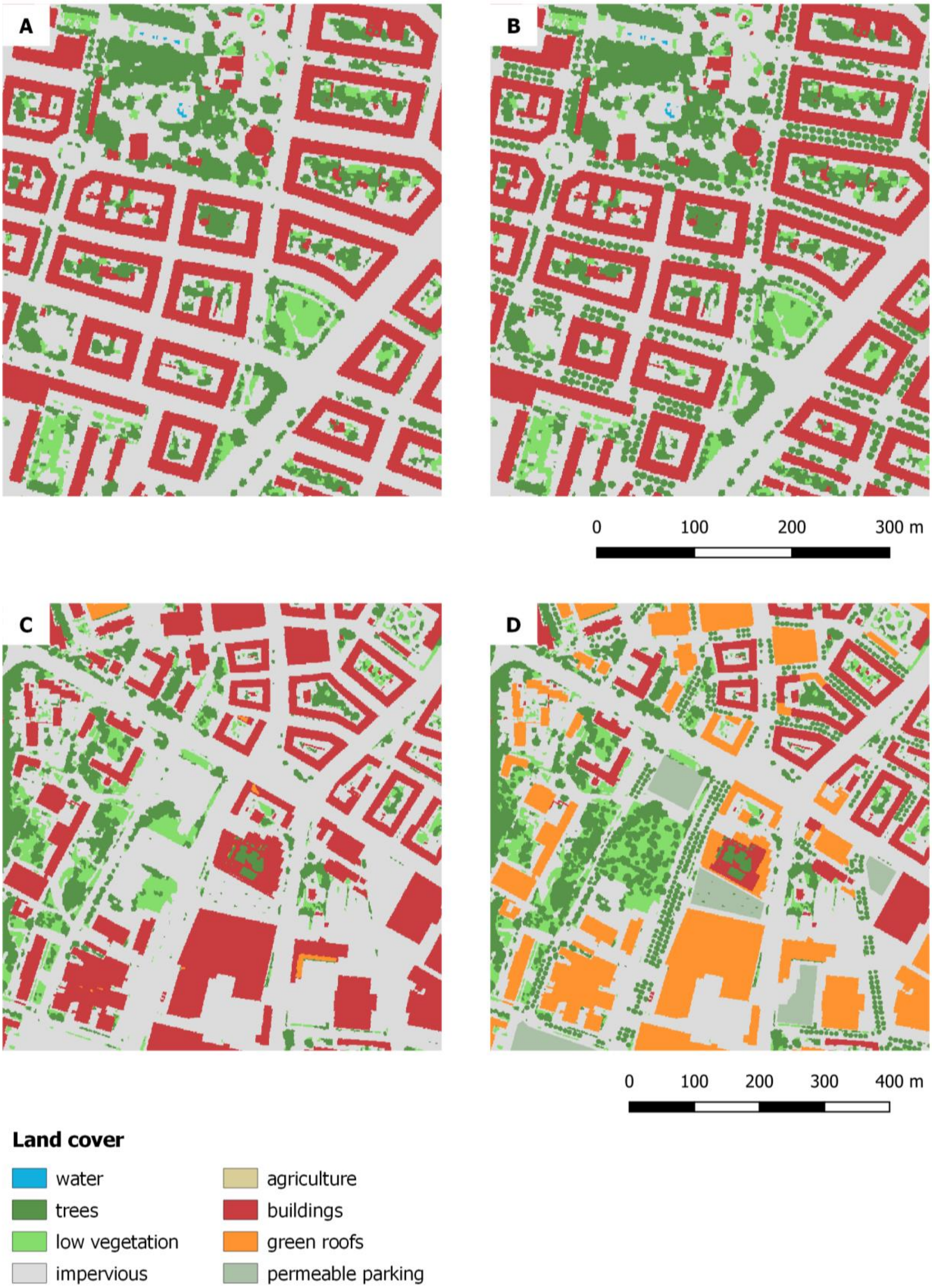

Figure B-4: A detail of the land cover maps of Malmö in the Current (A and C), StreetTrees (B), and GreenDream (D) scenarios, showing the effects of NBS implementation.

3.2. Climate change adaptation and mitigation benefits of NBS

We present, for each city, the result of climate change adaptation and mitigation benefits of NBS at three spatial scales; city (result presented in this section report), UA class (full result in Appendix B2), and UA block (full result in Appendix B3). The benefits presented are heat mitigation, carbon storage, and runoff reduction which are presented for all six land cover scenarios but separated by city in the sections below.

Heat Mitigation is presented as an average index which indicates the area's potential to reduce heat using green infrastructure. An area with index 1 has the maximum capacity to reduce heat with the help of shade, albedo, and evapotranspiration (an example could be a forest with good water availability). Heat mitigation 0 implies that green infrastructure is lacking in the area, or have no cooling capacity (an example could be an area without green or with just green roof with no water available, thus no evapotranspiration, no shade and potentially increased albedo). Heat mitigation is by model design not comparable across cities.

Carbon storage is presented as an average (ton/ha) of the steady state total carbon storage based on below and above ground pools. *Runoff reduction* is presented as an average value of how much, in percent, of a 20 mm rain event that can be retained in the area.

3.2.1. Barcelona

Heat mitigation is, for Barcelona, increasing in all scenarios (0.01-0.02 index change) except *ParkingAreas* compared to *Current* (Table B-9). However, when looking at the local level there are areas with a higher change in *heat mitigation*, up to 0.5 in the *GreenDream* scenario compared to *Current* (Figure B-5A).

Carbon storage is on the city level increasing in all scenarios (0.1-2.8 ton/ha change) compared to the current, with the highest increase in the *GreenDream*, followed by the *GreenRoofs* (Table B-9). However, we can see that single UA blocks are increasing with up to 11.5 ton/ha in the *GreenDream* scenario compared to *Current* (Figure B-5B).

Runoff reduction is on the city level increasing in all scenarios (0.2-5.8 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *GreenRoofs* (Table B-9). We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe a change of up to 56.6 % units in the *GreenDream* scenario compared to *Current* (Figure B-5C).

Table B-9. Summary result for climate change adaptation and mitigation benefits of NBS on the city level for Barcelona.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Heat Mitigation (index)	0.30	0.31	0.30	0.31	0.31	0.32
Carbon Storage (ton/ha)	28.0	29.2	28.1	28.9	28.6	30.8
Runoff Reduction (%)	50.2	54.3	50.4	51.2	50.8	56.0

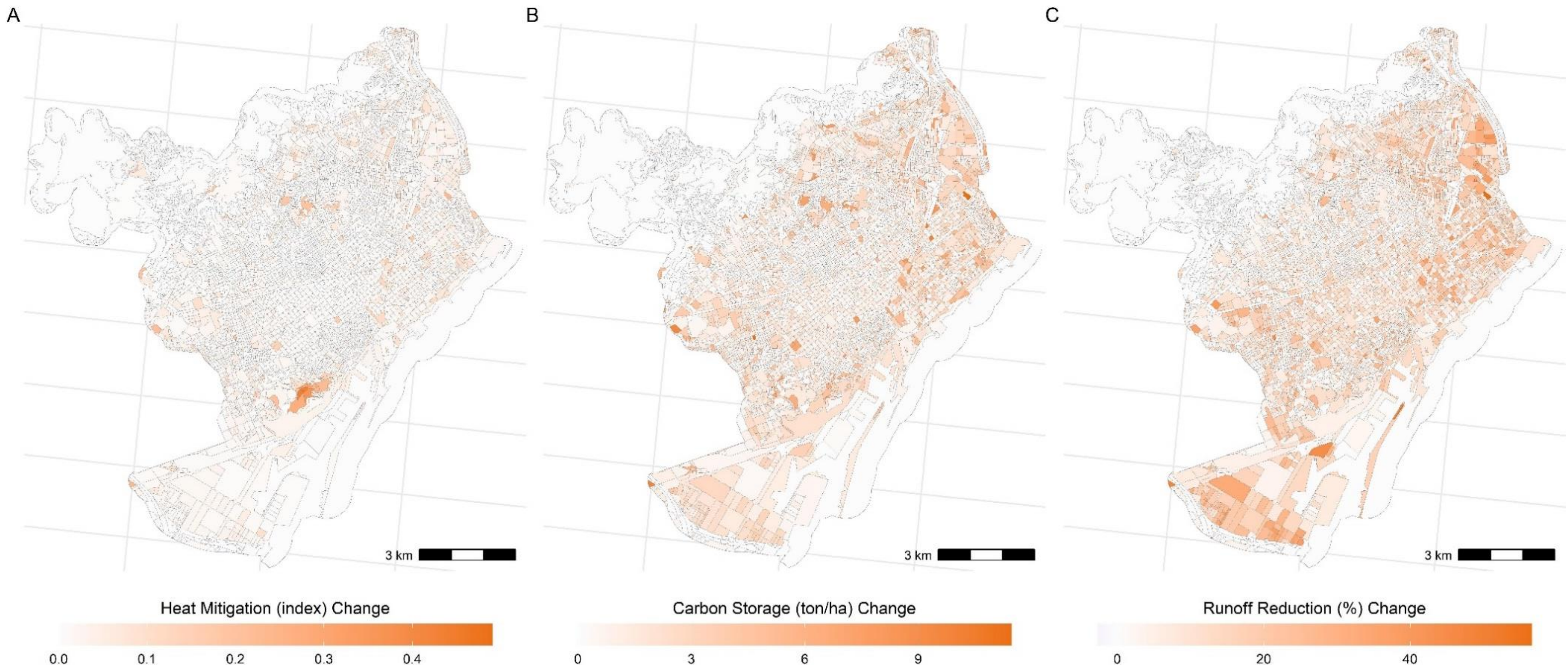

Figure B-1. Change in Barcelona between scenarios Current and GreenDream for; A: Heat mitigation (index), B: Carbon storage (ton/ha), C: Runoff reduction (%).

3.2.2. Malmö

Heat mitigation is, for Malmö, increasing in *Parks*, *StreetTrees*, and *GreenDream* scenarios (0.01-0.02 index change) compared to *Current* (Table B-10). However, when looking at the local level there are areas with a higher change in *heat mitigation*, up to 0.3 in the *GreenDream* scenario compared to *Current* (Figure B-6A). *Carbon storage* is on the city level increasing in all scenarios (0.2-7.4 ton/ha change) compared to the current, with the highest increase in the *GreenDream*, followed by the *StreetTrees* (Table B-10). However, we can see that single UA blocks can increase with up to 15.8 ton/ha in the *GreenDream* scenario compared to *Current* (Figure B-6B).

Runoff reduction is on the city level increasing in all scenarios (0.3-4.8 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *GreenRoofs* (Table B-10). We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe an change of up to 62.4 %-units in the *GreenDream* scenario compared to *Current* (Figure B-6C).

Table B-10. Summary result for climate change adaptation and mitigation benefits of NBS on the city level for Malmö.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Heat Mitigation (index)	0.26	0.26	0.26	0.28	0.27	0.28
Carbon Storage (ton/ha)	41.8	43.2	42.0	45.2	44.2	49.2
Runoff Reduction (%)	55.4	57.9	55.7	56.5	56.3	60.2

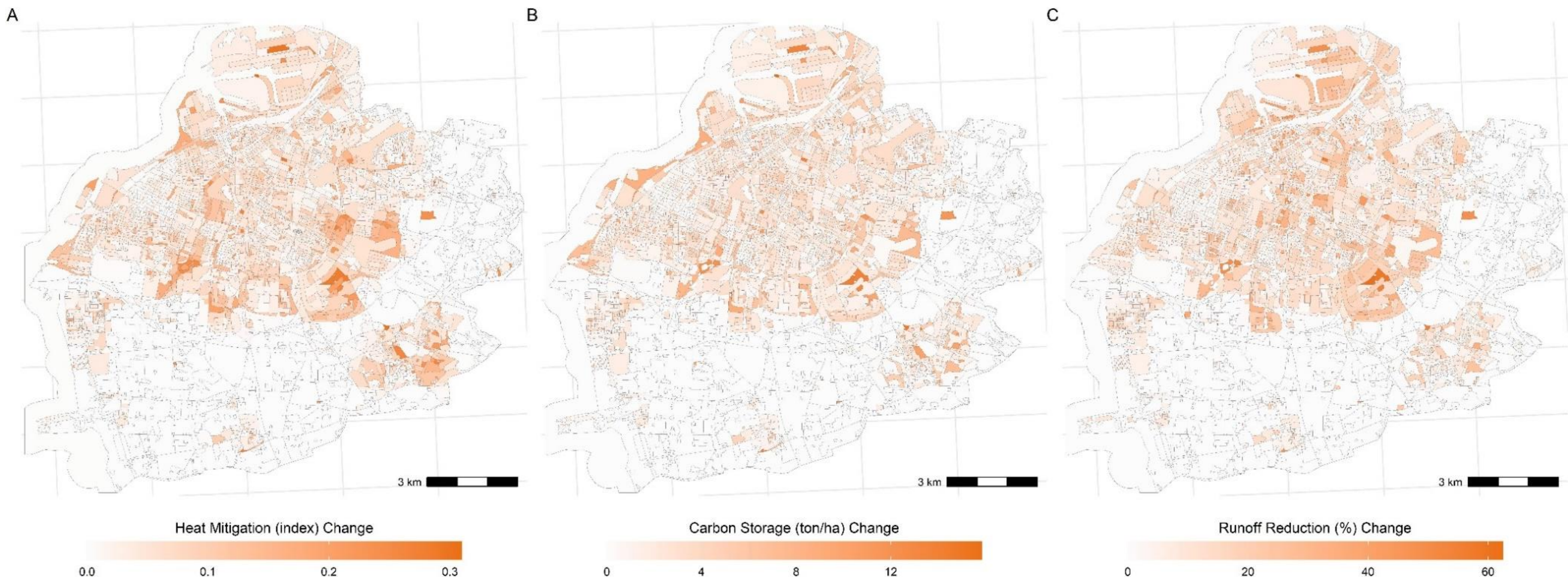

Figure B-2. Change in Malmö between scenarios Current and GreenDream for; A: Heat mitigation (index), B: Carbon storage (ton/ha), C: Runoff reduction (%).

3.2.3. Utrecht

Heat mitigation is, for Utrecht, increasing in *GreenRoofs*, *Parks*, *StreetTrees*, and *GreenDream* scenarios (0.01-0.02 index change) compared to *Current* (Table B-11). However, when looking at the local level there are areas with a higher change in *heat mitigation*, up to 0.3 in the *GreenDream* scenario compared to *Current* (Figure B-7A).

Carbon storage is on the city level increasing in all scenarios (0.2-5.8 ton/ha change) compared to the current, with the highest increase in the *GreenDream*, followed by the *Parks* (Table B-11). However, we can see that single UA blocks can increase with up to 14.9 ton/ha in the *GreenDream* scenario compared to *Current* (Figure B-7B).

Runoff reduction is on the city level increasing in all scenarios (0.4-5.2 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *GreenRoofs* (Table B-11). We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe a change of up to 53.6 %-units in the *GreenDream* scenario compared to *Current* (Figure B-7C).

Table B-11. Summary result for climate change adaptation and mitigation benefits of NBS on the city level for Utrecht.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Heat Mitigation (index)	0.50	0.51	0.50	0.51	0.51	0.52
Carbon Storage (ton/ha)	59.3	60.7	59.5	61.9	60.9	65.1
Runoff Reduction (%)	58.9	62.3	59.3	59.6	59.7	64.1

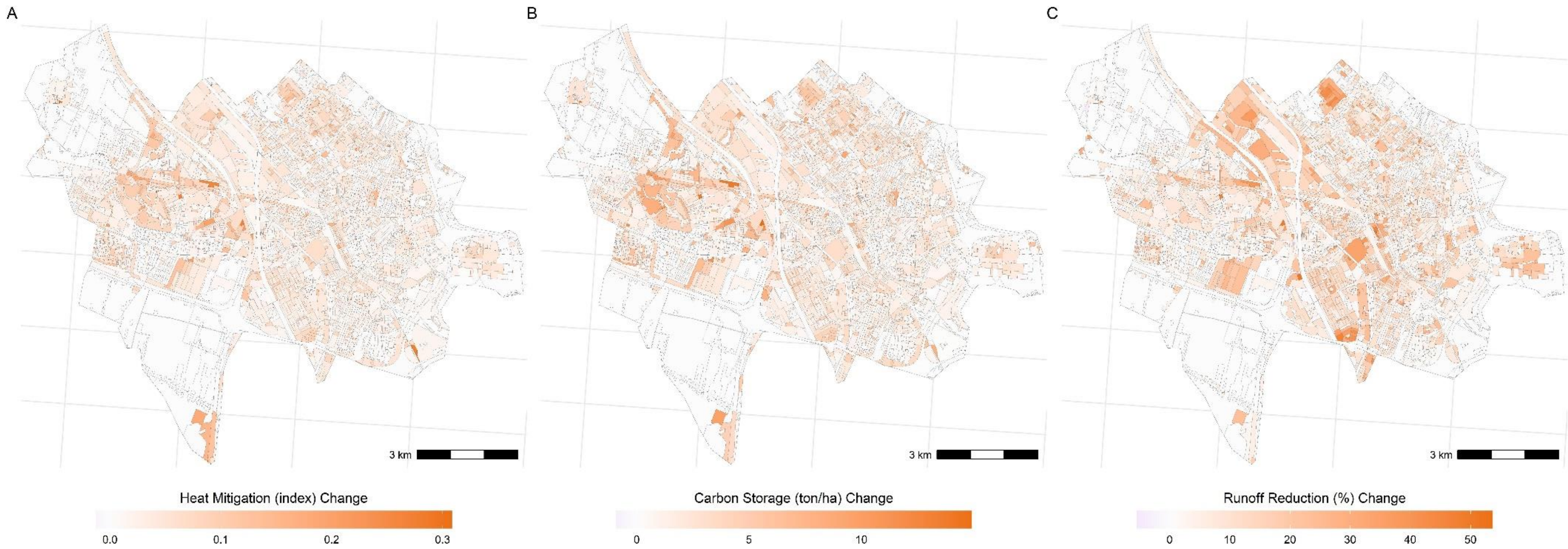

Figure B-3. Change in Utrecht between scenarios Current and GreenDream for; A: Heat mitigation (index), B: Carbon storage (ton/ha), C: Runoff reduction (%).

3.3. NBS co-benefits

We present, for each city, the result of NBS co-benefits at three spatial scales; city (result presented in this section report), UA class (full result in appendix B2), and UA block (full result in appendix B3). The co-benefits presented are biodiversity potential, accessibility and greenness which is presented for all six land cover scenarios but separated by city in the sections below.

Biodiversity potential is presented as an average index which indicates the potential of biodiversity based on the evenness of the landcover, scaled with the fractional green area content. A higher index indicates a higher potential.

Accessibility is presented as the average distance (m) per person from a building to the nearest urban park. The smaller the value of the indicator, the shorter the average distance that a resident in the analysed area needs to travel to reach the closest urban park. A positive change therefore corresponds to a reduction in the indicator. Note that only the *Parks* and the *GreenDream* scenarios affect this indicator, since they are the only ones involving a change in the urban parks.

Greenness is presented as the average percent share of "green" land cover classes within 500 m from points within the analysed area. A unit change in the indicator corresponds to an average 1% increase in the share of green cover in the surroundings.

3.3.1. Barcelona

Biodiversity Potential is, for Barcelona, increasing in all scenarios (0.02-0.22 index change) except *ParkingAreas* compared to *Current*, with the highest increase in *GreenDream* followed by *GreenRoofs* (Table B-12). However, when looking at the local level there are areas with a higher change *Biodiversity Potential*, up to 1.5 in the *GreenDream* scenario compared to *Current* and some areas with a decrease (A).

Accessibility is on the city level decreasing for *Parks* and *GreenDream* scenarios (-1.5 m change for both) compared to the current (Table B-12). However, we can see that single UA blocks are decreasing with up to 1717 m in the *GreenDream* scenario compared to *Current* (B).

Greenness is on the city level increasing for *Parks*, *StreetTrees*, and *GreenDream* (0.7-2.0 8 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *Parks* (Table B-12). We also observe a decrease of 0.1 %-units in the *ParkingAreas* scenario. We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe a change of up to 10.8 %-units in the *GreenDream* scenario compared to *Current* (C).

Table B-12. Summary result for NBS co-benefits on the city level for Barcelona.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Biodiversity Potential (index)	0.37	0.54	0.37	0.39	0.39	0.59
Accessibility (m)	258.8	258.8	258.8	257.3	258.8	257.3
Greenness (%)	45.4	45.4	45.3	46.7	46.1	47.4

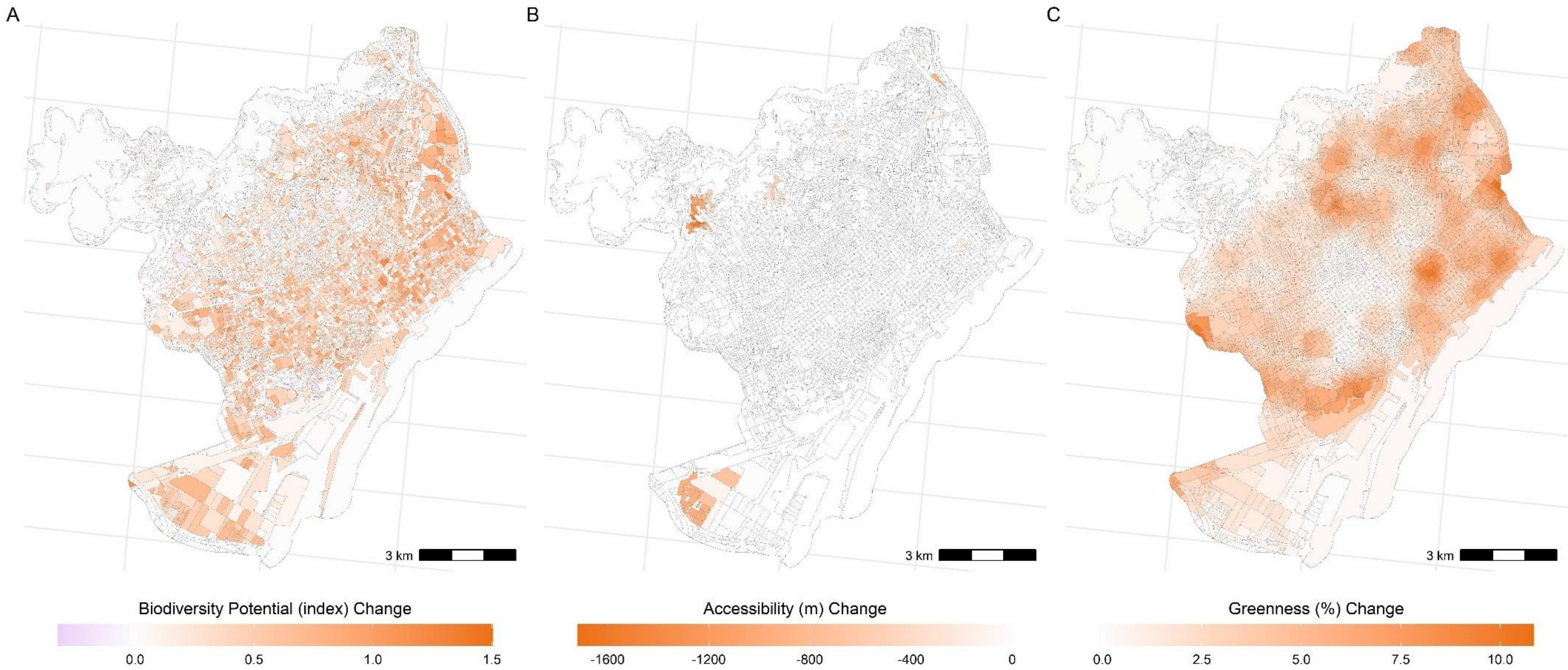

Figure B-4. Change in Barcelona between scenarios Current and GreenDream for A: Biodiversity Potential (index), B: Accessibility (m), C: Greenness (%). Note: white polygons (in panel B) indicate missing data due to no population living there.

3.3.2. Malmö

Biodiversity Potential is, for Malmö, increasing in all scenarios (0.01-0.21 index change) compared to *Current*, with the highest increase in *GreenDream* followed by *GreenRoofs* (Table B-13). However, when looking at the local level there are areas with a higher change *Biodiversity Potential*, up to 1.3 in the *GreenDream* scenario compared to *Current* and some areas with a decrease (Figure B-9A).

Accessibility is on the city level decreasing for *Parks* and *GreenDream* scenarios (-1.3 m change for both) compared to the current (Table B-13). However, we can see that single UA blocks are decreasing with up to 1265 m in the *GreenDream* scenario compared to *Current* (Figure B-9B).

Greenness is on the city level increasing for *Parks*, *StreetTrees*, and *GreenDream* (1.2-2.6 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *Parks* (Table B-13). We also observe a decrease of 0.1 %-units in the *ParkingAreas* scenario. We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe a change of up to 24.6 %-units in the *GreenDream* scenario compared to *Current* (Figure B-9C).

Table B-13. Summary result for NBS co-benefits on the city level for Malmö.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Biodiversity Potential (index)	0.60	0.72	0.61	0.63	0.65	0.81
Accessibility (m)	220.8	220.8	220.8	219.5	220.8	219.5
Greenness (%)	64.8	64.8	64.7	66.2	66.0	67.4

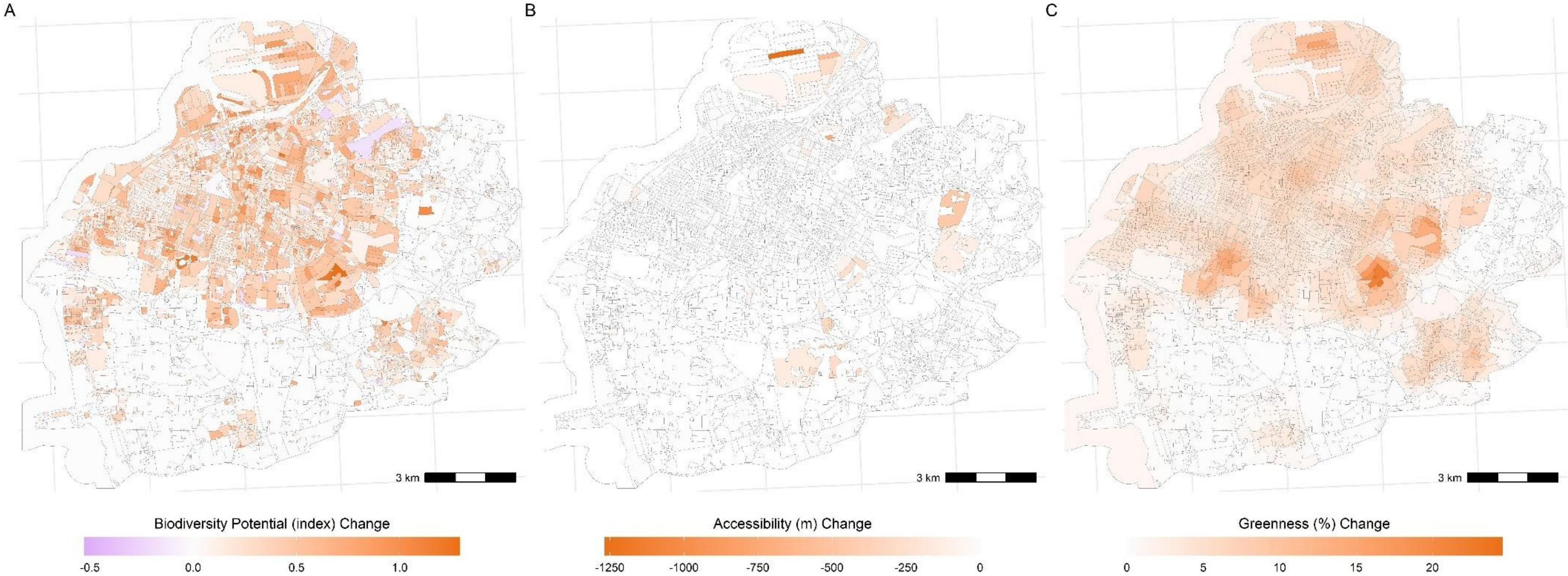

Figure B-5. Change in Malmö between scenarios Current and GreenDream for A: Biodiversity Potential (index), B: Accessibility (m), C: Greenness (%). Note: white polygons (in panel B) indicate missing data due to no population living there.

3.3.3. Utrecht

Biodiversity Potential is, for Utrecht, increasing in all scenarios (0.01-0.21 index change) except for *ParkingAreas* compared to *Current*, with the highest increase in *GreenDream* followed by *GreenRoofs* (Table B-14). However, when looking at the local level there are areas with a higher change *Biodiversity Potential*, up to 1.2 in the *GreenDream* scenario compared to *Current* and some areas with a decrease (Figure B-10A).

Accessibility is on the city level decreasing for *Parks* and *GreenDream* scenarios (-10.3 m change for both) compared to the current (Table B-14). However, we can see that single UA blocks are decreasing with up to 703 m in the *GreenDream* scenario compared to *Current* (Figure B-10B).

Greenness is on the city level increasing for *Parks*, *StreetTrees*, and *GreenDream* (0.9-1.8 %-units change) compared to the current with the highest increase in the *GreenDream*, followed by the *Parks* (Table B-14). We also observe a decrease of 0.1 %-units in the *ParkingAreas* scenario. We see similar patterns, as the other two benefits, with single UA blocks increasing more, and observe a change of up to 9.8 %-units in the *GreenDream* scenario compared to *Current* (Figure B-10C).

Table B-14. Summary result for NBS co-benefits on the city level for Utrecht.

	Current	***GreenRoofs***	***ParkingAreas***	***Parks***	***StreetTrees***	***GreenDream***
Biodiversity Potential (index)	0.67	0.82	0.67	0.68	0.70	0.88
Accessibility (m)	240.6	240.6	240.6	230.3	240.6	230.3
Greenness (%)	61.1	61.1	61.0	62.0	62.2	62.9

Figure B-6. Change in Utrecht between scenarios Current and GreenDream for A: Biodiversity Potential (index), B: Accessibility (m), C: Greenness (%). Note: white polygons (in panel B) indicate missing data due to no population living there.

4. Discussion and Conclusion

A full implementation of NBS to improve climate change adaptation and mitigation produces, according to our *GreenDream* scenario, a change of about 10 % of each city's land area. The largest change is due to the implementation of green roofs, followed by actions to enhance urban parks, street tree planting, and de-sealing of parking areas. To demonstrate what NBS interventions could realistically be pursued in the near future, we did not include in the scenarios any action that involves a change of existing land uses, except for abandoned or unused areas, and all buildings and transportation networks were preserved. Hence, there exists an additional unknown potential outside of the simulated scenarios, if other and more intense land-use changes are considered. However, even within the defined restrictions, a change of 10% implies a relevant transformation including, for example, planting more than 24 000 street trees or converting more than 40% of the roof area to green roofs.

Overall, the results of the assessment in the three case study cities reveal that NBS provide multiple benefits, but with a different potential to address different challenges. Regarding climate change adaptation and mitigation benefits, none of our scenarios reveals a strong increase in heat mitigation in the analysed cities, with <1 to 2 percent points increases in the average heat mitigation capacity at the city scale. Runoff retention increases in all cities by about 5 percent points in the *GreenDream* scenario, with the greatest contribution from the implementation of green roofs. As for climate mitigation, carbon storage capacity increases in the *GreenDream* scenario between 10 to 18 %, with Malmö showing the largest potential both in percent and in absolute terms (7.4 tons/ha). Among the scenarios considering a single NBS type, the *GreenRoofs* scenario in Barcelona has the strongest potential to increase carbon storage, while in Malmö and Utrecht the *Parks* scenario has the greatest effects. However, under many circumstances, the expected climate adaptation benefits could be greater than the presented results, given that we modelled heat mitigation and runoff retention under conservative conditions. For example, we did not consider the water storage capacity of green roofs, which can significantly reduce runoff for small rain events (Fassman-Beck et al., 2016), and simulated green roofs cooling capacity under low water availability (low crop coefficient) resulting in a low evapotranspiration and cooling.

Regarding the analysed co-benefits, greenness increases in *Parks*, *StreetTrees* and *GreenDream* scenarios, but is unaffected by the implementation of green roofs and de-sealing of parking areas. Greenness decreases in all cities in the *ParkingAreas* scenario, since some areas of low vegetation are converted by the algorithm to permeable parking areas, which are not included in the estimation of the greenness index. Accessibility to urban parks is affected only by the creation of new parks in the *Parks* and *GreenDream* scenarios. In Utrecht we see the largest effect on accessibility, with the average distance to the closest urban park decreasing by 10 meters. Accessibility improves also in Barcelona and Malmö, but with a reduction in the average distance of less than two meters. Much stronger effects on accessibility can be observed locally. Finally, the biodiversity index is increasing in most scenarios, for all cities. Comparing the *Current* and *GreenDream* scenarios, the biodiversity potential is increasing by 60% for Barcelona, by 35% for Malmö, and by 31% for Utrecht. Locally, some negative effects on biodiversity potential are generated in the *Parks* scenario. This can be explained by the fact that, in few areas, NBS implementation decreases local-scale habitat diversity, which is at the basis of the adopted index (Radford and James, 2013).

This evidence about the provision of multiple benefits, not limited to climate change adaptation and mitigation, is coherent with the literature on NBS in urban contexts (Kabisch et al., 2016) and justifies policies supporting NBS implementation to take advantage of synergies in the provision of urban ecosystem services (European Commission, 2015). Our analysis focused on a limited set of co-benefits, but NBS are expected to provide additional benefits (Raymond et al., 2017), some of which are currently not easy or possible to assess ex-ante (e.g., social cohesion). Furthermore, the results at the city scale do not highlight any trade-offs among the analysed benefits and co-benefits. Only in a few cases do we observe, at the level of single blocks, negative effects produced by NBS implementation on biodiversity potential and greenness. This lack of trade-offs is coherent with a view of NBS as win-win strategies and with the literature on urban ecosystem services, which shows limited trade-offs among ecosystem services in cities (differently, for example, from what emerges about ecosystem services related to the management of productive landscapes) (Howe et al., 2014).

In the case of NBS in cities, trade-offs can be expected more frequently to emerge at the decision-making level (Shoemaker et al., 2019), where critical decisions are to be made about which NBS should be prioritised and where, i.e. how to distribute available resources. 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, more efficient NBS might require a change in land use, as in the case of new parks, while others might provide less benefits per unit area but coexist with current land uses, as is the case of permeable parking areas, street trees, or green roofs. In this context, scenarios can support decision-making by envisioning possible futures and the impacts of alternative options and their trade-offs (EEA, 2009).

It should also be mentioned that, beyond the analysed benefits and co-benefits, an extensive implementation of NBS such as the one depicted in our scenarios generates the risk of an increase in ecosystem dis-services (von Döhren and Haase, 2015). For example, extensive planting interventions might increase the allergenic potential or result in more damage to infrastructures by vegetation. However, these aspects often depend on specific features of NBS that can be addressed by a careful design and management of the solutions (e.g., species selection, correct location, maintenance, etc.) (Tiwary et al., 2016).

As revealed by our analysis, the full potential of NBS at the city scale depends on two factors: 1) the existing possibilities of NBS integration in the urban fabric of the cities, and 2) the capacity of the solution itself to deliver the selected benefits in certain conditions. These two factors, combined, explain why the same scenario performs better in one city compared to another and they should be both considered when assessing

the effectiveness of NBS in a certain context. In our approach, the first aspect is addressed and revealed by the results about the scenarios, while the second aspect is considered in the setup of the assessment methods, including input data used. In this context, breaking down the results by land use class can be a starting point to analyse the relation between NBS potential and urban fabric, and its variation across cities.
However, it should be taken into account that the benefits experienced in a certain area are affected not only by the NBS implemented therein, but also by the actual flow of ecosystem services, which might be enjoyed in areas different from where they are produced (Fisher et al., 2009). This is true, for example, in the case of heat mitigation, where proximity to large green areas affects the condition of the surroundings, as well as for cultural ecosystem services that are controlled by access mechanisms (e.g., recreation) (Geneletti et al., 2020). The role played by these local effects on the results aggregated by land use class is not easy to discriminate. The more detailed analysis at the block level is useful also from this perspective, and essential to capture the variations in the benefits across the city. Compared to analyses based on land use classes, our assessment grounded on the preliminary detailed classification of land cover allows the identification of specific areas that experience greater NBS benefits due to location and current conditions (e.g., a block far from existing green areas but close to a brownfield where a new park could be created). This detailed resolution opens to the possibility of further investigating the results in a perspective of distributional equity (La Rosa and Pappalardo, 2019) and, if combined with additional socio-economic data, to identify winners and losers of NBS interventions among populating groups (Nesbitt et al., 2019).

To conclude, we analysed three cities with very different conditions in terms of climate, size, and urban form. The potential for integrating different types of NBS in the three contexts is different, as is the full potential of NBS implementation to mitigate and adapt to climate change. However, the results for Barcelona, Malmö, and Utrecht consistently show an increase in heat mitigation, carbon storage, and runoff retention, and the provision of additional co-benefits such as increased biodiversity potential, greenness, and accessibility to urban parks.

Acknowledgement

This work could not have been done without the help of many people who provided or supported us in the retrieval of local data, particularly Dr. Francesc Baró (UAB) and Dr. Luís Campos Rodrigues (ENT) for Barcelona; Åke Hesslekrans, Tim Delshammar, and Mozafar Veysipanah (Malmö stad) for Malmö; and Ton Dassen, Martjin Spoon, and Clara Veerkamp (PBL) for Utrecht.

References

ABDI, A. M. 2020. Land cover and land use classification performance of machine learning algorithms in a boreal landscape using Sentinel-2 data. *GIScience & Remote Sensing,* 57**,** 1-20.

ALLEN, R. G., MORTON, C., KAMBLE, B., KILIC, A., HUNTINGTON, J., THAU, D., GORELICK, N., ERICKSON, T., MOORE, R. & TREZZA, R. EEFlux: A Landsat-based evapotranspiration mapping tool on the Google Earth Engine. 2015 ASABE/IA Irrigation Symposium: Emerging Technologies for Sustainable Irrigation-A Tribute to the Career of Terry Howell, Sr. Conference Proceedings, 2015. American Society of Agricultural and Biological Engineers, 1-11.

AMOLY, E., DADVAND, P., FORNS, J., LÓPEZ-VICENTE, M., BASAGAÑA, X., JULVEZ, J., ALVAREZ-PEDREROL, M., NIEUWENHUIJSEN, M. J. & SUNYER, J. 2014. Green and blue spaces and behavioral development in Barcelona schoolchildren: the BREATHE project. *Environmental health perspectives,* 122**,** 1351-8.

BÖRJESON, L., HÖJER, M., DREBORG, K. H., EKVALL, T. & FINNVEDEN, G. 2006. Scenario types and techniques: Towards a user's guide. *Futures,* 38**,** 723-739.

CLIMATE-DATA.ORG. 2020. Available: CLIMATE-DATA.ORG [Accessed 2020].

DADVAND, P., NIEUWENHUIJSEN, M. J., ESNAOLA, M., FORNS, J., BASAGAÑA, X., ALVAREZ-PEDREROL, M., RIVAS, I., LÓPEZ-VICENTE, M., DE CASTRO PASCUAL, M., SU, J. G., JERRETT, M., QUEROL, X. & SUNYER, J. 2015. Green spaces and cognitive development in primary schoolchildren. *Proceedings of the National Academy of Sciences of the United States of America,* 112**,** 7937-7942.

DAMMERS, E., VEERKAMP, C., RUIJS, A., HEDLUND, K., OLSSON, P., ALSTERBERG, C., HANSON, H., LUNDMARK, L., OLSSON, J., PINTER, L., ALMASSY, D., ROCHA, S., WERNER , A., BOCKARJOVA, M. & BULKELEY, H. 2019. Working paper: Set up, applicability and use of the Naturvation Index. *Report to the European commission, deliverable 3.4 of the Naturvation project, https://www.naturvation.eu/result/urban-nature-navigator.*

DAVIES, Z. G., EDMONDSON, J. L., HEINEMEYER, A., LEAKE, J. R. & GASTON, K. J. 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of applied ecology,* 48**,** 1125-1134.

DJAMAN, K. & IRMAK, S. 2013. Actual crop evapotranspiration and alfalfa-and grass-reference crop coefficients of maize under full and limited irrigation and rainfed conditions. *Journal of Irrigation and Drainage Engineering,* 139**,** 433-446.

DJEDJIG, R., OULDBOUKHITINE, S.-E., BELARBI, R. & BOZONNET, E. 2012. Development and validation of a coupled heat and mass transfer model for green roofs. *International Communications in Heat and Mass Transfer,* 39**,** 752-761.

EDMONDSON, J. L., O'SULLIVAN, O. S., INGER, R., POTTER, J., MCHUGH, N., GASTON, K. J. & LEAKE, J. R. 2014. Urban tree effects on soil organic carbon. *PloS one,* 9**,** e101872.

EEA 2009. Looking back on looking forward: a review of evaluative scenario literature. Luxembourg.

EEA 2010. Mapping guide for a European Urban Atlas, European Environment Agency. *http://www.eea.europa.eu/data-and-maps/data/urban-atlas#tab-methodology.* Copenhagen.

EUROPEAN COMMISSION 2015. Towards an EU Research and Innovation Policy Agenda for Nature-based Solutions & Re-naturing Cities: Final Report of the Horizon 2020 Expert Group on'Nature-based Solutions and Re-naturing Cities'.

FASSMAN-BECK, E., HUNT, W., BERGHAGE, R., CARPENTER, D., KURTZ, T., STOVIN, V. & WADZUK, B. 2016. Curve number and runoff coefficients for extensive living roofs. *Journal of Hydrologic Engineering,* 21**,** 04015073.

FISHER, B., TURNER, R. K. & MORLING, P. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics,* 68**,** 643-653.

FRIEDMAN, A. 2015. Design strategies for integration of green roofs in sustainable housing. *VITRUVIO - International Journal of Architectural Technology and Sustainability***,** 57-57.

FUERTES, E., MARKEVYCH, I., VON BERG, A., BAUER, C. P., BERDEL, D., KOLETZKO, S., SUGIRI, D. & HEINRICH, J. 2014. Greenness and allergies: Evidence of differential associations in two areas in Germany. *Journal of Epidemiology and Community Health,* 68**,** 787-790.

GAFFIN, S. R., KHANBILVARDI, R. & ROSENZWEIG, C. 2009. Development of a green roof environmental monitoring and meteorological network in New York City. *Sensors,* 9**,** 2647-2660.

GENELETTI, D., CORTINOVIS, C., ZARDO, L. & ESMAIL, B. A. 2020. Planning for Ecosystem Services in Cities.

GETTER, K. L., ROWE, D. B. & ANDRESEN, J. A. 2007. Quantifying the effect of slope on extensive green roof stormwater retention. *Ecological Engineering,* 31**,** 225-231.

GRÊT-REGAMEY, A., GALLEGUILLOS-TORRES, M., DISSEGNA, A. M. & WEIBEL, B. 2020. How urban densification influences ecosystem services – a comparison between a temperate and a tropical city. *Environmental Research Letters***,** 0-11.

GRIZONNET, M., MICHEL, J., POUGHON, V., INGLADA, J., SAVINAUD, M. & CRESSON, R. 2017. Orfeo ToolBox: open source processing of remote sensing images. *Open Geospatial Data, Software and Standards,* 2**,** 1-8.

GRUNWALD, L., HEUSINGER, J. & WEBER, S. 2017. A GIS-based mapping methodology of urban green roof ecosystem services applied to a Central European city. *Urban Forestry and Urban Greening,* 22**,** 54-63.

HENGL, T., DE JESUS, J. M., HEUVELINK, G. B. M., GONZALEZ, M. R., KILIBARDA, M., BLAGOTIĆ, A., SHANGGUAN, W., WRIGHT, M. N., GENG, X., BAUER-MARSCHALLINGER, B., GUEVARA, M. A., VARGAS, R., MACMILLAN, R. A., BATJES, N. H., LEENAARS, J. G. B., RIBEIRO, E., WHEELER, I., MANTEL, S. & KEMPEN, B. 2017. SoilGrids250m: Global gridded soil information based on machine learning. *PLoS ONE,* 12**,** 1-40.

HIEDERER, R. & KÖCHY, M. 2011. Global soil organic carbon estimates and the harmonized world soil database. *EUR,* 79**,** 25225.

HOWE, C., SUICH, H., VIRA, B. & MACE, G. M. 2014. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Global Environmental Change,* 28**,** 263-275.

INSTITUTO NACIONAL DE ESTADÍSTICA. 2020. *Open online data* [Online]. Available: https://www.ine.es/nomen2/index.do?accion=busquedaAvanzada&entidad_amb=no&codProv=08&codMuni=19&codEC=0&codES=0&codNUC=0&denominacion_op=like&denominacion_txt=&L=1 [Accessed 2020].

KABISCH, N., FRANTZESKAKI, N., PAULEIT, S., NAUMANN, S., DAVIS, M., ARTMANN, M., HAASE, D., KNAPP, S., KORN, H., STADLER, J., ZAUNBERGER, K. & BONN, A. 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas - perspectives on indicators, knowledge gaps, barriers and opportunities for action. *Ecology and Society,* 21.

KARTERIS, M., THEODORIDOU, I., MALLINIS, G., TSIROS, E. & KARTERIS, A. 2016. Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roofs implementation in Thessaloniki, Northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data. *Renewable and Sustainable Energy Reviews,* 58**,** 510-525.

KREKEL, C., KOLBE, J. & WÜSTEMANN, H. 2016. The greener, the happier? The effect of urban land use on residential well-being. *Ecological Economics,* 121**,** 117-127.

KWOK, A. G. & GRONDZIK, W. T. 2007. The Green Studio Handbook: Environmental Strategies for Schematic Design. *ARCC Journal,* 4**,** 43-50.

LA ROSA, D. 2014. Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context. *Ecological Indicators,* 42**,** 122-134.

LA ROSA, D. & PAPPALARDO, V. 2019. Planning for spatial equity - A performance based approach for sustainable urban drainage systems. *Sustainable Cities and Society***,** 101885.

LANGEMEYER, J., WEDGWOOD, D., MCPHEARSON, T., BARÓ, F., MADSEN, A. L. & BARTON, D. N. 2020. Creating urban green infrastructure where it is needed – A spatial ecosystem service-based decision analysis of green roofs in Barcelona. *Science of the Total Environment,* 707.

LAZZARIN, R. M., CASTELLOTTI, F. & BUSATO, F. 2005. Experimental measurements and numerical modelling of a green roof. *Energy and Buildings,* 37**,** 1260-1267.

LINDÉN, L., RIIKONEN, A., SETÄLÄ, H. & YLI-PELKONEN, V. 2020. Quantifying carbon stocks in urban parks under cold climate conditions. *Urban Forestry & Urban Greening,* 49**,** 126633.

MAAS, J., VERHEIJ, R. A., DE VRIES, S., SPREEUWENBERG, P., SCHELLEVIS, F. G. & GROENEWEGEN, P. P. 2009. Morbidity is related to a green living environment. *Journal of Epidemiology & Community Health,* 63**,** 967-973.

MATHEY, J., RÖßLER, S., BANSE, J., LEHMANN, I. & BRÄUER, A. 2015. Brownfields as an element of green infrastructure for implementing ecosystem services into urban areas. *Journal of Urban Planning and Development,* 141**,** A4015001.

MCPHEARSON, T., KREMER, P. & HAMSTEAD, Z. A. 2013. Mapping ecosystem services in New York City: Applying a social-ecological approach in urban vacant land. *Ecosystem Services,* 5**,** 11-26.

NEDKOV, S., ZHIYANSKI, M., NIKOLOVA, M., GIKOV, A., NIKOLOV, P. & TODOROV, L. Mapping of carbon storage in urban ecosystems: a Case study of Pleven District, Bulgaria. Conference paper, Conference: Geographical aspects of land use and planning under climate change, At Varshets, Bulgaria,, Volume, 2016.

NESBITT, L., MEITNER, M. J., GIRLING, C. & SHEPPARD, S. R. J. 2019. Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning,* 181**,** 51-79.

NOWAK, D. J. & CRANE, D. E. 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental pollution,* 116**,** 381-389.

NRCS 1986. Urban Hydrology for Small Watersheds TR-55.

NRCS 2007. Chapter 7 Hydrologic Soil Groups.

OPEN STREET MAP, C. 2020. Planet dump retrieved from https://planet.osm.org.

PAULEIT, S., ENNOS, R. & GOLDING, Y. 2005. Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK. *Landscape and urban planning,* 71**,** 295-310.

POUYAT, R. V., YESILONIS, I. D. & GOLUBIEWSKI, N. E. 2009. A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosystems,* 12**,** 45-62.

RADFORD, K. G. & JAMES, P. 2013. Changes in the value of ecosystem services along a rural–urban gradient: A case study of Greater Manchester, UK. *Landscape and urban planning,* 109**,** 117-127.

RAYMOND, C. M., FRANTZESKAKI, N., KABISCH, N., BERRY, P., BREIL, M., NITA, M. R., GENELETTI, D. & CALFAPIETRA, C. 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy,* 77**,** 15-24.

ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE. 2020. *Klimaattabel De Bilt, langjarige gemiddelden, tijdvak 1981–2010* [Online]. Available: http://www.klimaatatlas.nl/klimaatatlas.php [Accessed 2020].

SANTOS, T., TENEDÓRIO, J. A. & GONÇALVES, J. A. 2016. Quantifying the city's green area potential gain using remote sensing data. *Sustainability (Switzerland),* 8**,** 1-16.

SCHEURER, J. & CURTIS, C. 2007. Accessibility measures: overview and practical applications.

SCHWARZ, C. 2015. Green roof energy balances for native grasses and sedum.

SHANGGUAN, W., HENGL, T., MENDES DE JESUS, J., YUAN, H. & DAI, Y. 2017. Mapping the global depth to bedrock for land surface modeling. *Journal of Advances in Modeling Earth Systems,* 9**,** 65-88.

SHARP, R., DOUGLASS, J., WOLNY, S., ARKEMA, K., BERNHARDT, J., BIERBOWER, W., CHAUMONT, N., DENU, D., FISHER, D., GLOWINSKI, K., GRIFFIN, R., GUANNEL, G., GUERRY, A., JOHNSON, J., HAMEL, P., KENNEDY,

C., KIM, C. K., LACAYO, M., LONSDORF, E., MANDLE, L., ROGERS, L., SILVER, J., TOFT, J., VERUTES, G., VOGL, A. L., WOOD, S. & WYATT, K. 2020. InVEST 3.8.7 User's Guide.

SHOEMAKER, D. A., BENDOR, T. K. & MEENTEMEYER, R. K. 2019. Anticipating trade-offs between urban patterns and ecosystem service production: Scenario analyses of sprawl alternatives for a rapidly urbanizing region. *Computers, Environment and Urban Systems,* 74**,** 114-125.

STATISTICS SWEDEN. 2020. *50 largest municipalities by population* [Online]. Available: https://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/topplistor-kommuner/folkmangd-topp-50/ [Accessed 2020].

STROHBACH, M. W. & HAASE, D. 2012. Above-ground carbon storage by urban trees in Leipzig, Germany: Analysis of patterns in a European city. *Landscape and Urban Planning,* 104**,** 95-104.

TIWARY, A., WILLIAMS, I. D., HEIDRICH, O., NAMDEO, A., BANDARU, V. & CALFAPIETRA, C. 2016. Development of multi-functional streetscape green infrastructure using a performance index approach. *Environmental Pollution,* 208**,** 209-220.

TÓTH, B., WEYNANTS, M., NEMES, A., MAKÓ, A., BILAS, G. & TÓTH, G. 2015. New generation of hydraulic pedotransfer functions for Europe. *European Journal of Soil Science,* 66**,** 226-238.

TÓTH, B., WEYNANTS, M., PÁSZTOR, L. & HENGL, T. 2017. 3D soil hydraulic database of Europe at 250 m resolution. *Hydrological Processes,* 31**,** 2662-2666.

TRIGUERO-MAS, M., DADVAND, P., CIRACH, M., MARTÍNEZ, D., MEDINA, A., MOMPART, A., BASAGAÑA, X., GRAŽULEVIČIENE, R. & NIEUWENHUIJSEN, M. J. 2015. Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International,* 77**,** 35-41.

TRLICA, A., HUTYRA, L. R., MORREALE, L. L., SMITH, I. A. & REINMANN, A. B. 2020. Current and future biomass carbon uptake in Boston's urban forest. *Science of the Total Environment,* 709**,** 136196-136196.

VASENEV, V. & KUZYAKOV, Y. 2018. Urban soils as hot spots of anthropogenic carbon accumulation: Review of stocks, mechanisms and driving factors. *Land Degradation & Development,* 29**,** 1607-1622.

WHITTINGHILL, L. J., ROWE, D. B., SCHUTZKI, R. & CREGG, B. M. 2014. Quantifying carbon sequestration of various green roof and ornamental landscape systems. *Landscape and Urban Planning,* 123**,** 41-48.

WIHLBORG, M., SÖRENSEN, J. & ALKAN OLSSON, J. 2019. Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities. *Journal of Environmental Management,* 233**,** 706-718.

VILLENEUVE, P. J., JERRETT, M., G. SU, J., BURNETT, R. T., CHEN, H., WHEELER, A. J. & GOLDBERG, M. S. 2012. A cohort study relating urban green space with mortality in Ontario, Canada. *Environmental Research,* 115**,** 51-58.

VON DÖHREN, P. & HAASE, D. 2015. Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators,* 52**,** 490-497.

YAO, L., CHEN, L., WEI, W. & SUN, R. 2015. Potential reduction in urban runoff by green spaces in Beijing: A scenario analysis. *Urban Forestry and Urban Greening,* 14**,** 300-308.

Appendix Part B1

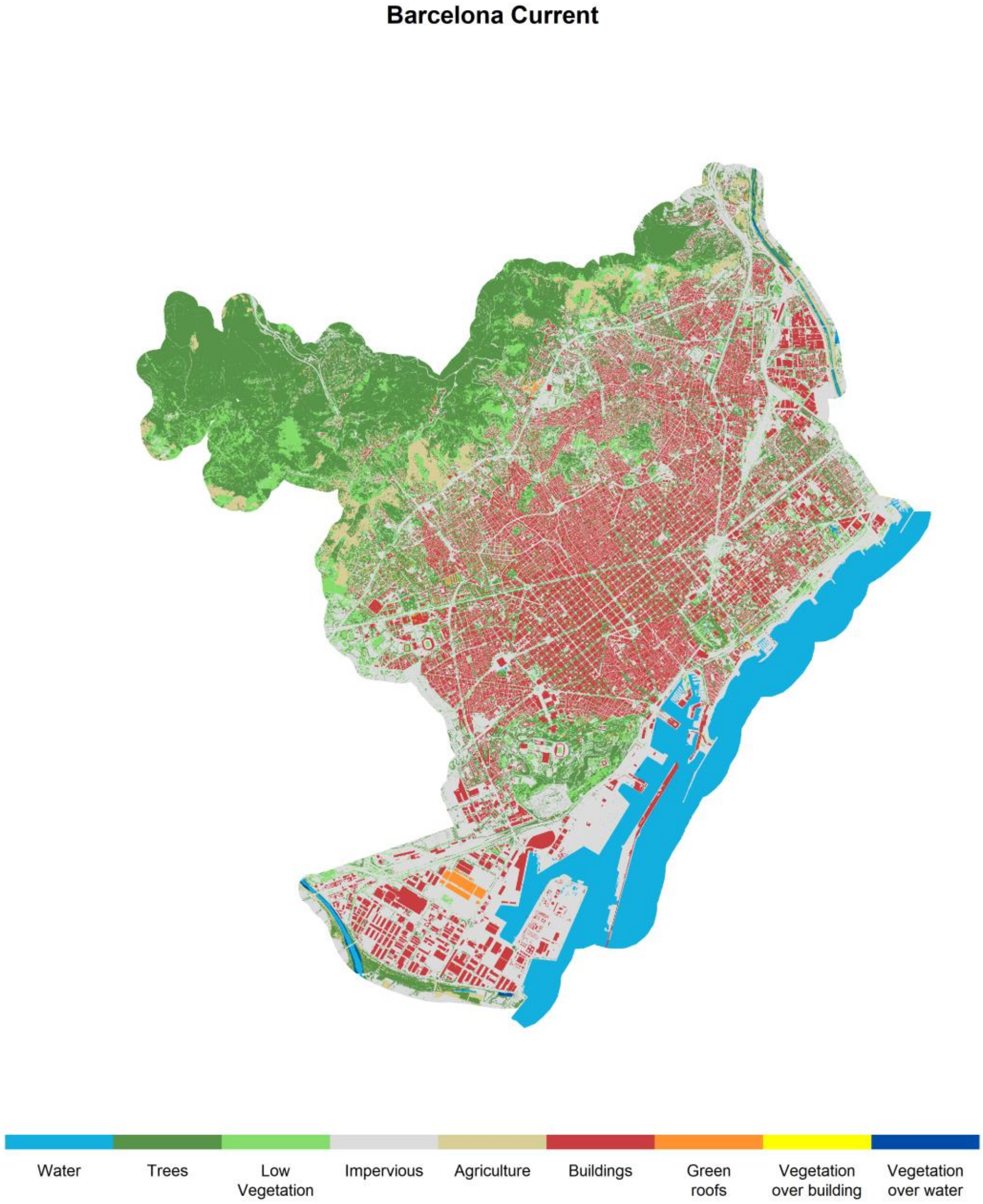

Figure LC1. Landcover for Barcelona Current scenario

Figure LC2. Landcover for Barcelona GreenRoofs scenario

Barcelona ParkingAreas

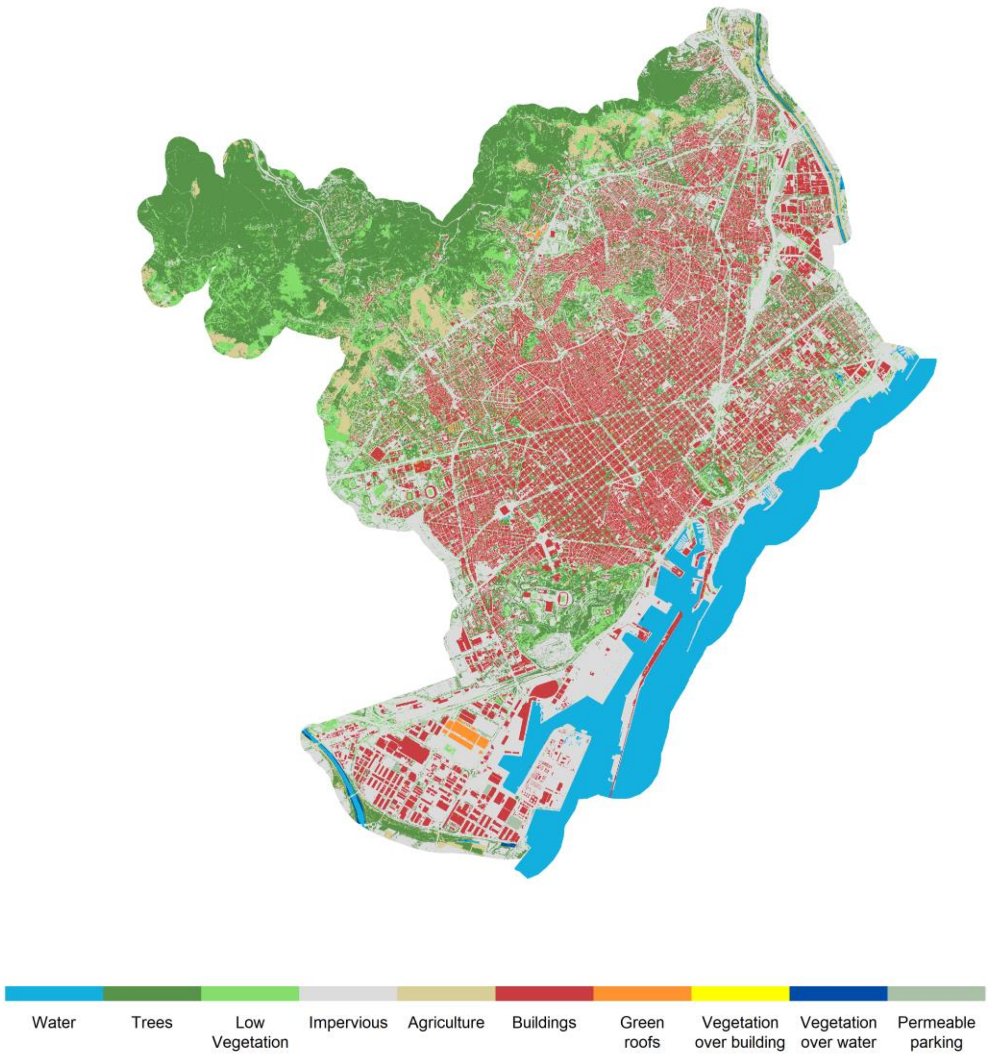

Figure LC3. Landcover for Barcelona ParkingAreas scenario

Figure LC4. Landcover for Barcelona Parks scenario

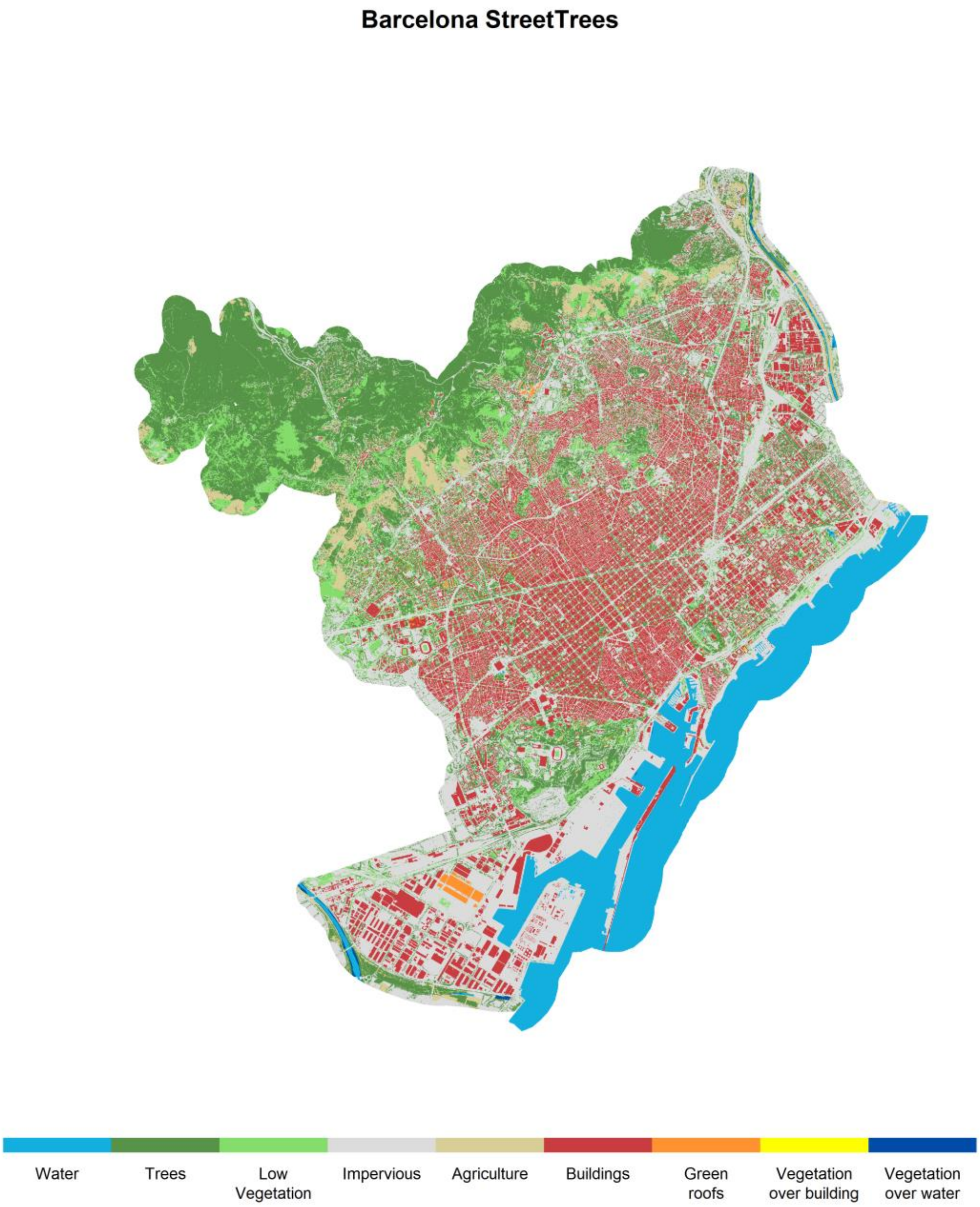

Figure LC5. Landcover for Barcelona StreetTrees scenario

Figure LC6. Landcover for Barcelona GreenDream scenario

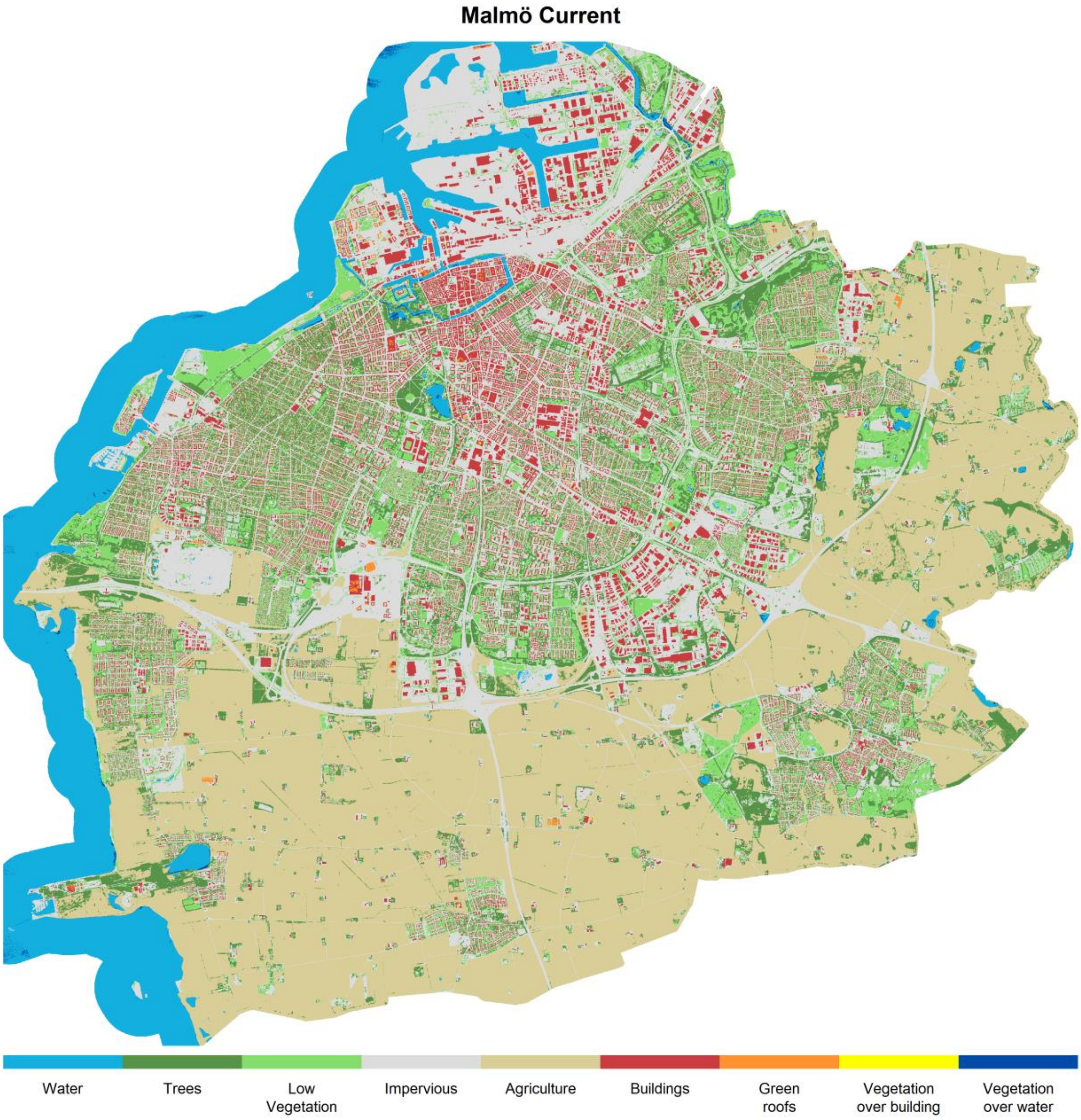

Figure LC7. Landcover for Malmö Current scenario

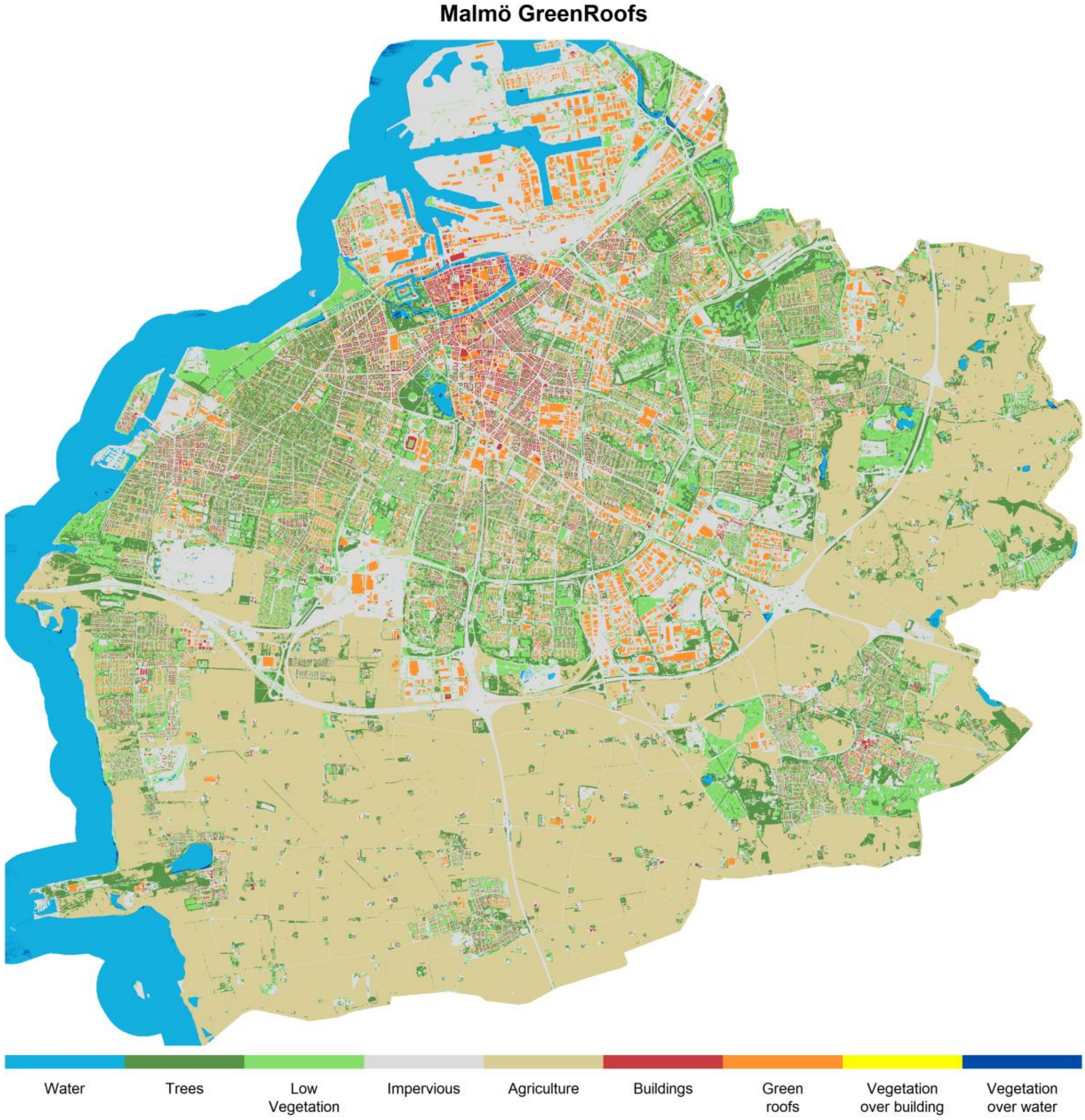

Figure LC8. Landcover for Malmö GreenRoofs scenario

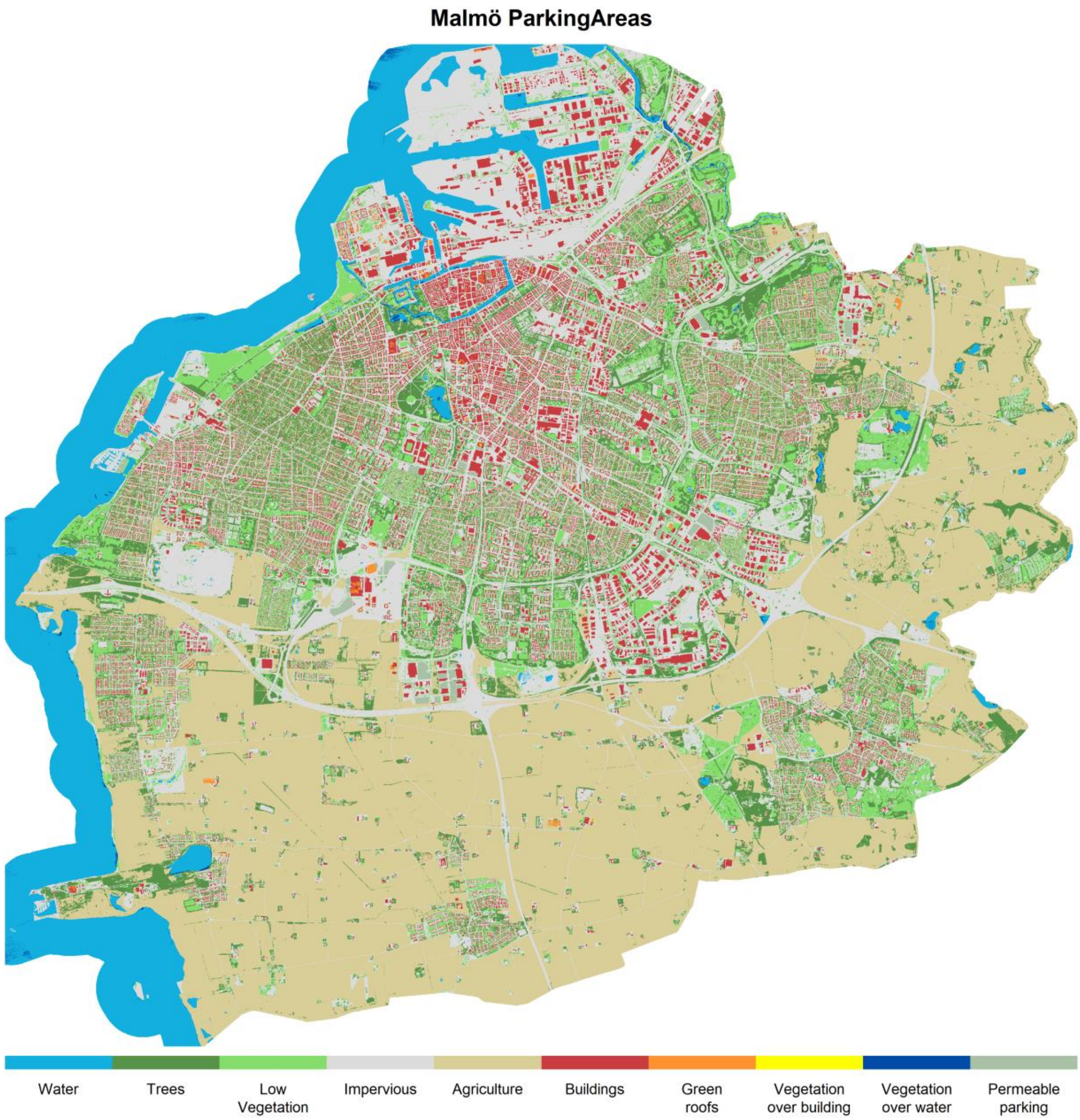

Figure LC9. Landcover for Malmö ParkingAreas scenario

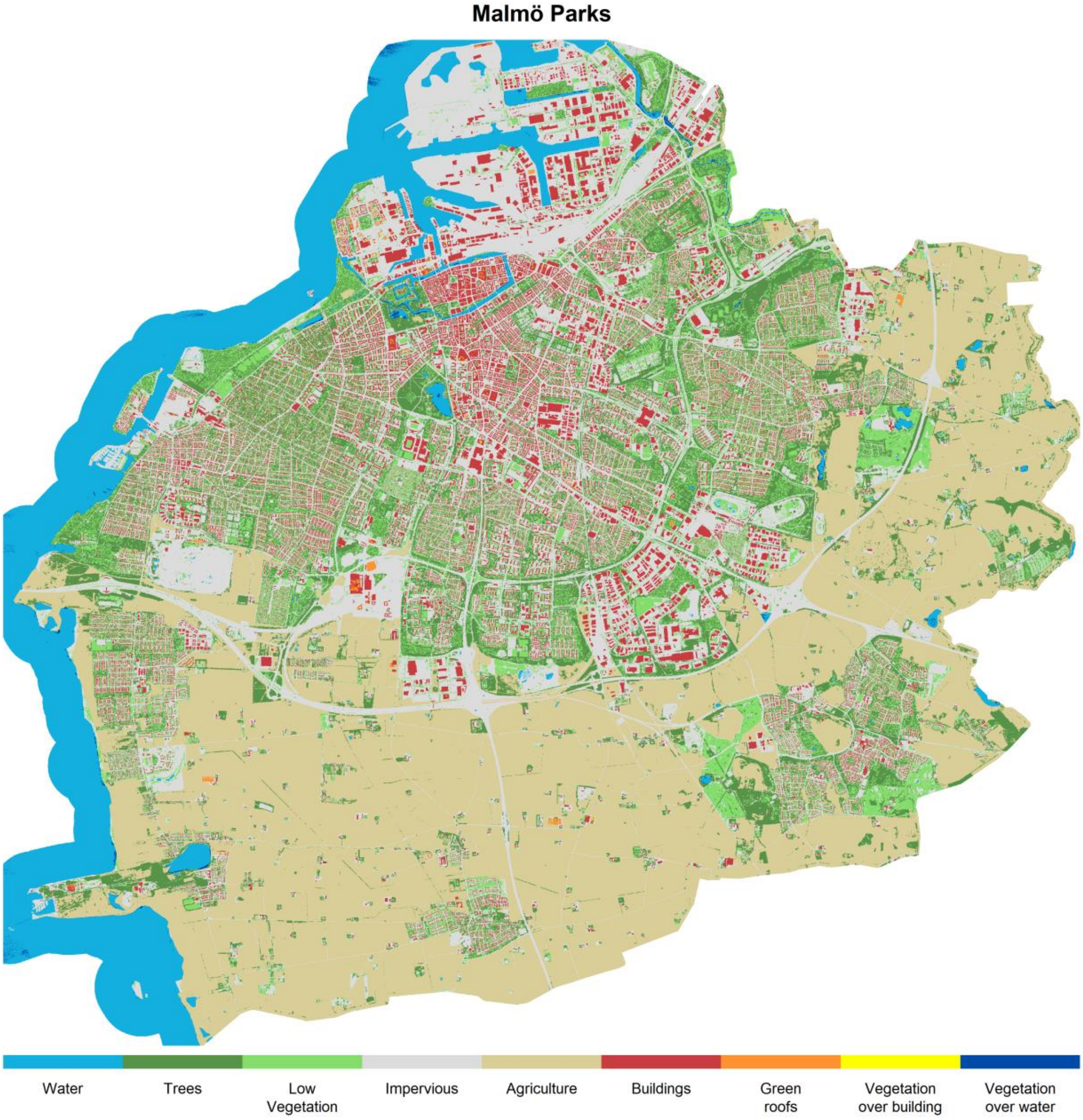

Figure LC10. Landcover for Malmö Parks scenario

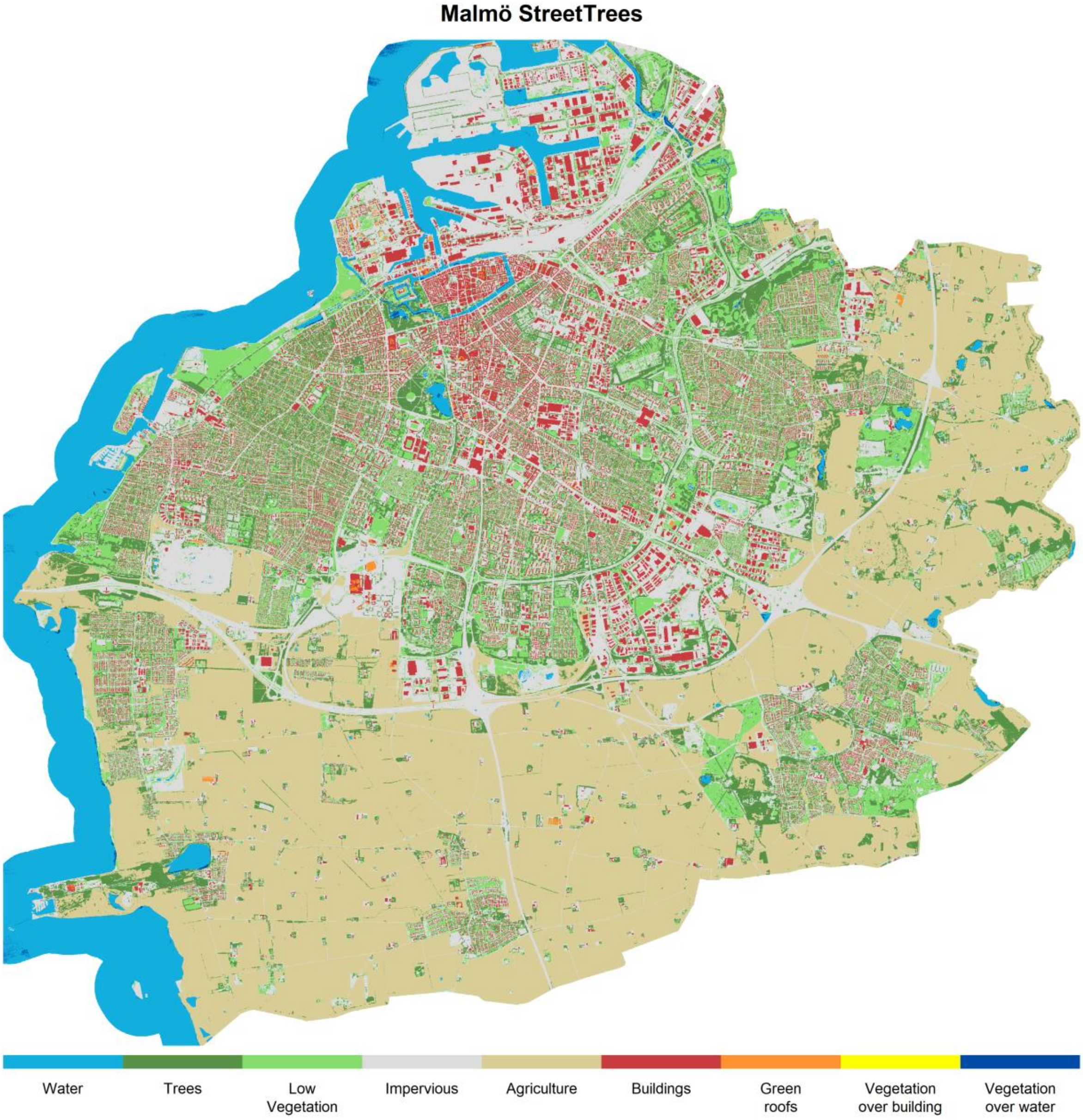

Figure LC11. Landcover for Malmö StreetTrees scenario

Figure LC12. Landcover for Malmö GreenDream scenario

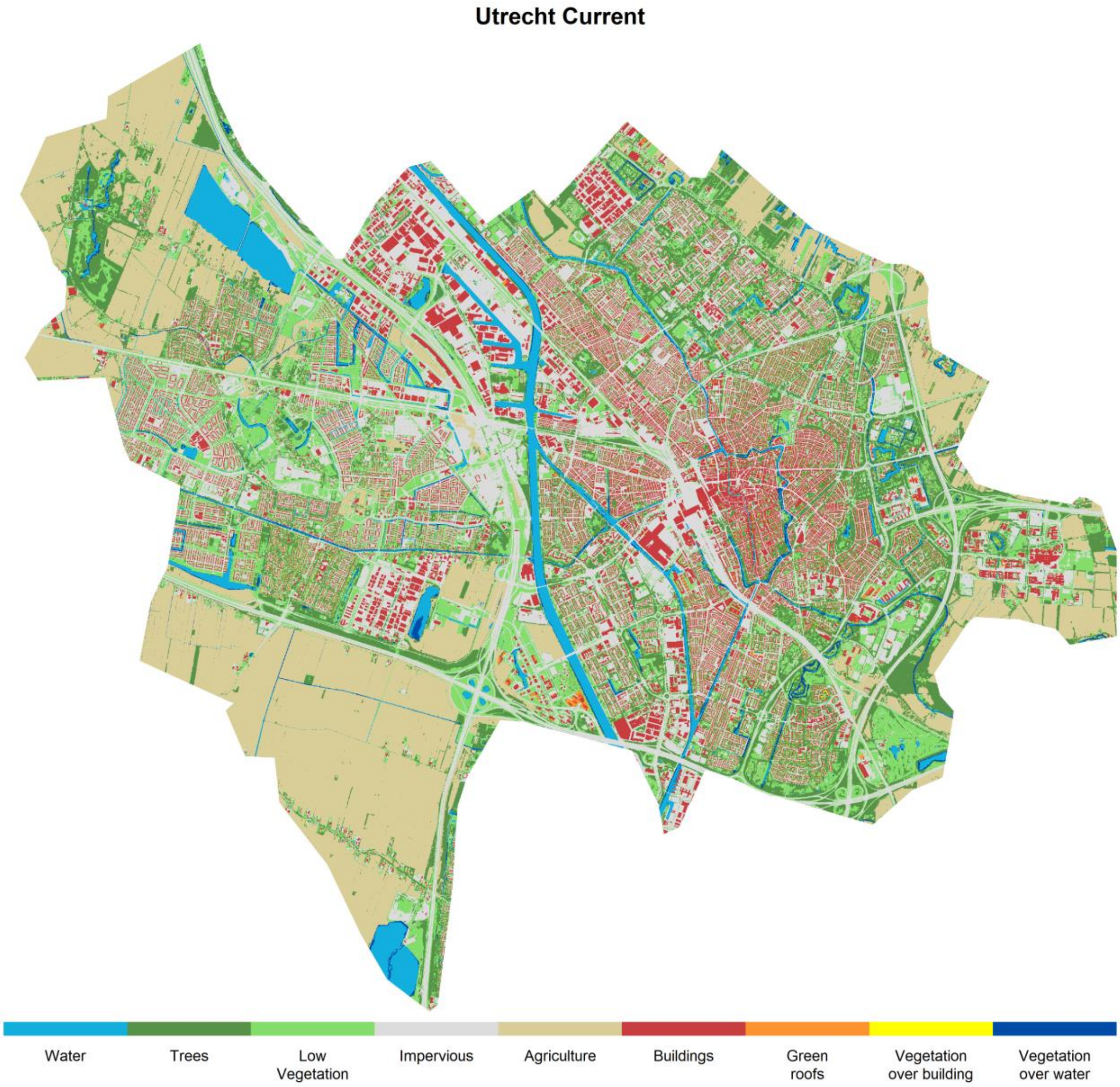

Figure LC13. Landcover for Utrecht Current scenario

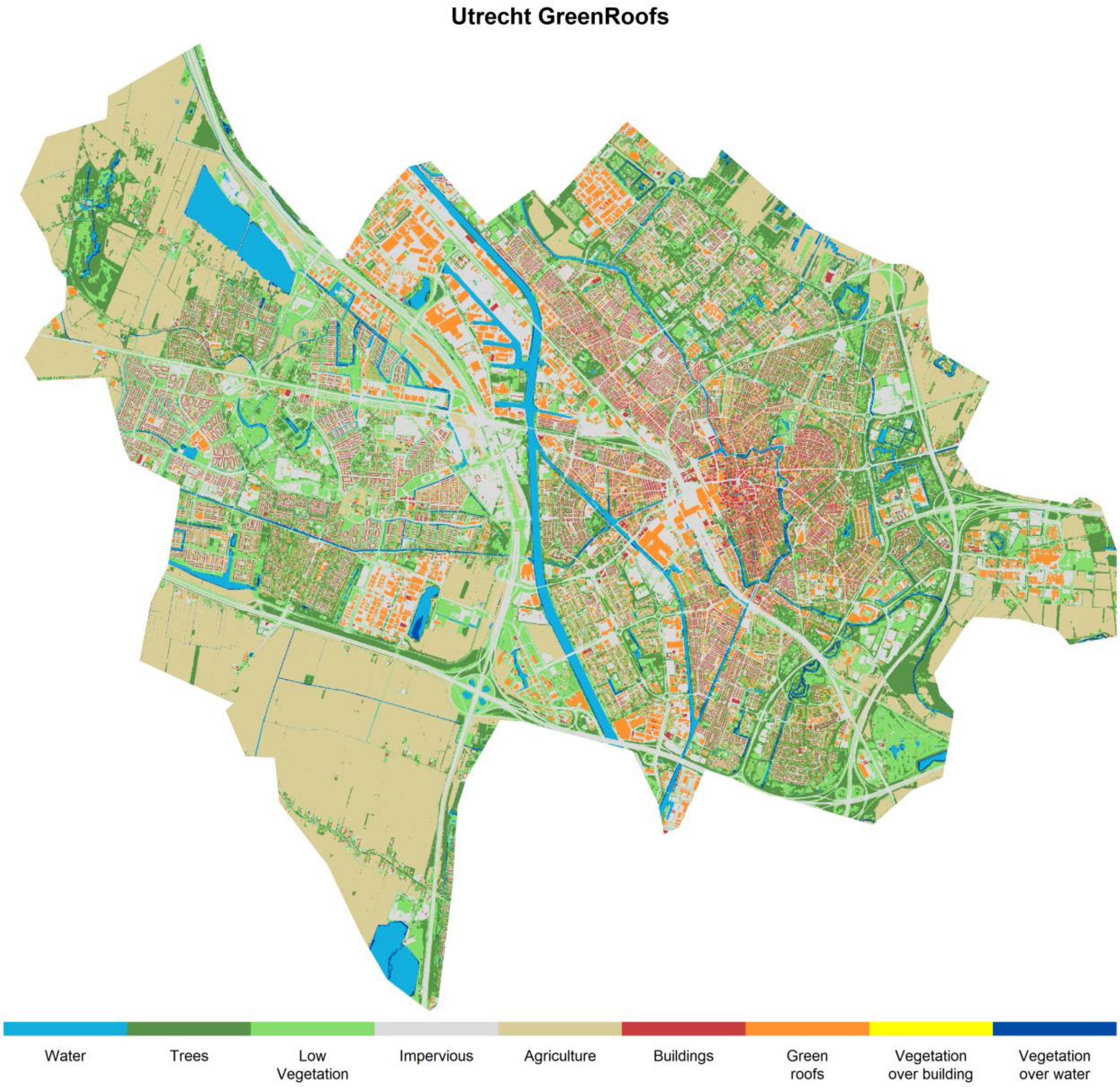

Figure LC14. Landcover for Utrecht GreenRoofs scenario

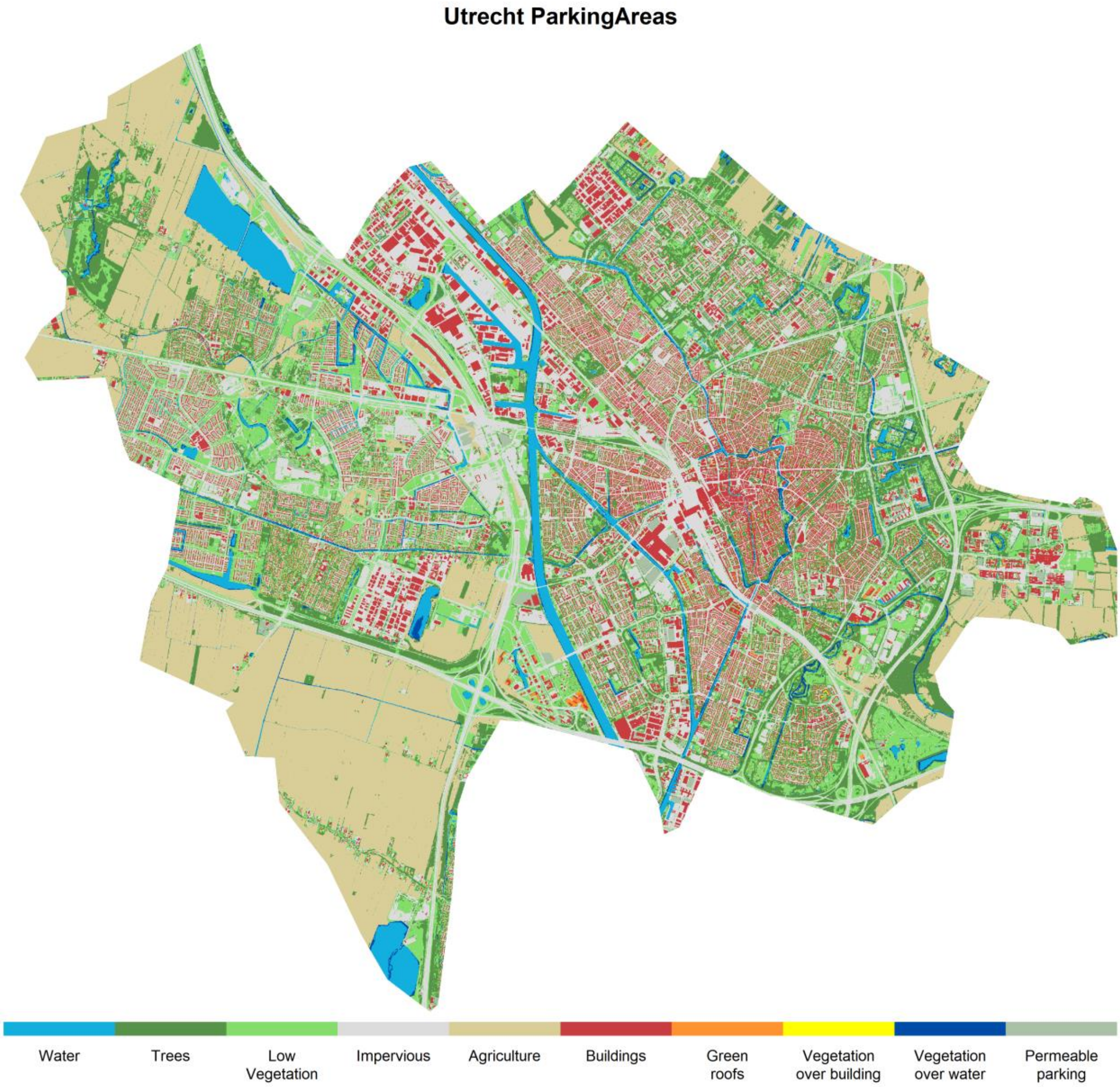

Figure LC15. Landcover for Utrecht ParkingAreas scenario

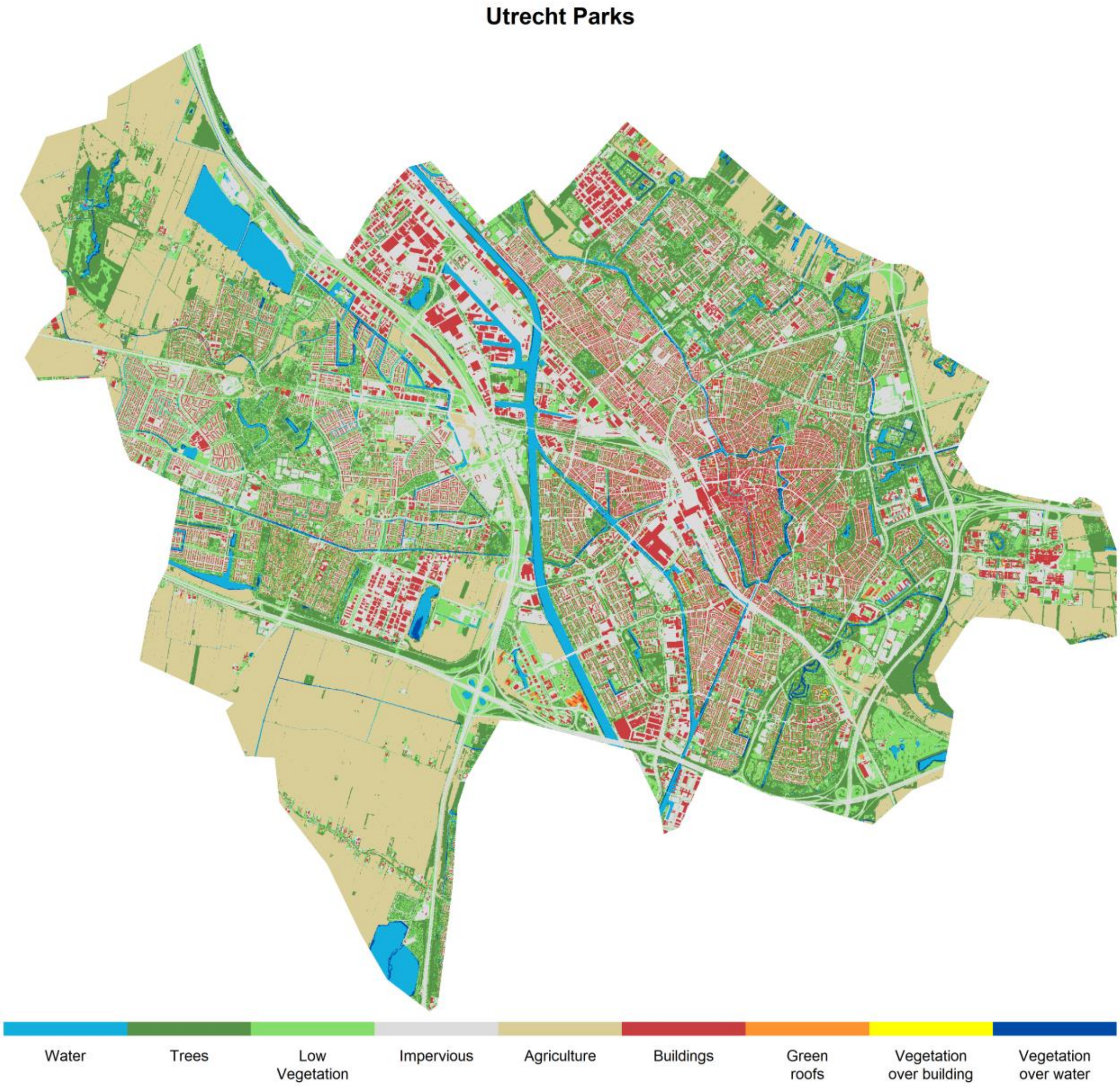

Figure LC16. Landcover for Utrecht Parks scenario

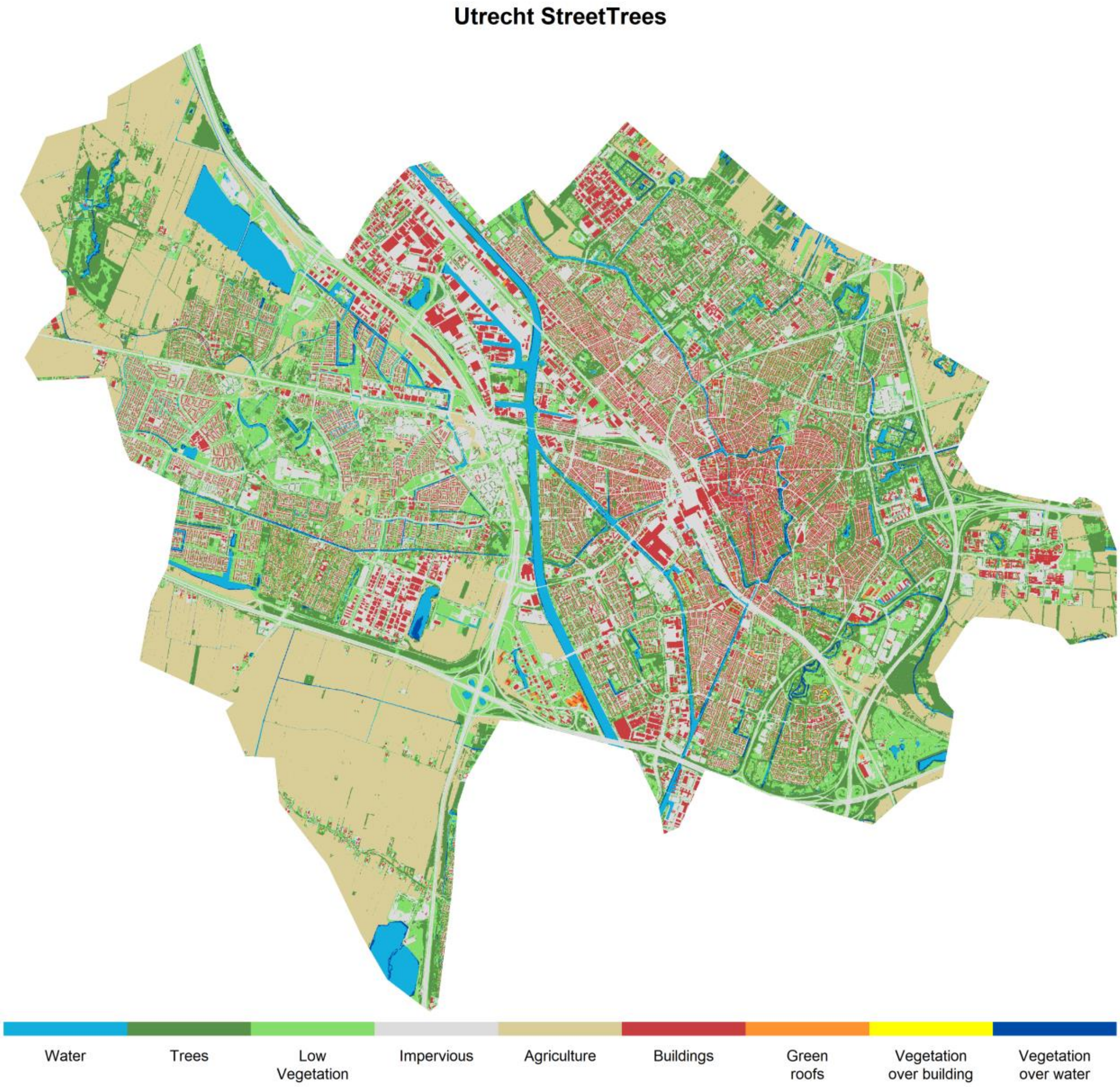

Figure LC17. Landcover for Utrecht StreetTrees scenario

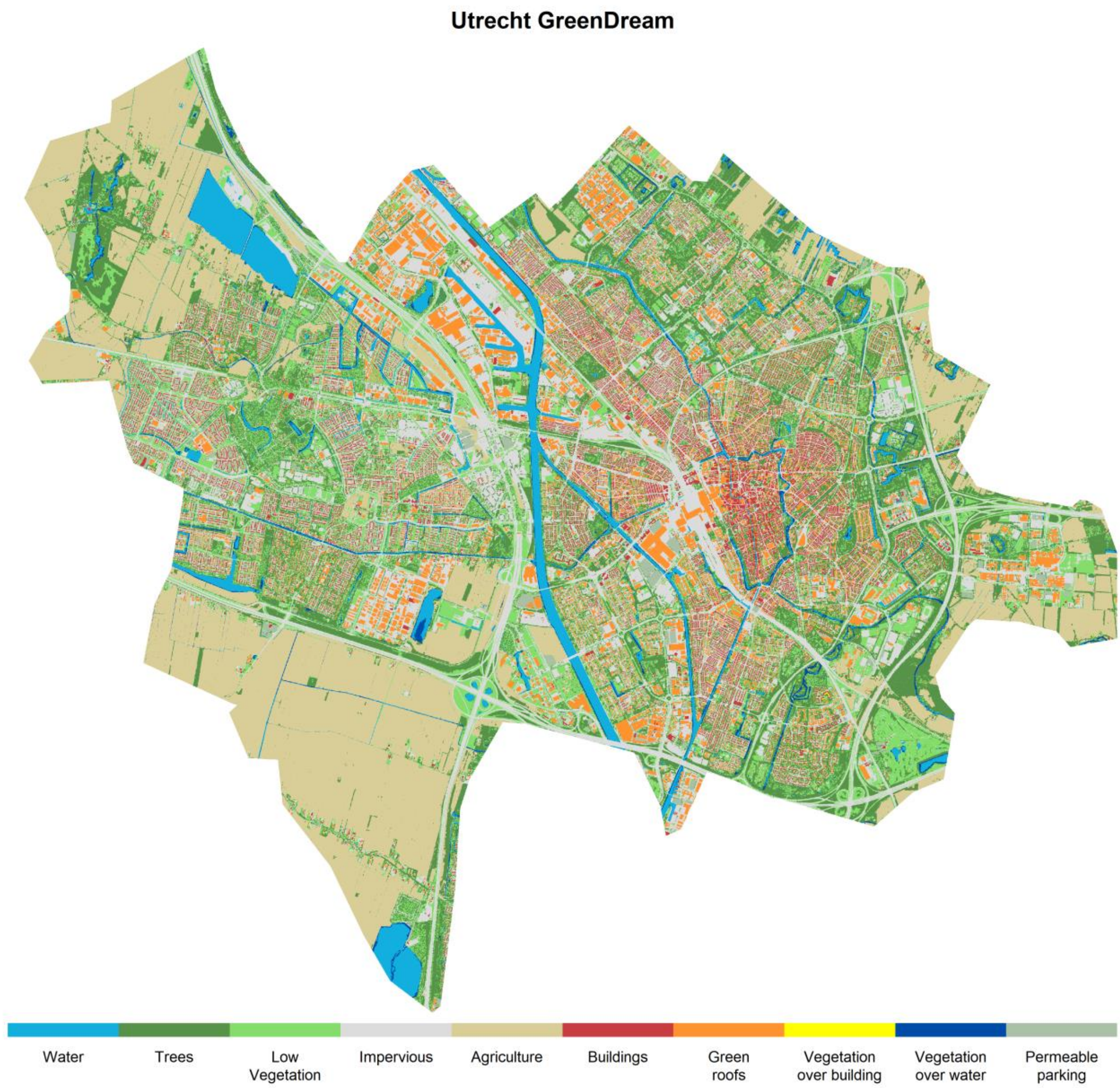

Figure LC18. Landcover for Utrecht GreenDream scenario

Appendix Part B2

Table UA-1. Barcelona, Heat Mitigation (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.23	0.24	0.23	0.23	0.23	0.24
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.27	0.27	0.27	0.27	0.27	0.28
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.28	0.29	0.28	0.29	0.29	0.29
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.35	0.35	0.35	0.35	0.35	0.35
Discontinuous very low density urban fabric (S.L. : < 10%)	0.56	0.56	0.56	0.57	0.57	0.57
Isolated structures	0.50	0.50	0.50	0.51	0.50	0.51
Industrial, commercial, public, military and private units	0.18	0.19	0.18	0.18	0.19	0.20
Fast transit roads and associated land	0.30	0.30	0.30	0.30	0.30	0.30
Other roads and associated land	0.29	0.29	0.29	0.30	0.30	0.31
Railways and associated land	0.18	0.18	0.18	0.18	0.18	0.18
Port areas	0.33	0.33	0.33	0.33	0.33	0.34
Mineral extraction and dump sites	0.39	0.39	0.39	0.39	0.39	0.39
Construction sites	0.32	0.32	0.32	0.32	0.32	0.33
Land without current use	0.23	0.23	0.23	0.33	0.23	0.33
Green urban areas	0.38	0.38	0.38	0.46	0.39	0.46
Sports and leisure facilities	0.29	0.29	0.29	0.31	0.29	0.32
Arable land (annual crops)	0.43	0.43	0.43	0.43	0.43	0.43
Permanent crops	0.44	0.44	0.44	0.44	0.44	0.44
Pastures	0.32	0.32	0.32	0.32	0.32	0.33
Forests	0.88	0.88	0.88	0.88	0.88	0.88
Herbaceous vegetation associations	0.41	0.41	0.41	0.41	0.41	0.41
Open spaces with little or no vegetation	0.35	0.35	0.35	0.35	0.35	0.35
Water	0.21	0.21	0.21	0.21	0.21	0.21

Table UA-2. Barcelona, Carbon Storage (ton/ha)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	44.6	50.4	44.6	45.4	46.7	53.5
Discontinuous dense urban fabric (S.L. : 50% - 80%)	82.1	86.1	82.3	85.2	85.8	92.8
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	107.8	109.6	107.9	110.1	110.8	115.0
Discontinuous low density urban fabric (S.L. : 10% - 30%)	131.6	132.4	131.7	133.2	133.2	135.5
Discontinuous very low density urban fabric (S.L. : < 10%)	183.6	183.8	183.7	183.7	183.8	184.1
Isolated structures	144.3	144.6	144.7	145.3	144.5	146.1
Industrial, commercial, public, military and private units	54.7	64.0	55.3	56.1	59.0	70.3
Fast transit roads and associated land	79.2	79.3	79.2	82.7	79.4	83.0
Other roads and associated land	85.5	85.8	85.7	89.1	88.6	92.5
Railways and associated land	42.5	47.1	42.6	42.7	43.5	48.3
Port areas	29.6	37.7	29.8	29.6	30.1	38.5
Mineral extraction and dump sites	87.4	87.4	87.4	87.6	88.1	88.3
Construction sites	50.6	50.7	50.7	52.5	52.8	54.8
Land without current use	91.5	91.9	91.8	137.0	94.6	139.4
Green urban areas	140.3	140.4	140.5	171.9	142.0	173.0
Sports and leisure facilities	72.7	75.3	73.4	80.3	75.0	85.5
Arable land (annual crops)	102.8	102.8	102.8	102.9	102.9	103.0
Permanent crops	16.5	16.5	16.5	16.5	16.5	16.5
Pastures	72.3	72.3	72.3	72.5	72.6	72.8
Forests	228.3	228.3	228.3	228.3	228.3	228.4
Herbaceous vegetation associations	125.5	125.5	125.5	125.5	125.8	125.9
Open spaces with little or no vegetation	36.4	36.5	36.4	38.0	36.8	38.3
Water	3.1	3.1	3.1	3.1	3.1	3.1

Table UA-3. Barcelona, Runoff Reduction (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	34.7	40.9	34.7	35.0	35.3	42.0
Discontinuous dense urban fabric (S.L. : 50% - 80%)	46.4	50.6	46.5	47.6	47.4	53.1
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	55.8	57.8	55.9	56.7	56.7	59.6
Discontinuous low density urban fabric (S.L. : 10% - 30%)	68.0	68.8	68.0	68.3	68.4	69.7
Discontinuous very low density urban fabric (S.L. : < 10%)	80.7	80.9	80.7	80.7	80.8	81.0
Isolated structures	73.9	74.2	74.3	74.4	74.0	75.2
Industrial, commercial, public, military and private units	37.8	48.4	38.5	38.4	39.1	50.9
Fast transit roads and associated land	40.3	40.3	40.3	41.9	40.3	42.1
Other roads and associated land	47.3	47.7	47.5	48.7	48.2	50.0
Railways and associated land	31.5	36.3	31.6	31.6	31.8	36.8
Port areas	26.6	36.6	26.8	26.6	26.7	37.0
Mineral extraction and dump sites	66.7	66.7	66.7	66.8	66.9	67.0
Construction sites	33.7	33.8	33.8	34.3	34.4	35.0
Land without current use	53.9	54.4	54.2	71.4	54.9	72.4
Green urban areas	68.8	69.0	69.0	78.3	69.3	78.8
Sports and leisure facilities	44.5	47.6	45.2	47.5	45.2	51.7
Arable land (annual crops)	76.1	76.1	76.1	76.2	76.1	76.2
Permanent crops	65.0	65.0	65.0	65.0	65.0	65.0
Pastures	69.4	69.5	69.5	69.5	69.5	69.7
Forests	94.9	94.9	94.9	94.9	94.9	94.9
Herbaceous vegetation associations	78.9	78.9	78.9	78.9	78.9	79.0
Open spaces with little or no vegetation	27.4	27.5	27.4	28.1	27.5	28.3
Water	25.6	25.6	25.6	25.6	25.6	25.6

Table UA-4. Barcelona, Biodiversity Potential (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.19	0.41	0.19	0.20	0.20	0.44
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.50	0.67	0.50	0.53	0.53	0.74
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.73	0.83	0.73	0.76	0.76	0.89
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.98	1.02	0.98	0.99	1.00	1.05
Discontinuous very low density urban fabric (S.L. : < 10%)	0.99	1.00	0.99	0.99	1.00	1.01
Isolated structures	1.03	1.03	1.03	1.03	1.03	1.05
Industrial, commercial, public, military and private units	0.30	0.54	0.31	0.32	0.33	0.61
Fast transit roads and associated land	0.26	0.27	0.27	0.28	0.27	0.28
Other roads and associated land	0.40	0.42	0.40	0.43	0.42	0.48
Railways and associated land	0.07	0.15	0.07	0.07	0.07	0.16
Port areas	0.02	0.16	0.02	0.02	0.03	0.17
Mineral extraction and dump sites	0.35	0.35	0.35	0.36	0.37	0.37
Construction sites	0.15	0.15	0.15	0.16	0.18	0.20
Land without current use	0.55	0.55	0.56	0.96	0.58	0.99
Green urban areas	0.82	0.83	0.83	0.99	0.84	1.00
Sports and leisure facilities	0.41	0.46	0.42	0.48	0.43	0.55
Arable land (annual crops)	0.92	0.92	0.92	0.92	0.92	0.92
Permanent crops	0.33	0.33	0.33	0.33	0.33	0.33
Pastures	0.82	0.82	0.82	0.83	0.83	0.83
Forests	0.82	0.82	0.82	0.82	0.82	0.82
Herbaceous vegetation associations	0.68	0.68	0.68	0.68	0.68	0.69
Open spaces with little or no vegetation	0.01	0.01	0.01	0.02	0.01	0.02
Water	0.26	0.26	0.26	0.27	0.26	0.27

Table UA-5. Barcelona, Accessibility (m)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	262.5	262.5	262.5	262.3	262.5	262.3
Discontinuous dense urban fabric (S.L. : 50% - 80%)	211.7	211.7	211.7	209.6	211.7	209.6
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	248.3	248.3	248.3	243.8	248.3	243.8
Discontinuous low density urban fabric (S.L. : 10% - 30%)	498.2	498.2	498.2	431.1	498.2	431.1
Discontinuous very low density urban fabric (S.L. : < 10%)	2 099.0	2 099.0	2 099.0	1 944.6	2 099.0	1 944.6
Isolated structures	1 223.3	1 223.3	1 223.3	1 179.5	1 223.3	1 179.5
Industrial, commercial, public, military and private units	352.4	352.4	352.4	341.6	352.4	341.6
Port areas	1 199.2	1 199.2	1 199.2	1 199.2	1 199.2	1 199.2
Land without current use	48.3	48.3	48.3	48.3	48.3	48.3
Sports and leisure facilities	239.4	239.4	239.4	237.3	239.4	237.3
Arable land (annual crops)	450.8	450.8	450.8	410.5	450.8	410.5
Pastures	350.4	350.4	350.4	331.3	350.4	331.3

Table UA-6. Barcelona, Greenness (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	18.8	18.8	18.8	20.6	19.7	21.4
Discontinuous dense urban fabric (S.L. : 50% - 80%)	29.0	29.0	29.0	31.2	30.3	32.4
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	40.2	40.2	40.2	41.9	41.5	43.0
Discontinuous low density urban fabric (S.L. : 10% - 30%)	62.7	62.7	62.7	63.5	63.4	64.1
Discontinuous very low density urban fabric (S.L. : < 10%)	81.4	81.4	81.4	81.5	81.5	81.6
Isolated structures	90.7	90.7	90.6	90.8	90.8	90.9
Industrial, commercial, public, military and private units	23.6	23.6	23.6	25.0	25.1	26.4
Fast transit roads and associated land	37.1	37.1	37.1	39.3	38.2	40.3
Other roads and associated land	27.9	27.9	27.9	30.5	29.1	31.6
Railways and associated land	18.2	18.2	18.2	19.7	19.5	21.0
Port areas	34.4	34.4	34.4	34.7	34.6	34.8
Mineral extraction and dump sites	65.5	65.5	65.5	66.0	66.4	66.9
Construction sites	32.1	32.1	32.0	34.1	32.8	34.7
Land without current use	33.2	33.2	33.2	36.7	34.6	38.0
Green urban areas	40.8	40.8	40.7	44.8	41.6	45.4
Sports and leisure facilities	38.2	38.2	38.2	41.6	39.2	42.3
Arable land (annual crops)	79.5	79.5	79.5	79.9	79.8	80.2
Permanent crops	92.4	92.4	92.4	92.6	92.4	92.6
Pastures	61.1	61.1	61.1	62.3	62.1	63.2
Forests	91.8	91.8	91.8	91.8	91.8	91.9
Herbaceous vegetation associations	72.7	72.7	72.7	73.4	73.2	73.8
Open spaces with little or no vegetation	53.6	53.6	53.6	56.5	54.0	56.8
Water	78.6	78.6	78.6	78.9	78.7	79.0

Table UA-7. Malmö, Heat Mitigation (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.06	0.07	0.06	0.06	0.09	0.10
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.09	0.09	0.09	0.10	0.12	0.13
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.10	0.11	0.10	0.12	0.13	0.14
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.13	0.14	0.14	0.15	0.15	0.17
Discontinuous very low density urban fabric (S.L. : < 10%)	0.20	0.20	0.20	0.21	0.21	0.22
Isolated structures	0.36	0.37	0.36	0.37	0.36	0.37
Industrial, commercial, public, military and private units	0.10	0.11	0.10	0.12	0.12	0.15
Fast transit roads and associated land	0.19	0.19	0.19	0.20	0.19	0.20
Other roads and associated land	0.11	0.11	0.11	0.16	0.14	0.19
Railways and associated land	0.05	0.05	0.05	0.05	0.05	0.06
Port areas	0.09	0.09	0.09	0.09	0.11	0.13
Mineral extraction and dump sites	0.20	0.20	0.20	0.21	0.21	0.22
Construction sites	0.14	0.14	0.14	0.16	0.17	0.19
Land without current use	0.19	0.19	0.19	0.36	0.20	0.37
Green urban areas	0.31	0.31	0.31	0.41	0.31	0.41
Sports and leisure facilities	0.26	0.26	0.26	0.29	0.26	0.30
Arable land (annual crops)	0.30	0.30	0.30	0.30	0.30	0.30
Pastures	0.30	0.30	0.30	0.30	0.30	0.30
Forests	0.66	0.66	0.66	0.67	0.66	0.67
Herbaceous vegetation associations	0.52	0.52	0.52	0.52	0.52	0.52
Open spaces with little or no vegetation	0.19	0.19	0.19	0.21	0.19	0.21
Water	0.43	0.43	0.43	0.43	0.43	0.43

Table UA-8. Malmö, Carbon Storage (ton/ha)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	43.3	48.7	43.7	43.7	56.8	62.9
Discontinuous dense urban fabric (S.L. : 50% - 80%)	69.0	73.0	69.6	70.5	82.7	88.8
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	89.5	94.5	90.5	90.3	98.8	105.5
Discontinuous low density urban fabric (S.L. : 10% - 30%)	104.6	108.3	105.0	105.8	112.3	117.6
Discontinuous very low density urban fabric (S.L. : < 10%)	124.6	125.9	124.7	125.6	129.8	132.2
Isolated structures	120.9	121.8	120.9	121.3	121.3	122.5
Industrial, commercial, public, military and private units	65.5	74.8	66.8	66.9	73.3	85.2
Fast transit roads and associated land	76.7	76.8	76.8	76.8	77.4	77.6
Other roads and associated land	84.1	84.4	84.2	85.0	93.2	94.3
Railways and associated land	49.1	50.8	49.1	49.1	50.8	52.5
Port areas	47.1	53.1	47.5	48.0	59.0	66.2
Mineral extraction and dump sites	58.4	58.6	58.8	59.0	65.4	66.4
Construction sites	68.1	69.2	68.1	75.6	79.7	88.3
Land without current use	104.3	104.9	104.4	184.0	107.2	187.0
Green urban areas	170.9	171.0	171.0	218.5	172.9	219.9
Sports and leisure facilities	115.2	116.2	115.8	120.3	116.5	123.1
Arable land (annual crops)	6.4	6.4	6.4	6.4	6.4	6.4
Pastures	34.3	34.4	34.3	34.3	34.4	34.5
Forests	265.7	265.7	265.8	266.9	265.9	267.2
Herbaceous vegetation associations	200.2	200.2	200.2	200.2	200.2	200.2
Open spaces with little or no vegetation	67.3	67.4	67.3	69.3	67.3	69.4
Water	6.2	6.2	6.2	6.3	6.4	6.5

Table UA-9. Malmö, Runoff Reduction (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	31.2	37.1	31.6	31.3	34.8	41.1
Discontinuous dense urban fabric (S.L. : 50% - 80%)	42.0	46.6	42.6	42.2	45.6	51.0
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	47.9	53.7	49.0	48.1	50.4	57.3
Discontinuous low density urban fabric (S.L. : 10% - 30%)	55.4	59.7	55.9	55.6	57.3	62.3
Discontinuous very low density urban fabric (S.L. : < 10%)	62.6	64.1	62.7	62.8	63.9	65.6
Isolated structures	56.3	57.2	56.3	56.4	56.4	57.4
Industrial, commercial, public, military and private units	38.5	50.0	39.9	38.8	40.5	53.7
Fast transit roads and associated land	38.2	38.3	38.3	38.2	38.4	38.6
Other roads and associated land	41.8	42.1	41.8	42.0	44.2	44.7
Railways and associated land	28.7	30.6	28.7	28.7	29.1	31.1
Port areas	29.8	36.9	30.2	30.0	32.9	40.5
Mineral extraction and dump sites	32.0	32.1	32.3	32.1	33.8	34.4
Construction sites	45.4	46.7	45.4	47.0	48.4	51.3
Land without current use	54.4	55.2	54.5	81.8	55.2	83.1
Green urban areas	77.3	77.5	77.4	86.5	77.8	87.0
Sports and leisure facilities	66.2	67.3	66.8	67.0	66.6	69.0
Arable land (annual crops)	68.3	68.3	68.3	68.3	68.3	68.3
Pastures	69.1	69.1	69.1	69.1	69.1	69.2
Forests	87.7	87.7	87.7	88.0	87.7	88.2
Herbaceous vegetation associations	77.0	77.0	77.0	77.0	77.0	77.0
Open spaces with little or no vegetation	45.2	45.3	45.2	45.5	45.2	45.6
Water	25.9	25.9	25.9	25.9	25.9	25.9

Table UA-10. Malmö, Biodiversity Potential (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.11	0.27	0.11	0.11	0.20	0.39
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.36	0.51	0.37	0.37	0.48	0.66
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.51	0.70	0.52	0.51	0.61	0.82
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.77	0.92	0.78	0.78	0.85	1.01
Discontinuous very low density urban fabric (S.L. : < 10%)	0.96	1.03	0.96	0.96	1.00	1.08
Isolated structures	0.73	0.76	0.73	0.73	0.73	0.77
Industrial, commercial, public, military and private units	0.34	0.59	0.36	0.36	0.39	0.71
Fast transit roads and associated land	0.26	0.26	0.26	0.26	0.26	0.26
Other roads and associated land	0.31	0.31	0.31	0.31	0.35	0.36
Railways and associated land	0.05	0.12	0.05	0.05	0.06	0.13
Port areas	0.08	0.29	0.08	0.08	0.18	0.46
Mineral extraction and dump sites	0.06	0.06	0.06	0.06	0.09	0.10
Construction sites	0.37	0.45	0.37	0.41	0.45	0.58
Land without current use	0.55	0.56	0.55	1.07	0.59	1.10
Green urban areas	0.93	0.94	0.94	1.09	0.95	1.09
Sports and leisure facilities	0.77	0.81	0.78	0.81	0.78	0.88
Arable land (annual crops)	0.42	0.42	0.42	0.42	0.42	0.43
Pastures	0.64	0.65	0.64	0.65	0.65	0.65
Forests	0.66	0.66	0.65	0.65	0.66	0.64
Herbaceous vegetation associations	1.00	1.00	1.00	1.00	1.00	1.00
Open spaces with little or no vegetation	0.26	0.27	0.26	0.28	0.26	0.28
Water	0.16	0.16	0.16	0.17	0.16	0.17

Table UA-11. Malmö, Accessibility (m)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	216.2	216.2	216.2	216.2	216.2	216.2
Discontinuous dense urban fabric (S.L. : 50% - 80%)	219.5	219.5	219.5	218.5	219.5	218.5
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	196.6	196.6	196.6	196.4	196.6	196.4
Discontinuous low density urban fabric (S.L. : 10% - 30%)	205.0	205.0	205.0	203.3	205.0	203.3
Discontinuous very low density urban fabric (S.L. : < 10%)	251.1	251.1	251.1	248.9	251.1	248.9
Isolated structures	1 181.6	1 181.6	1 181.6	1 175.0	1 181.6	1 175.0
Industrial, commercial, public, military and private units	323.5	323.5	323.5	313.8	323.5	313.8
Port areas	459.9	459.9	459.9	444.8	459.9	444.8
Sports and leisure facilities	205.3	205.3	205.3	199.7	205.3	199.7
Arable land (annual crops)	656.2	656.2	656.2	638.3	656.2	638.3
Pastures	491.9	491.9	491.9	486.8	491.9	486.8

Table UA-12. Malmö, Greenness (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	24.5	24.5	24.5	26.5	28.3	30.1
Discontinuous dense urban fabric (S.L. : 50% - 80%)	37.9	37.9	37.8	39.6	41.0	42.7
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	40.8	40.8	40.8	42.5	43.3	44.9
Discontinuous low density urban fabric (S.L. : 10% - 30%)	48.4	48.4	48.3	50.2	50.6	52.3
Discontinuous very low density urban fabric (S.L. : < 10%)	59.3	59.3	59.2	60.5	60.9	62.0
Isolated structures	88.5	88.5	88.5	88.9	88.7	89.0
Industrial, commercial, public, military and private units	35.7	35.7	35.7	38.5	38.1	40.7
Fast transit roads and associated land	57.2	57.2	57.1	58.6	57.9	59.3
Other roads and associated land	36.3	36.3	36.2	41.8	38.4	43.8
Railways and associated land	15.5	15.5	15.4	16.6	18.7	19.7
Port areas	29.2	29.2	29.2	30.7	32.4	33.9
Mineral extraction and dump sites	37.7	37.7	37.6	38.8	39.5	40.6
Construction sites	58.8	58.8	58.7	60.4	60.5	62.1
Land without current use	36.7	36.7	36.7	45.1	38.4	46.6
Green urban areas	51.8	51.8	51.8	55.5	53.5	57.0
Sports and leisure facilities	60.2	60.2	60.2	63.3	61.2	64.2
Arable land (annual crops)	88.4	88.4	88.4	88.7	88.6	88.9
Pastures	84.4	84.4	84.4	84.9	84.7	85.1
Forests	86.2	86.2	86.2	87.0	86.4	87.2
Herbaceous vegetation associations	84.4	84.4	84.3	84.7	84.7	84.9
Open spaces with little or no vegetation	76.2	76.2	76.1	77.7	76.5	77.9
Water	83.7	83.7	83.7	84.4	84.3	85.0

Table UA-13. Utrecht, Heat Mitigation (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.33	0.34	0.33	0.33	0.35	0.36
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.43	0.44	0.43	0.43	0.44	0.45
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.53	0.54	0.53	0.54	0.54	0.54
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.59	0.59	0.59	0.60	0.60	0.61
Discontinuous very low density urban fabric (S.L. : < 10%)	0.47	0.47	0.48	0.48	0.49	0.51
Isolated structures	0.61	0.61	0.61	0.61	0.61	0.61
Industrial, commercial, public, military and private units	0.32	0.34	0.33	0.32	0.33	0.36
Fast transit roads and associated land	0.48	0.48	0.48	0.49	0.49	0.49
Other roads and associated land	0.46	0.46	0.47	0.47	0.47	0.48
Railways and associated land	0.28	0.28	0.28	0.28	0.28	0.29
Port areas	0.34	0.36	0.34	0.34	0.35	0.37
Mineral extraction and dump sites	0.54	0.54	0.55	0.55	0.55	0.55
Construction sites	0.40	0.40	0.40	0.41	0.43	0.44
Land without current use	0.47	0.47	0.47	0.56	0.48	0.58
Green urban areas	0.62	0.62	0.62	0.69	0.62	0.69
Sports and leisure facilities	0.51	0.51	0.51	0.52	0.51	0.53
Arable land (annual crops)	0.60	0.60	0.60	0.60	0.60	0.60
Pastures	0.61	0.61	0.61	0.61	0.61	0.61
Forests	0.74	0.74	0.74	0.75	0.74	0.75
Herbaceous vegetation associations	0.40	0.40	0.40	0.40	0.41	0.41
Water	0.79	0.79	0.79	0.79	0.79	0.79

Table UA-14. Utrecht, Carbon Storage (ton/ha)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	93.6	98.1	94.0	94.1	101.3	106.4
Discontinuous dense urban fabric (S.L. : 50% - 80%)	147.1	150.5	147.5	148.0	151.6	156.5
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	196.3	198.1	196.4	199.2	198.7	203.5
Discontinuous low density urban fabric (S.L. : 10% - 30%)	191.1	193.5	191.4	198.2	193.7	203.4
Discontinuous very low density urban fabric (S.L. : < 10%)	119.2	120.2	120.8	126.5	127.8	137.5
Isolated structures	179.4	180.5	179.5	181.0	179.4	182.1
Industrial, commercial, public, military and private units	105.4	115.6	107.3	106.5	111.3	124.2
Fast transit roads and associated land	155.1	155.2	155.1	155.2	155.9	155.9
Other roads and associated land	166.0	166.4	166.8	168.0	170.3	173.5
Railways and associated land	104.6	106.6	104.6	104.7	105.3	107.4
Port areas	100.0	108.3	100.1	100.0	105.3	113.8
Mineral extraction and dump sites	113.5	113.5	114.6	113.6	115.2	116.2
Construction sites	117.8	119.1	119.3	124.0	131.9	140.4
Land without current use	140.4	141.1	140.9	198.9	149.1	205.4
Green urban areas	240.4	240.6	240.5	277.0	241.2	277.6
Sports and leisure facilities	191.2	192.3	192.2	197.3	192.2	200.1
Arable land (annual crops)	48.5	48.5	48.5	48.8	48.6	48.9
Pastures	26.4	26.4	26.4	26.7	26.4	26.7
Forests	311.7	311.7	311.7	316.4	311.7	316.4
Herbaceous vegetation associations	129.6	129.6	130.4	129.6	131.4	132.2
Water	89.5	89.6	89.5	89.9	89.8	90.3

Table UA-15. Utrecht, Runoff Reduction (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	42.0	47.1	42.3	42.1	43.8	49.2
Discontinuous dense urban fabric (S.L. : 50% - 80%)	57.2	61.2	57.5	57.3	58.2	62.8
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	70.1	72.2	70.2	70.5	70.6	73.3
Discontinuous low density urban fabric (S.L. : 10% - 30%)	72.0	74.8	72.2	73.0	72.6	76.6
Discontinuous very low density urban fabric (S.L. : < 10%)	55.0	56.3	56.1	55.9	57.0	60.1
Isolated structures	70.1	71.3	70.2	70.2	70.1	71.3
Industrial, commercial, public, military and private units	46.2	58.7	47.6	46.4	47.6	61.7
Fast transit roads and associated land	60.5	60.5	60.5	60.5	60.7	60.7
Other roads and associated land	60.9	61.3	61.5	61.3	61.9	63.4
Railways and associated land	39.1	41.4	39.1	39.1	39.3	41.5
Port areas	41.8	52.0	41.9	41.8	43.0	53.4
Mineral extraction and dump sites	49.5	49.5	50.4	49.5	49.9	50.7
Construction sites	53.1	54.6	54.2	53.9	56.5	59.8
Land without current use	64.5	65.3	64.9	73.7	66.6	75.8
Green urban areas	83.4	83.6	83.5	87.5	83.6	87.8
Sports and leisure facilities	74.0	75.4	74.8	75.0	74.2	77.4
Arable land (annual crops)	69.8	69.8	69.8	69.9	69.9	69.9
Pastures	67.2	67.2	67.2	67.2	67.2	67.2
Forests	92.0	92.0	92.0	92.3	92.0	92.3
Herbaceous vegetation associations	57.4	57.4	58.1	57.4	57.8	58.5
Water	29.2	29.3	29.2	29.2	29.3	29.3

Table UA-16. Utrecht, Biodiversity Potential (index)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	0.39	0.59	0.39	0.39	0.45	0.66
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.84	1.01	0.85	0.85	0.88	1.06
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	1.11	1.19	1.11	1.12	1.13	1.22
Discontinuous low density urban fabric (S.L. : 10% - 30%)	1.20	1.26	1.20	1.20	1.21	1.28
Discontinuous very low density urban fabric (S.L. : < 10%)	0.86	0.90	0.87	0.91	0.91	1.00
Isolated structures	1.14	1.18	1.13	1.13	1.14	1.17
Industrial, commercial, public, military and private units	0.58	0.87	0.59	0.59	0.62	0.97
Fast transit roads and associated land	0.56	0.56	0.56	0.56	0.57	0.57
Other roads and associated land	0.56	0.57	0.57	0.58	0.59	0.62
Railways and associated land	0.47	0.49	0.47	0.47	0.47	0.49
Port areas	0.46	0.74	0.46	0.46	0.50	0.78
Mineral extraction and dump sites	0.36	0.36	0.36	0.36	0.38	0.39
Construction sites	0.42	0.52	0.43	0.46	0.51	0.68
Land without current use	0.67	0.68	0.68	1.10	0.73	1.14
Green urban areas	1.08	1.09	1.08	1.12	1.08	1.13
Sports and leisure facilities	0.81	0.87	0.83	0.88	0.82	0.95
Arable land (annual crops)	0.64	0.64	0.64	0.65	0.64	0.65
Pastures	0.77	0.77	0.77	0.78	0.77	0.78
Forests	0.77	0.77	0.77	0.73	0.77	0.73
Herbaceous vegetation associations	0.47	0.47	0.48	0.47	0.48	0.49
Water	0.69	0.70	0.69	0.69	0.70	0.70

Table UA-17. Utrecht, Accessibility (m)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	239.6	239.6	239.6	233.7	239.6	233.7
Discontinuous dense urban fabric (S.L. : 50% - 80%)	225.5	225.5	225.5	220.2	225.5	220.2
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	214.0	214.0	214.0	200.9	214.0	200.9
Discontinuous low density urban fabric (S.L. : 10% - 30%)	413.3	413.3	413.3	197.5	413.3	197.5
Discontinuous very low density urban fabric (S.L. : < 10%)	359.3	359.3	359.3	245.6	359.3	245.6
Isolated structures	428.0	428.0	428.0	428.0	428.0	428.0
Industrial, commercial, public, military and private units	344.1	344.1	344.1	334.0	344.1	334.0
Port areas	711.9	711.9	711.9	711.9	711.9	711.9
Construction sites	206.4	206.4	206.4	206.4	206.4	206.4
Land without current use	325.5	325.5	325.5	0.0	325.5	0.0
Sports and leisure facilities	265.1	265.1	265.1	265.1	265.1	265.1
Arable land (annual crops)	572.0	572.0	572.0	494.2	572.0	494.2
Pastures	462.5	462.5	462.5	448.4	462.5	448.4

Table UA-18. Utrecht, Greenness (%)

UAclass	Current	Green Roofs	Parking Areas	Parks	Street Trees	Green Dream
Continuous urban fabric (S.L. : > 80%)	39.6	39.6	39.5	40.4	41.3	42.0
Discontinuous dense urban fabric (S.L. : 50% - 80%)	49.9	49.9	49.8	50.8	51.4	52.1
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	60.2	60.2	60.0	61.5	61.3	62.3
Discontinuous low density urban fabric (S.L. : 10% - 30%)	65.3	65.3	65.1	67.2	66.6	68.2
Discontinuous very low density urban fabric (S.L. : < 10%)	52.1	52.1	51.7	54.3	53.9	55.5
Isolated structures	88.6	88.6	88.5	88.7	88.7	88.8
Industrial, commercial, public, military and private units	45.6	45.6	45.4	46.4	47.2	47.7
Fast transit roads and associated land	63.6	63.6	63.4	64.0	64.1	64.4
Other roads and associated land	47.8	47.8	47.7	48.7	49.3	50.0
Railways and associated land	28.0	28.0	27.9	29.0	29.4	30.3
Port areas	35.8	35.8	35.8	36.1	37.4	37.6
Mineral extraction and dump sites	71.6	71.6	71.5	72.8	72.0	73.0
Construction sites	50.0	50.0	49.8	52.0	52.5	54.1
Land without current use	51.6	51.6	51.3	54.8	53.9	56.5
Green urban areas	60.7	60.7	60.6	62.4	61.8	63.2
Sports and leisure facilities	65.6	65.6	65.4	66.8	66.5	67.3
Arable land (annual crops)	87.4	87.4	87.3	87.6	87.6	87.7
Pastures	88.9	88.9	88.8	89.2	89.0	89.2
Forests	82.2	82.2	82.1	82.6	82.4	82.8
Herbaceous vegetation associations	57.2	57.2	56.8	57.9	59.4	59.7
Water	61.6	61.6	61.5	62.5	62.6	63.3

Appendix Part B3

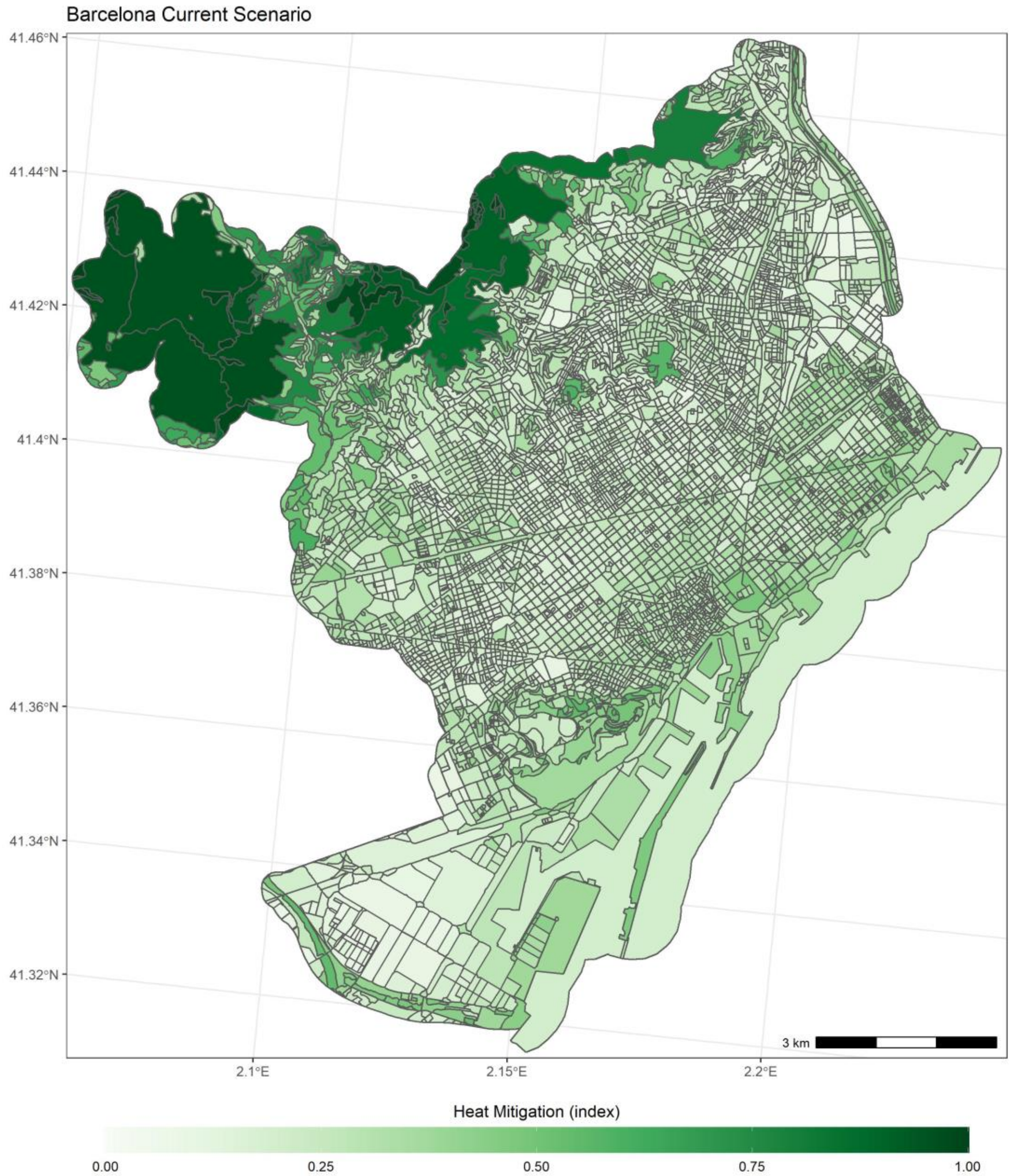

Figure M1. Barcelona Current scenario Heat Mitigation (index)

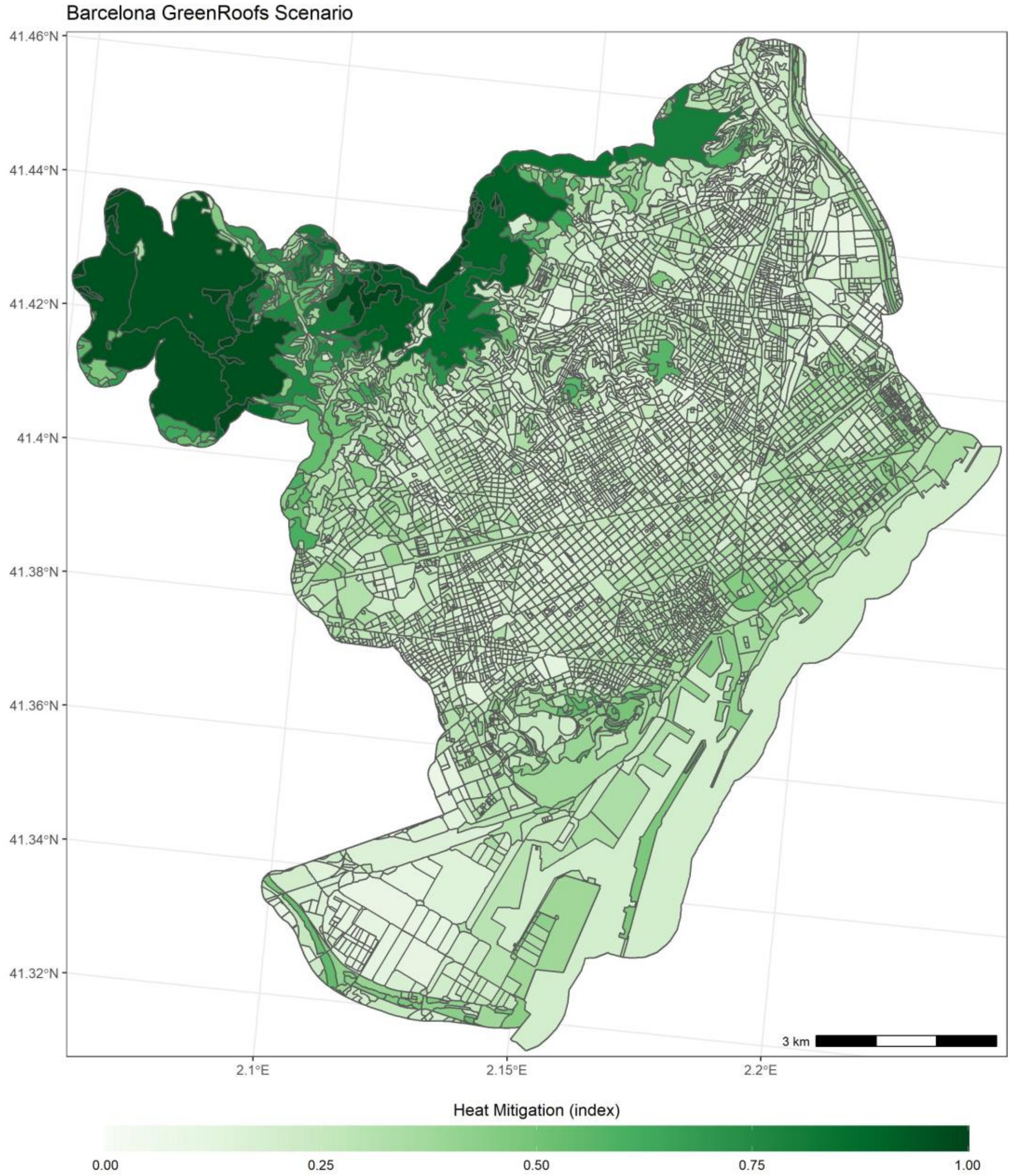

Figure M2. Barcelona GreenRoofs scenario Heat Mitigation (index)

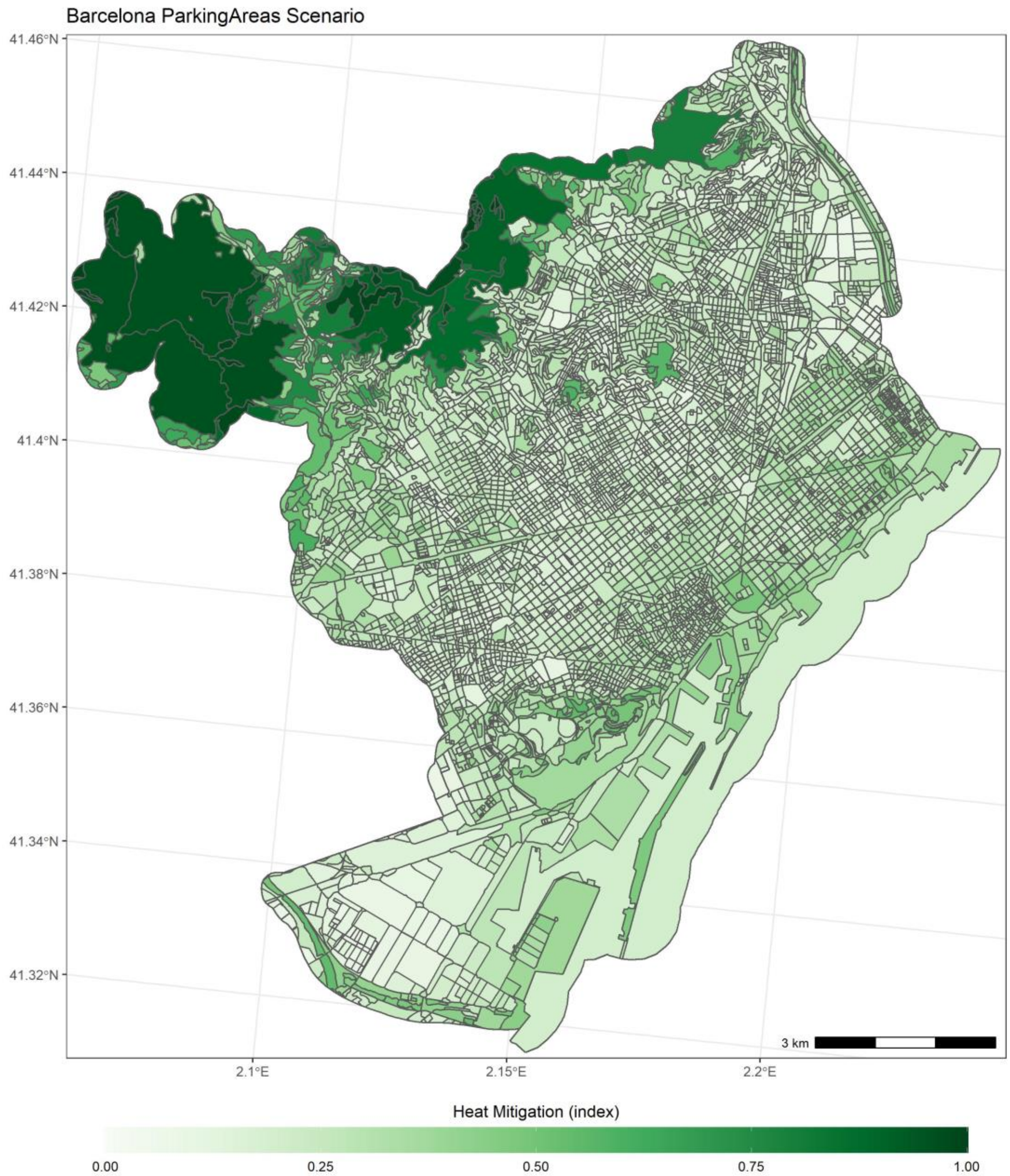

Figure M3. Barcelona ParkingAreas scenario Heat Mitigation (index)

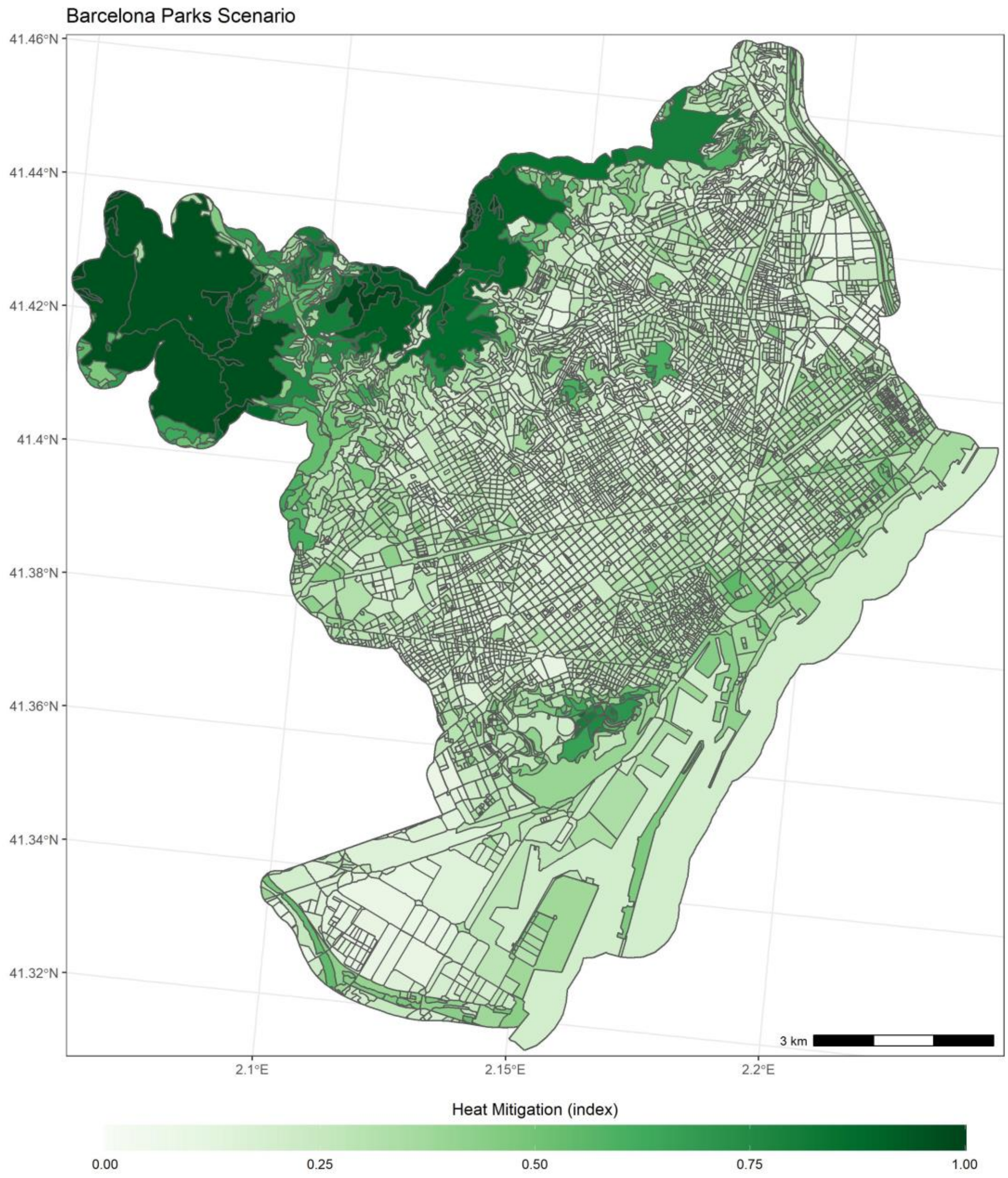

Figure M4. Barcelona Parks scenario Heat Mitigation (index)

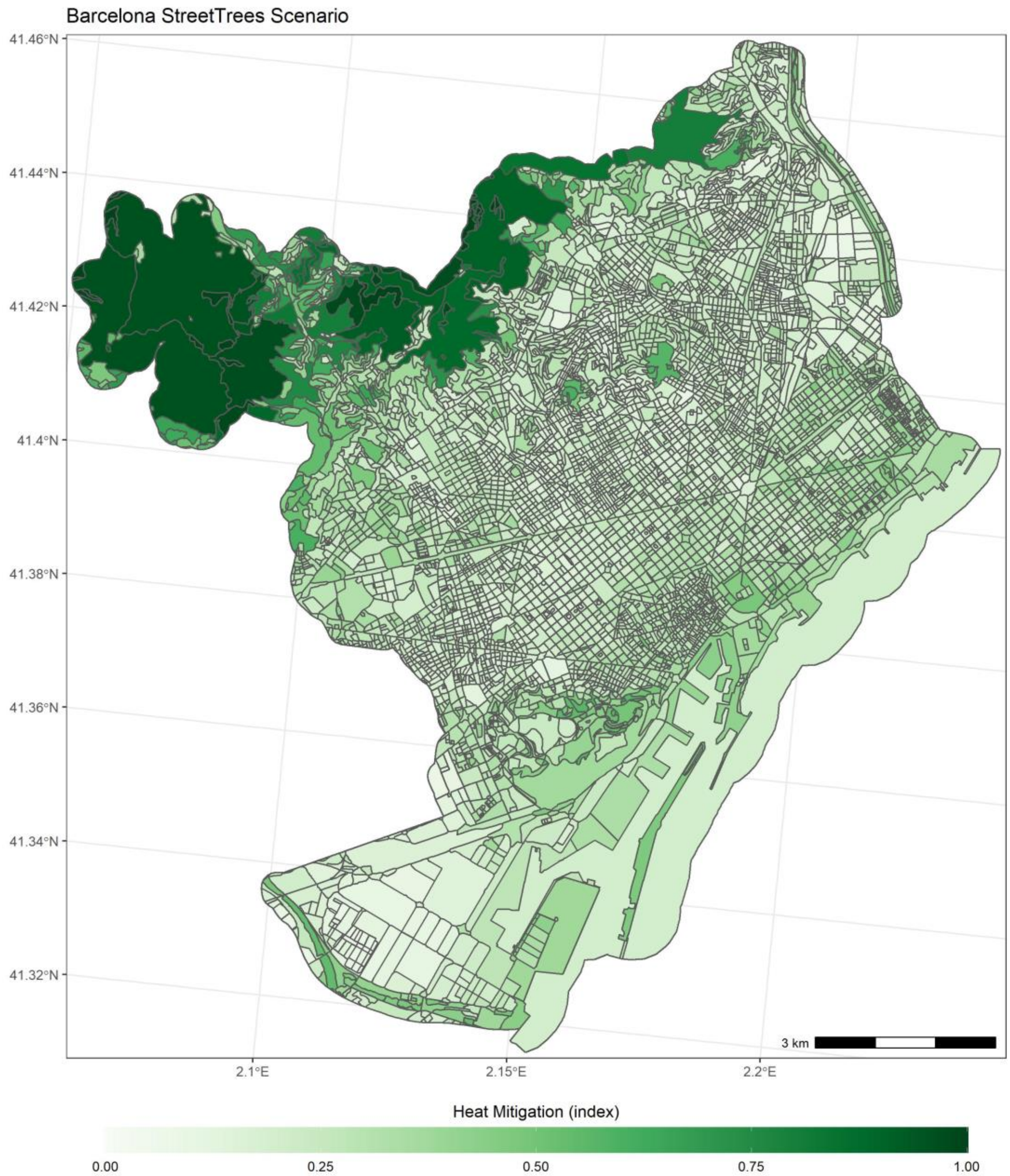

Figure M5. Barcelona StreetTrees scenario Heat Mitigation (index)

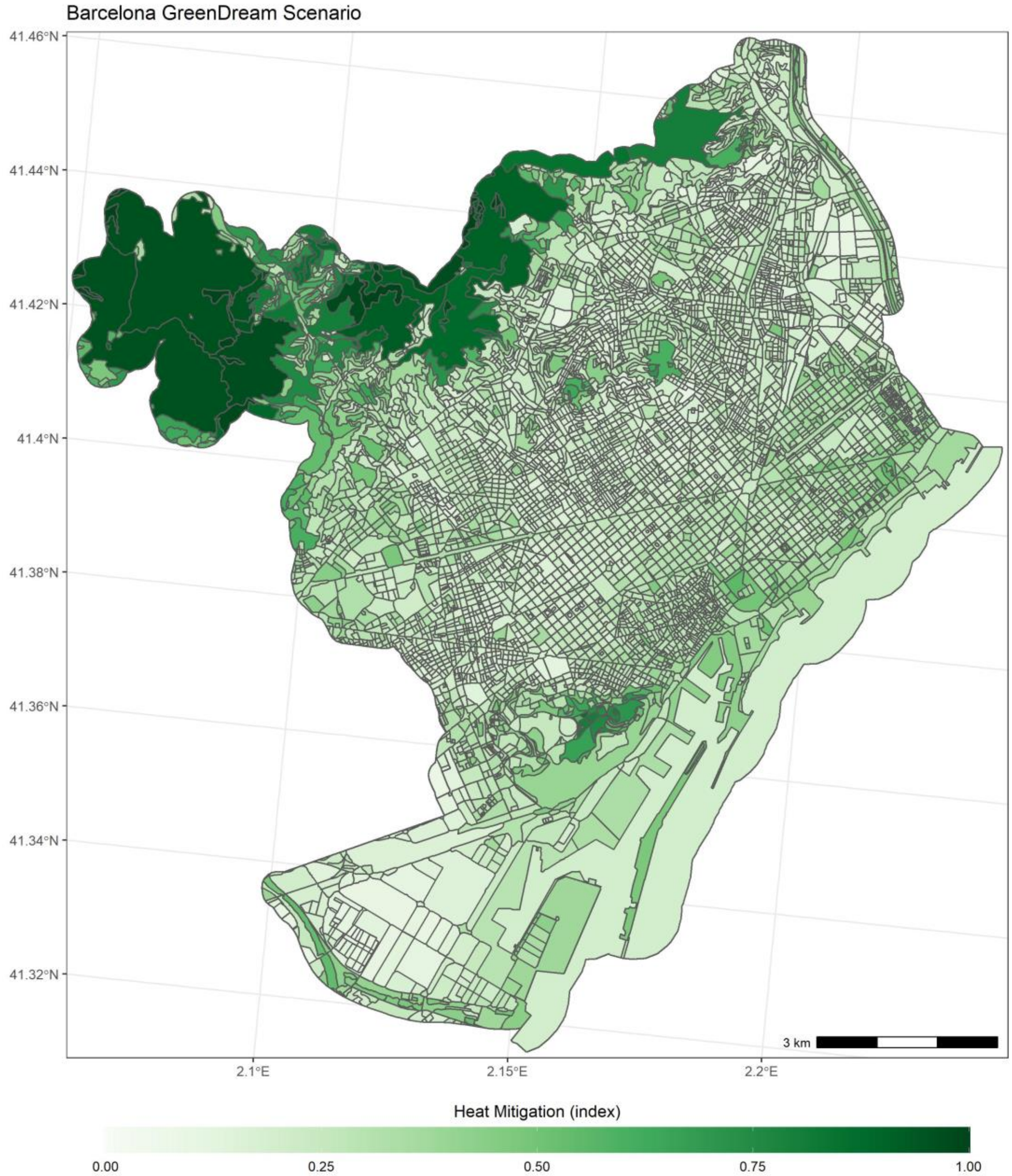

Figure M6. Barcelona GreenDream scenario Heat Mitigation (index)

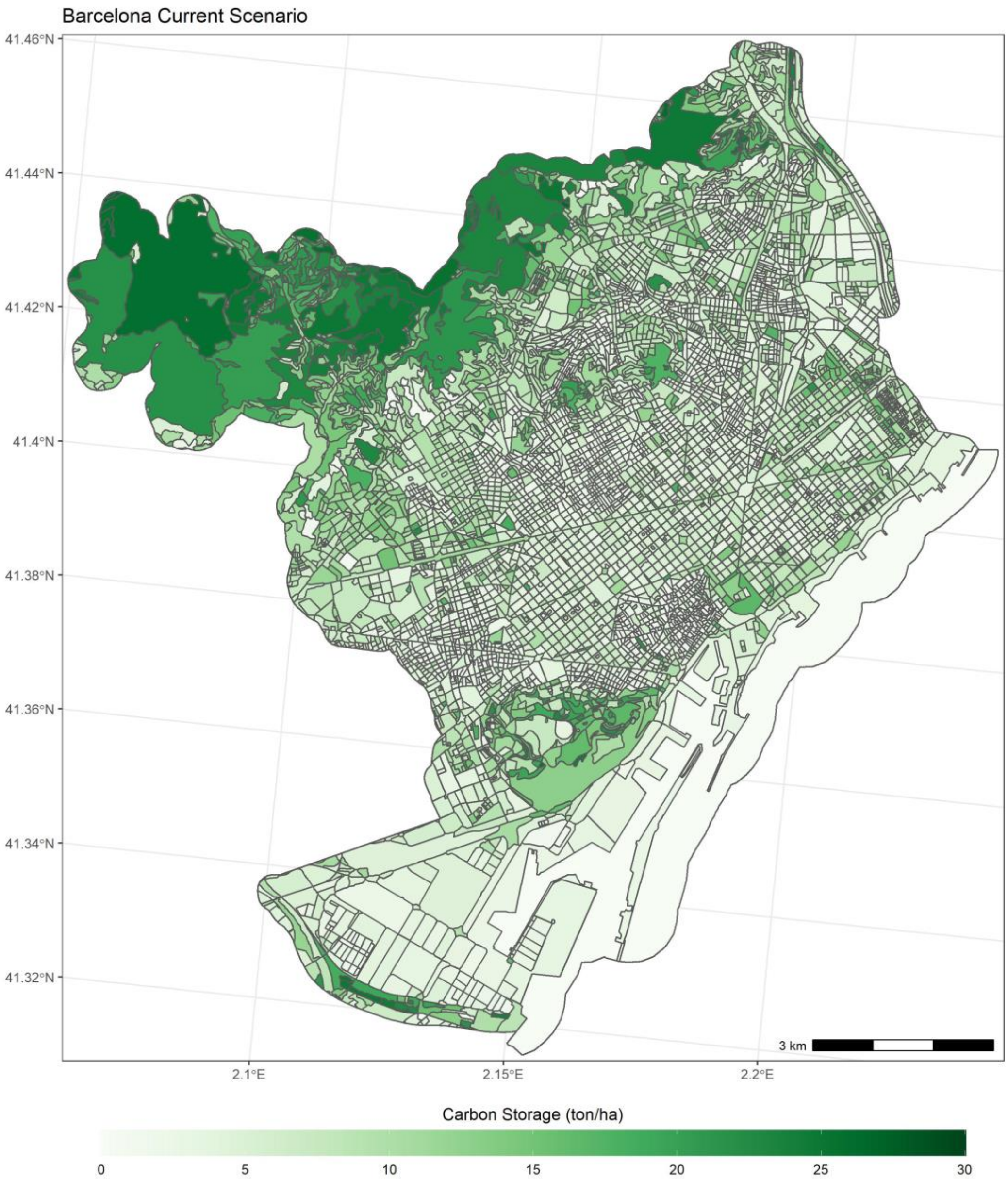

Figure M7. Barcelona Current scenario Carbon Storage (ton/ha)

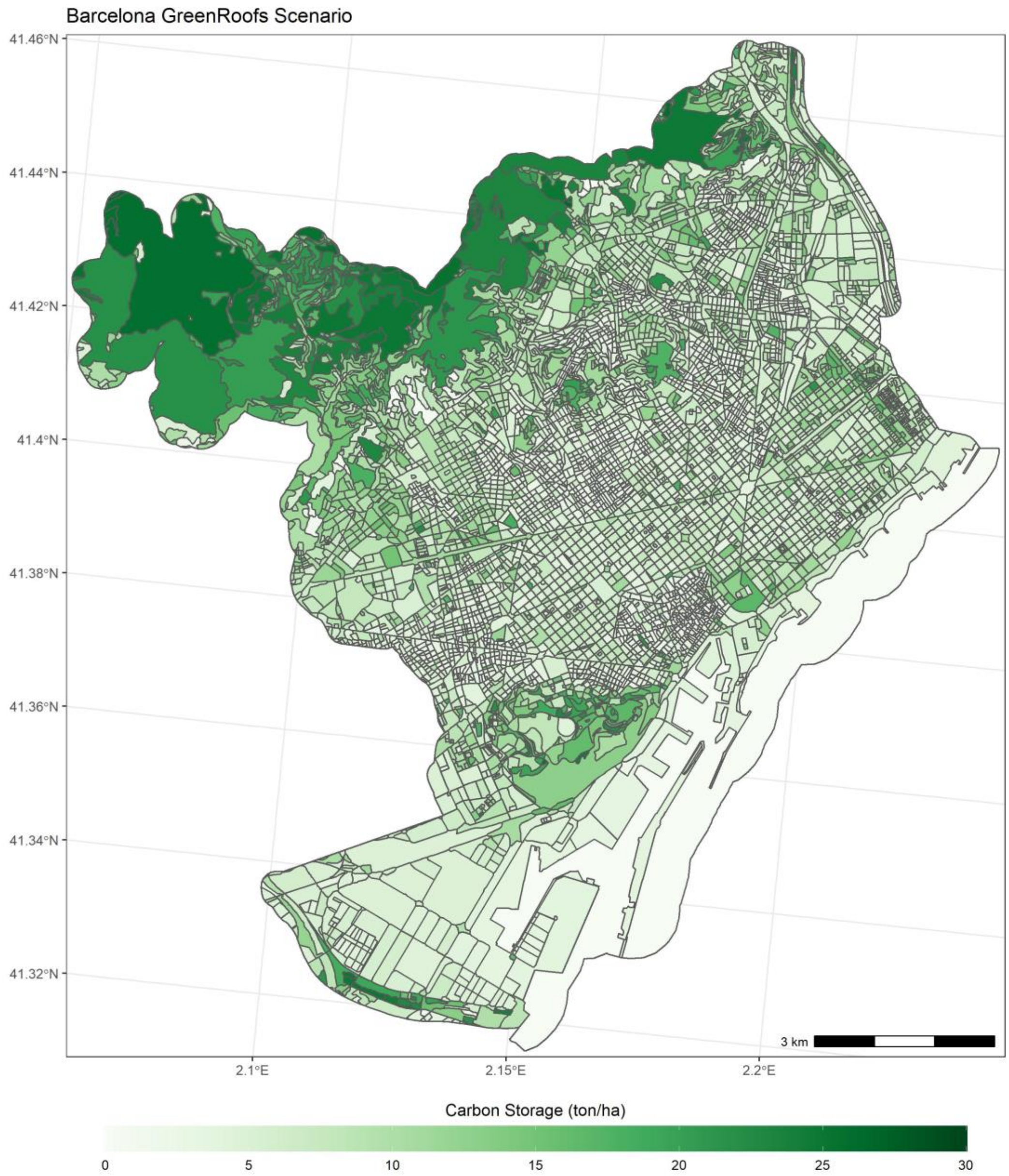

Figure M8. Barcelona GreenRoofs scenario Carbon Storage (ton/ha)

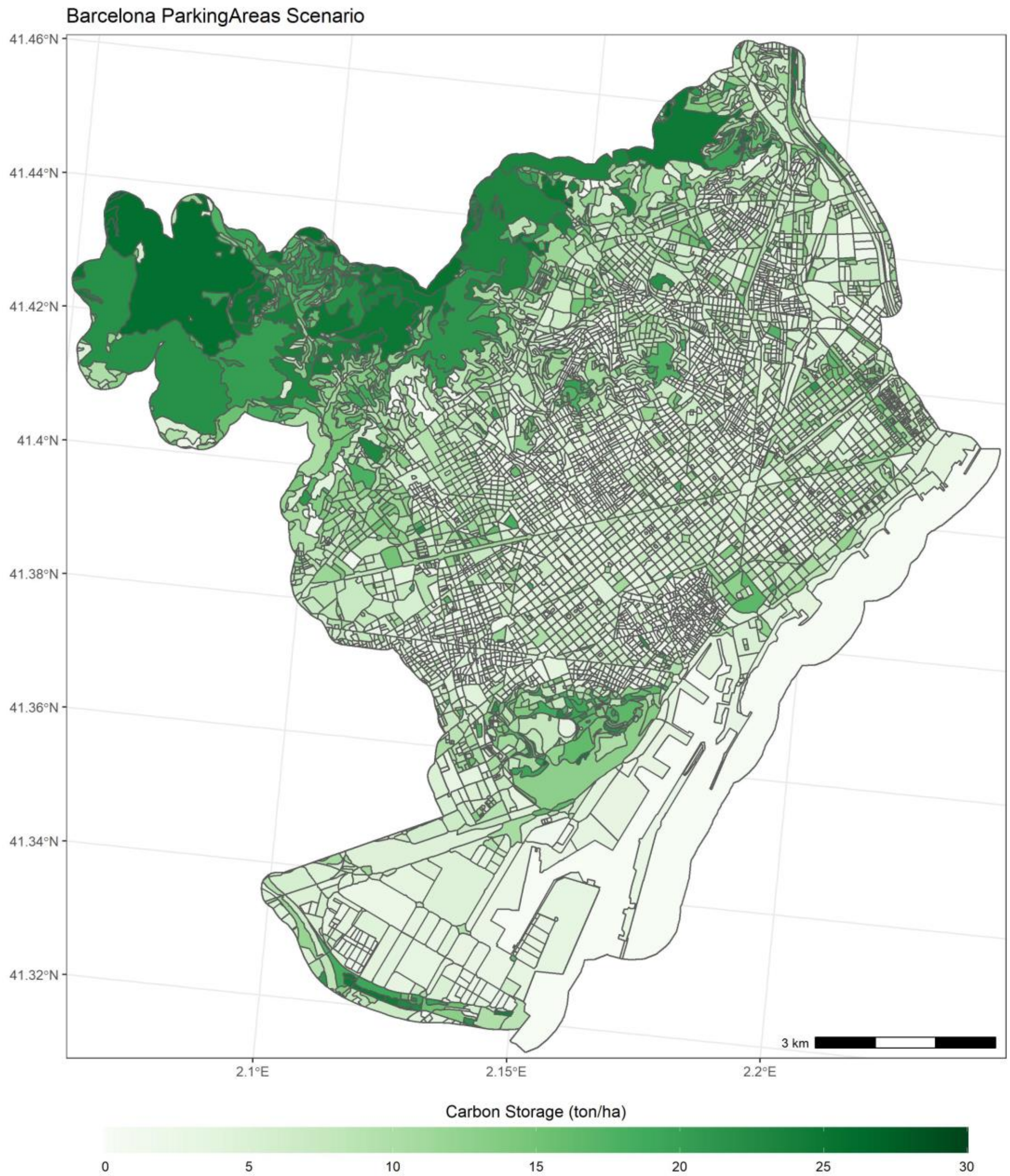

Figure M9. Barcelona ParkingAreas scenario Carbon Storage (ton/ha)

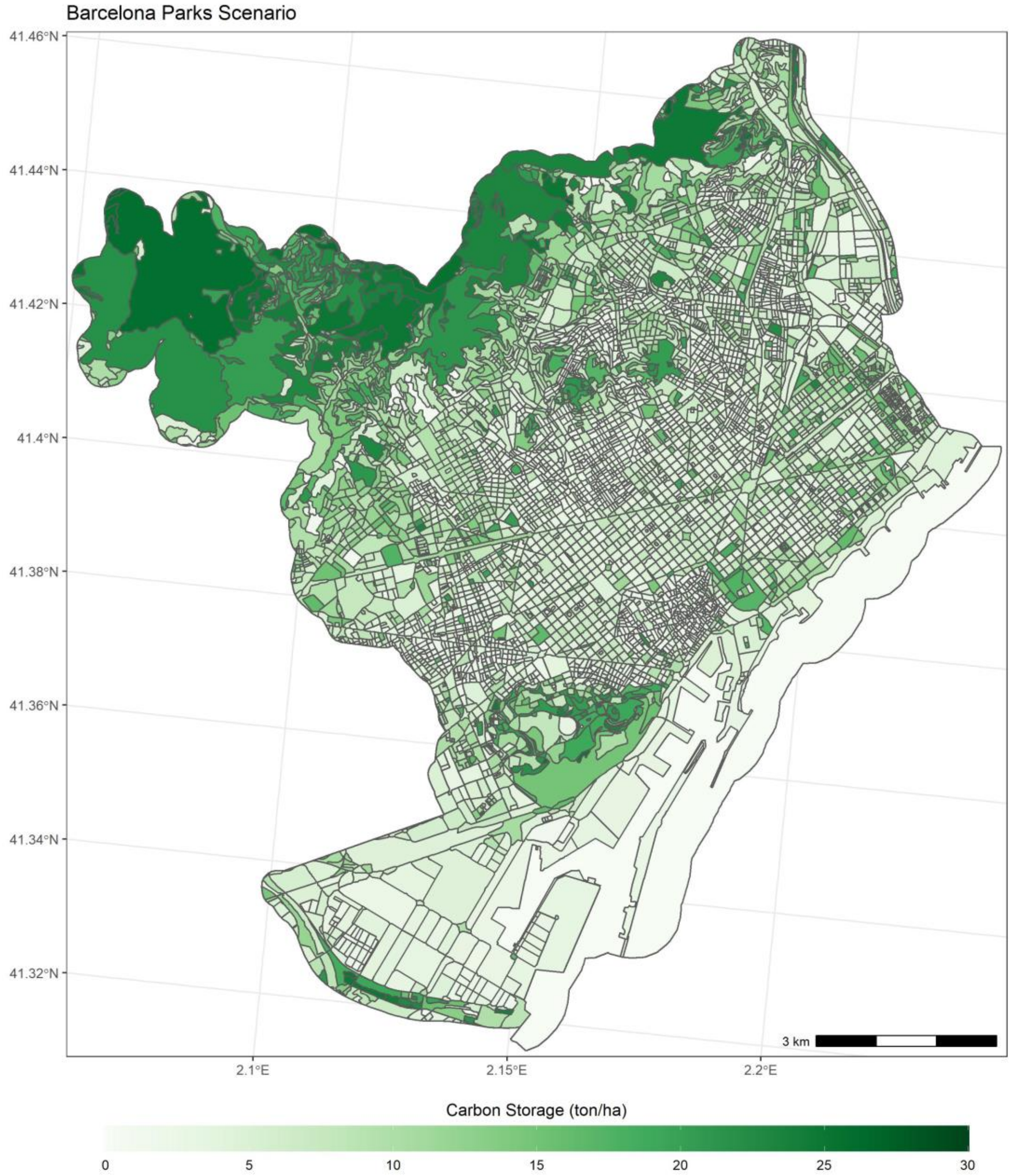

Figure M10. Barcelona Parks scenario Carbon Storage (ton/ha)

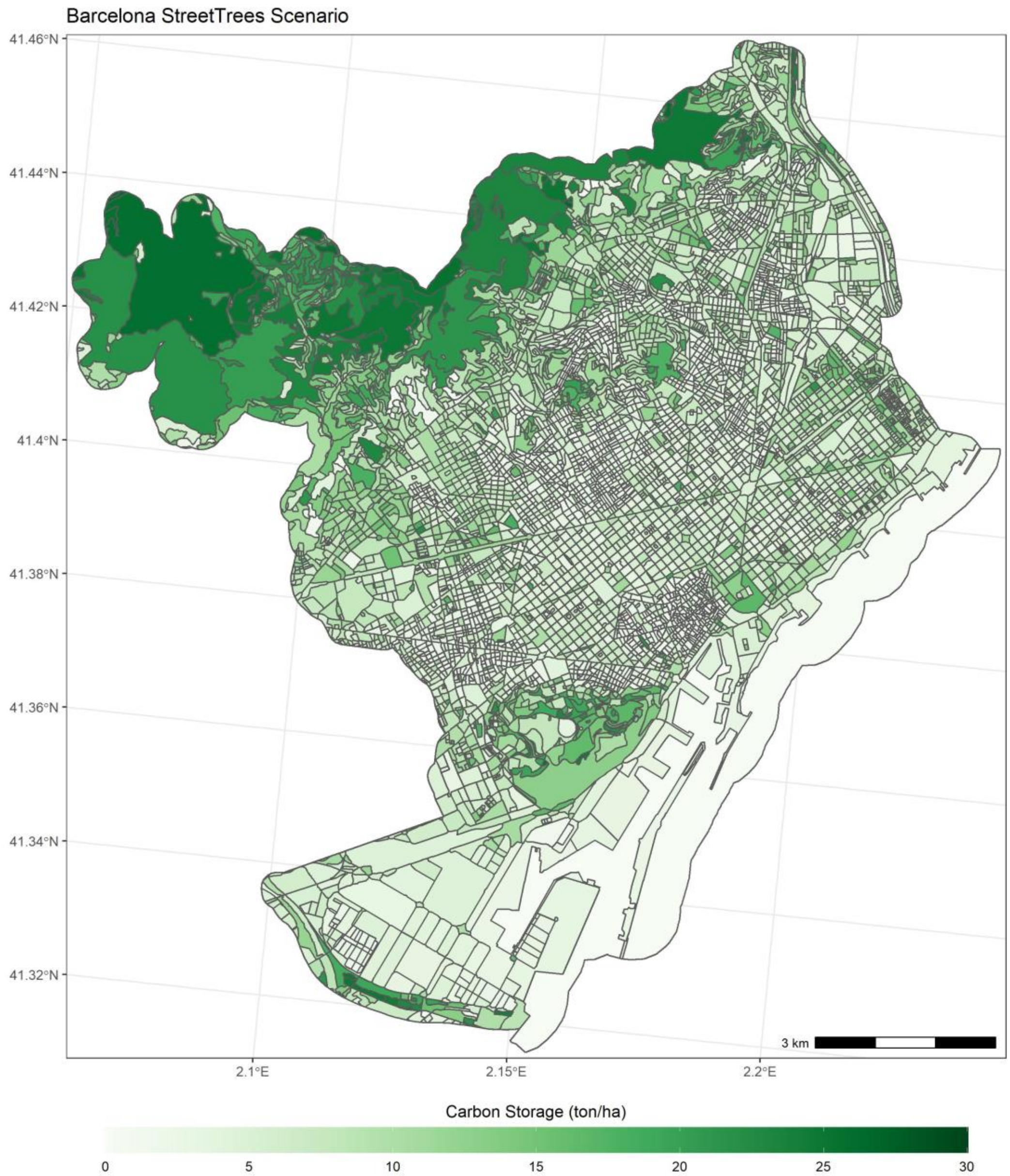

Figure M11. Barcelona StreetTrees scenario Carbon Storage (ton/ha)

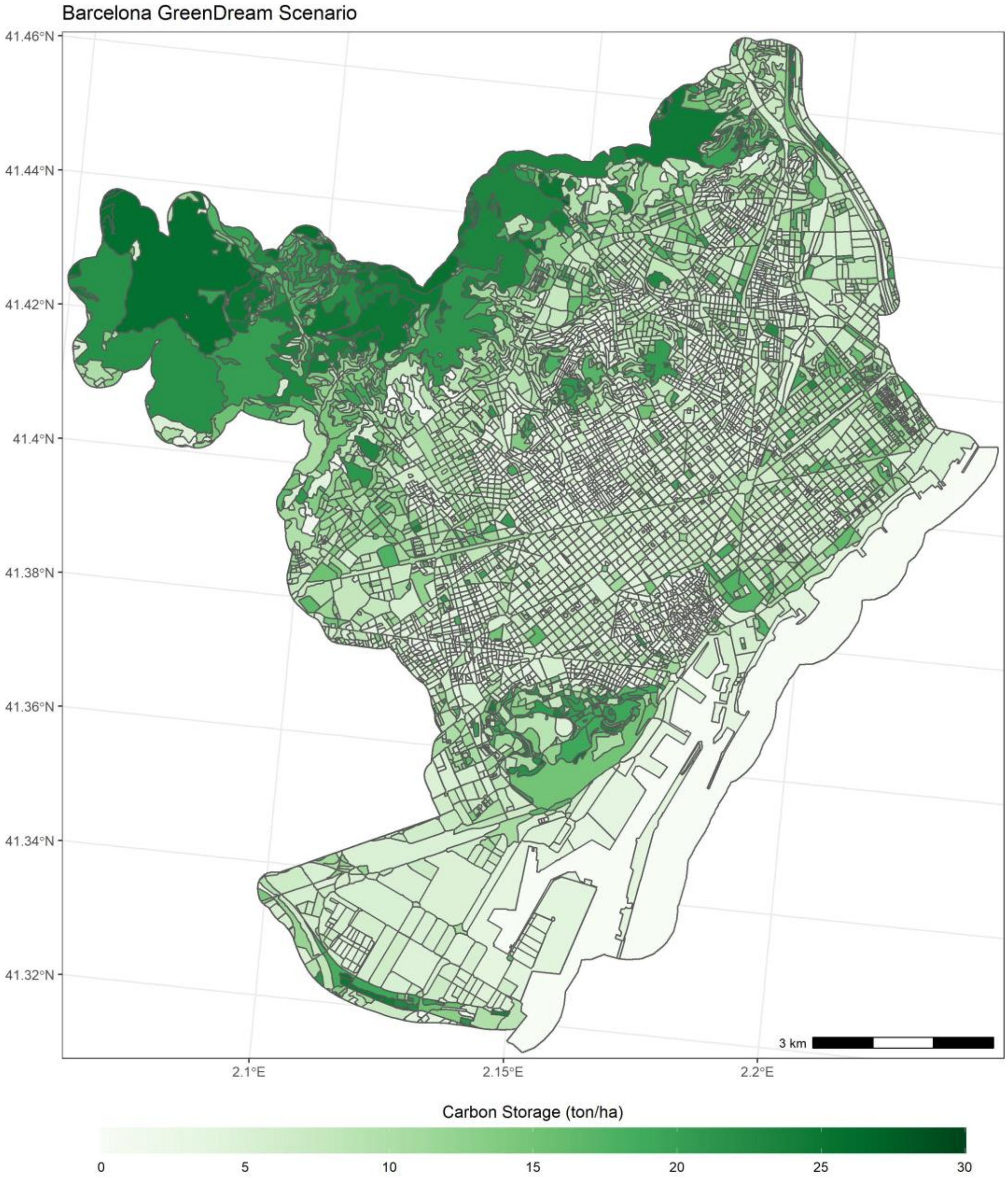

Figure M12. Barcelona GreenDream scenario Carbon Storage (ton/ha)

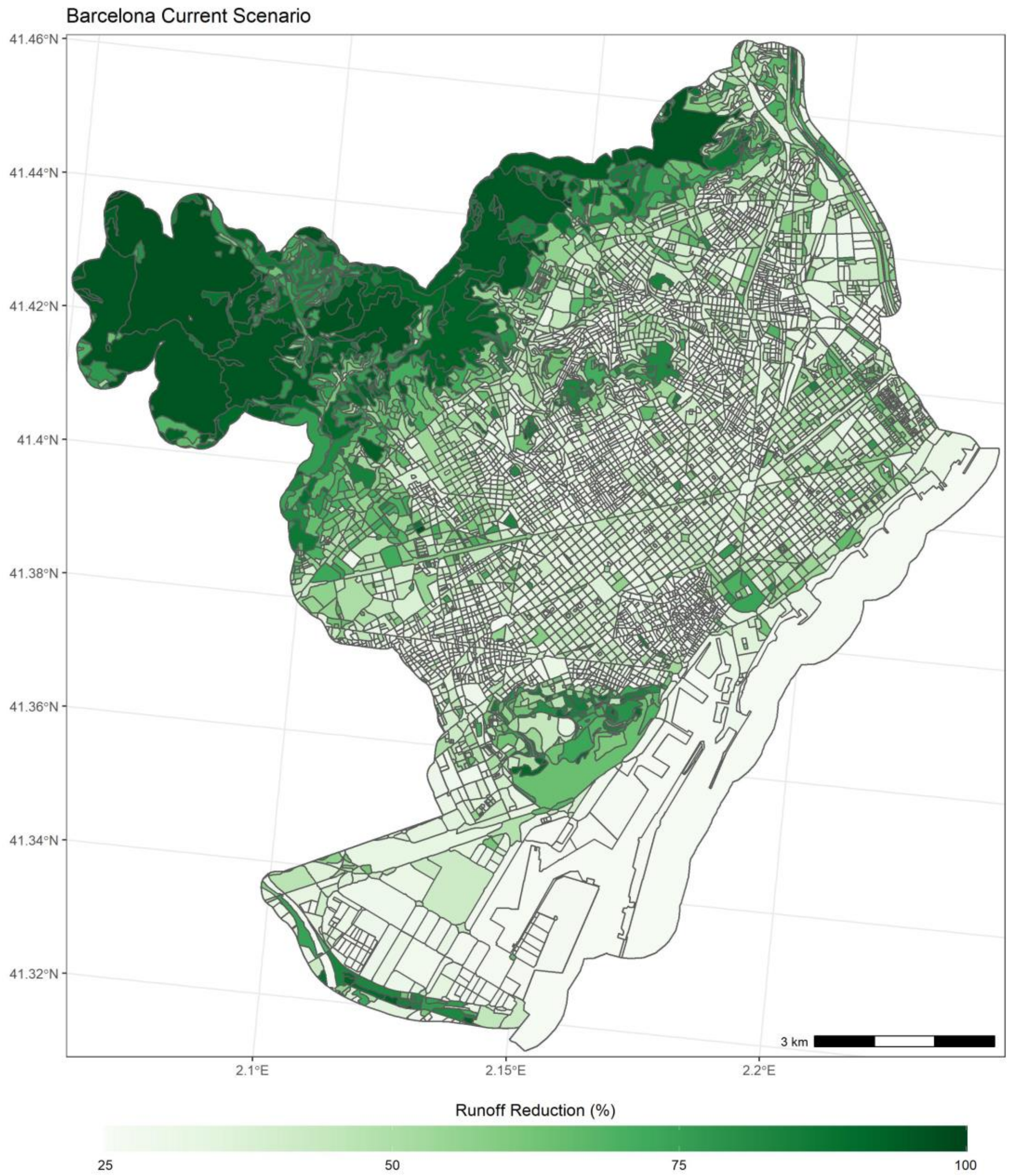

Figure M13. Barcelona Current scenario Runoff Reduction (%)

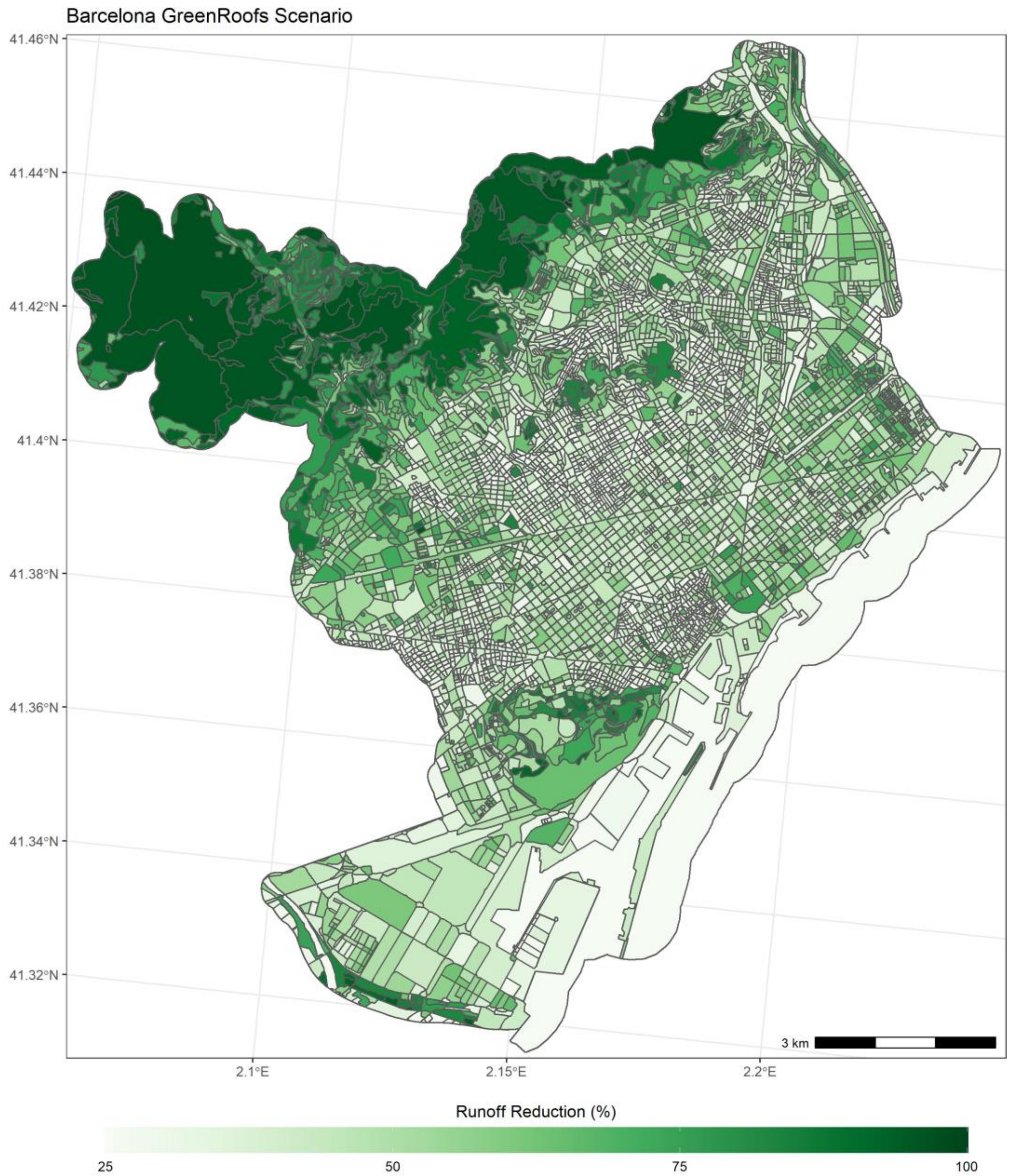

Figure M14. Barcelona GreenRoofs scenario Runoff Reduction (%)

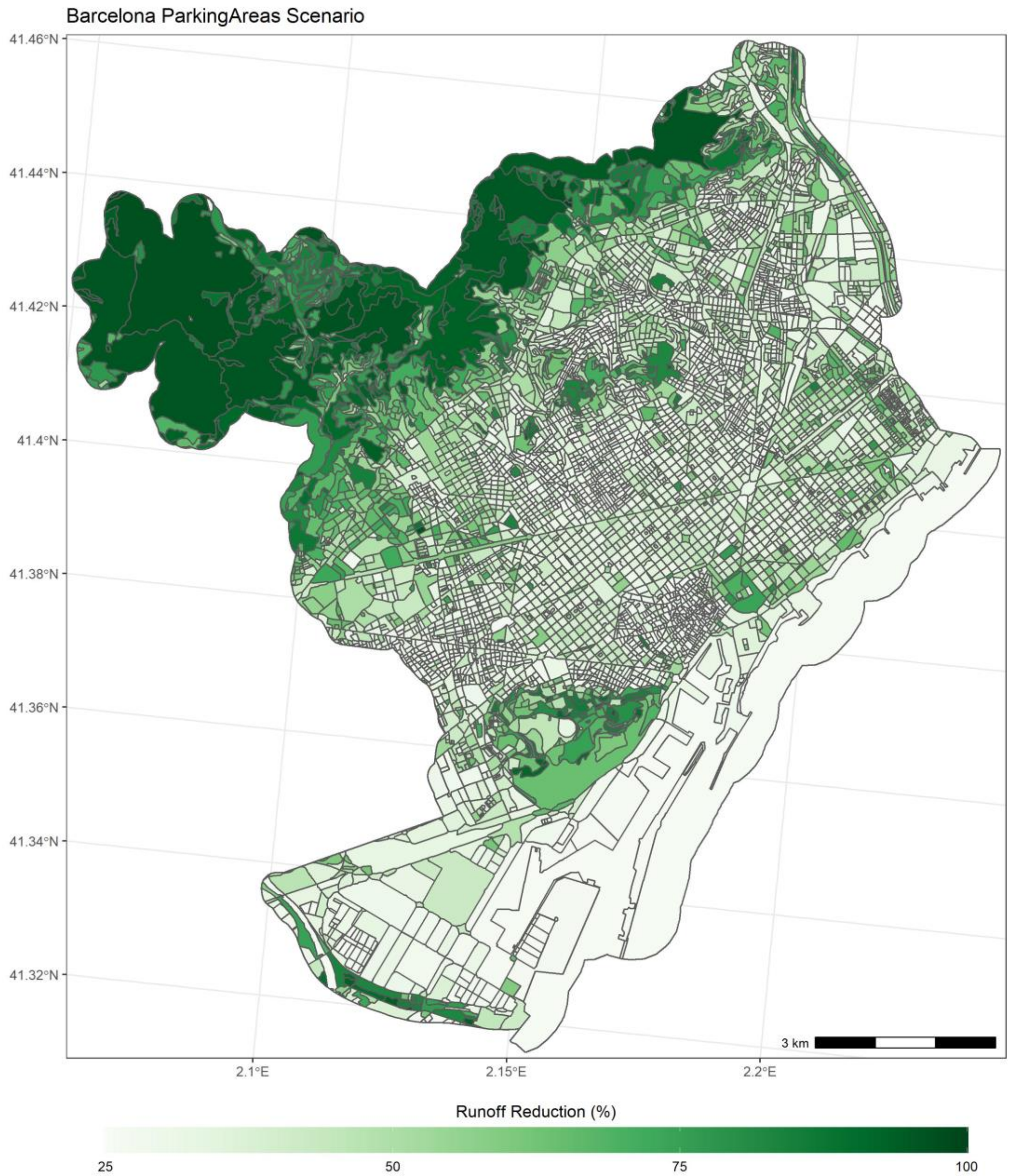

Figure M15. Barcelona ParkingAreas scenario Runoff Reduction (%)

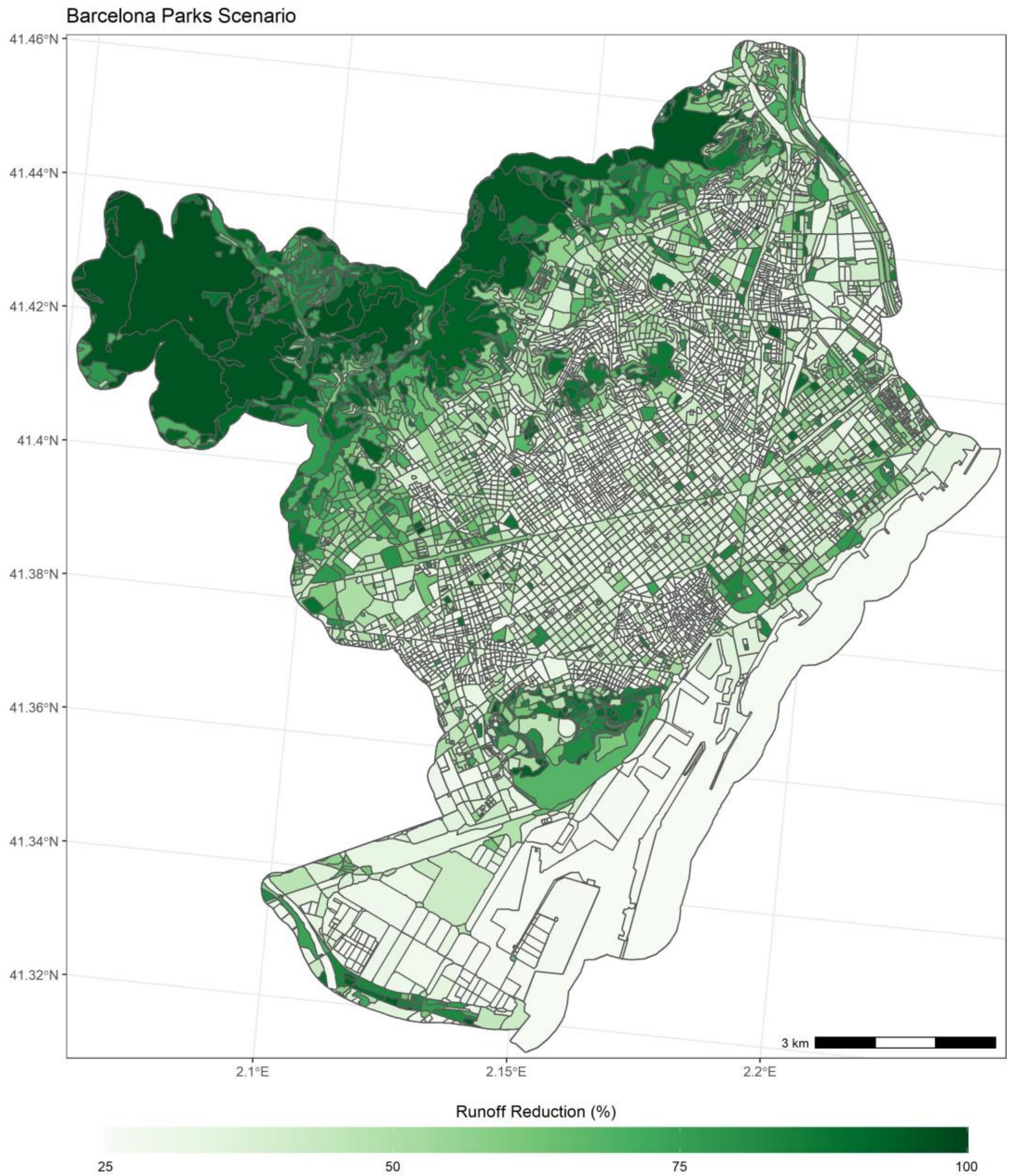

Figure M16. Barcelona Parks scenario Runoff Reduction (%)

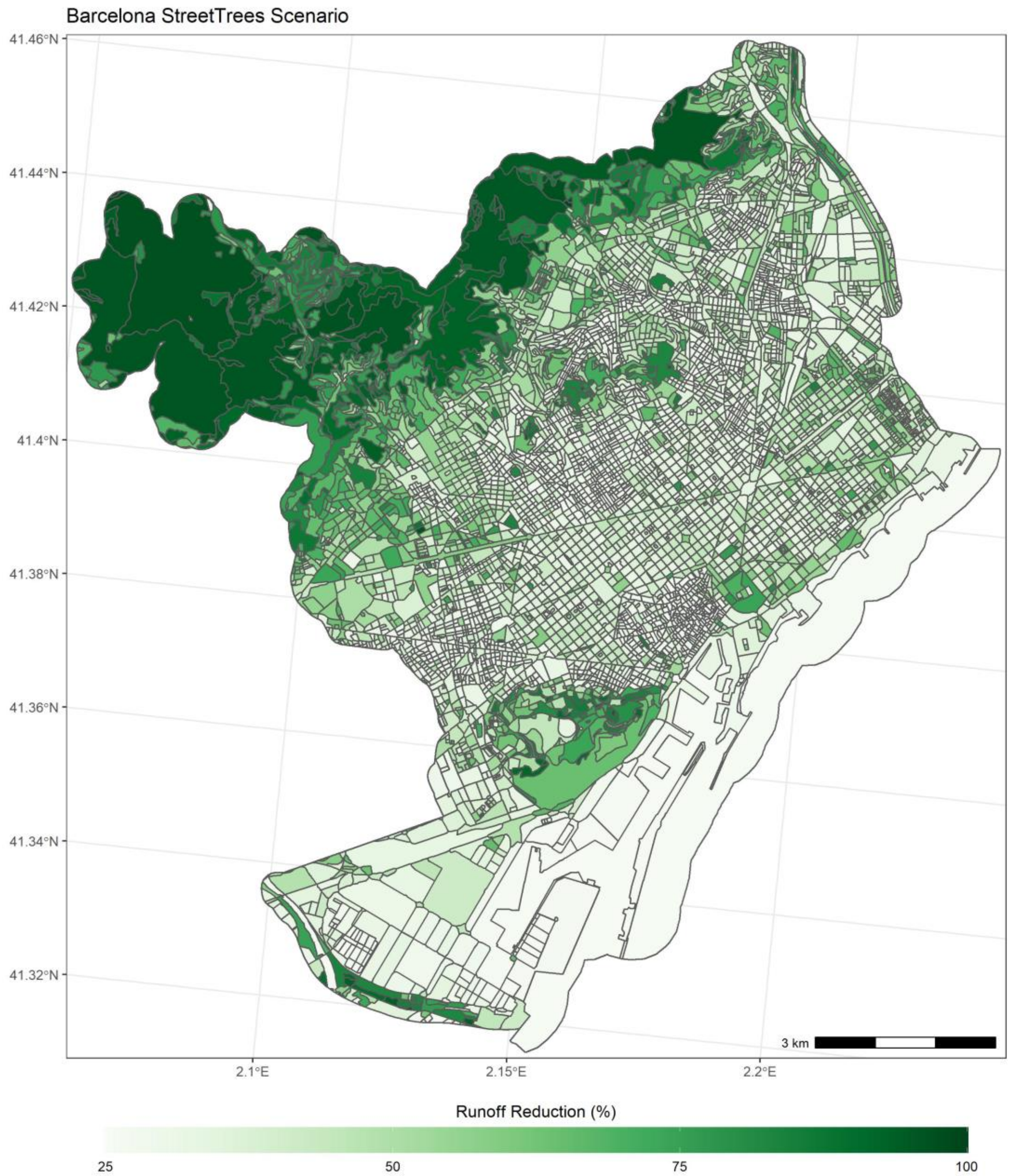

Figure M17. Barcelona StreetTrees scenario Runoff Reduction (%)

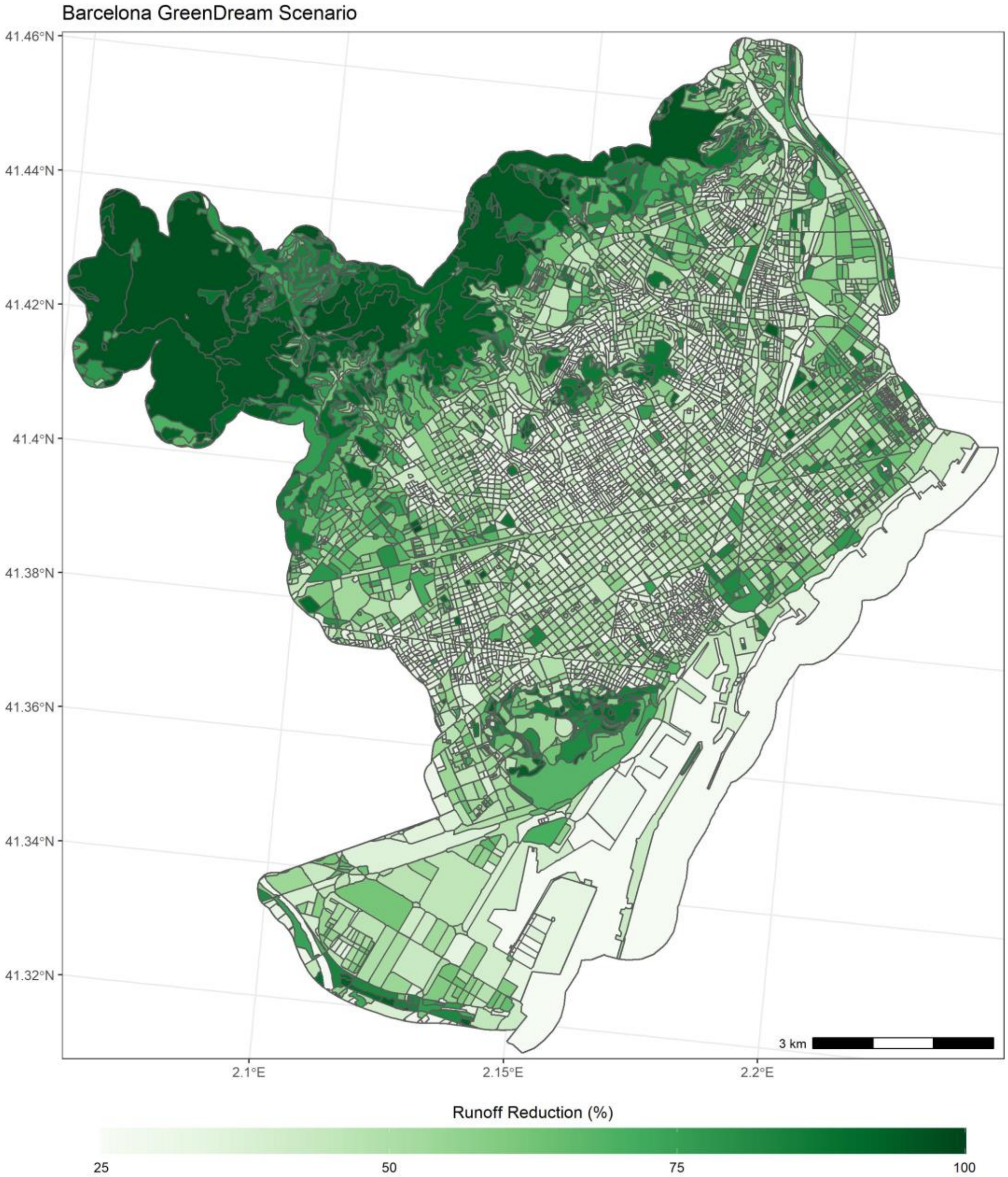

Figure M18. Barcelona GreenDream scenario Runoff Reduction (%)

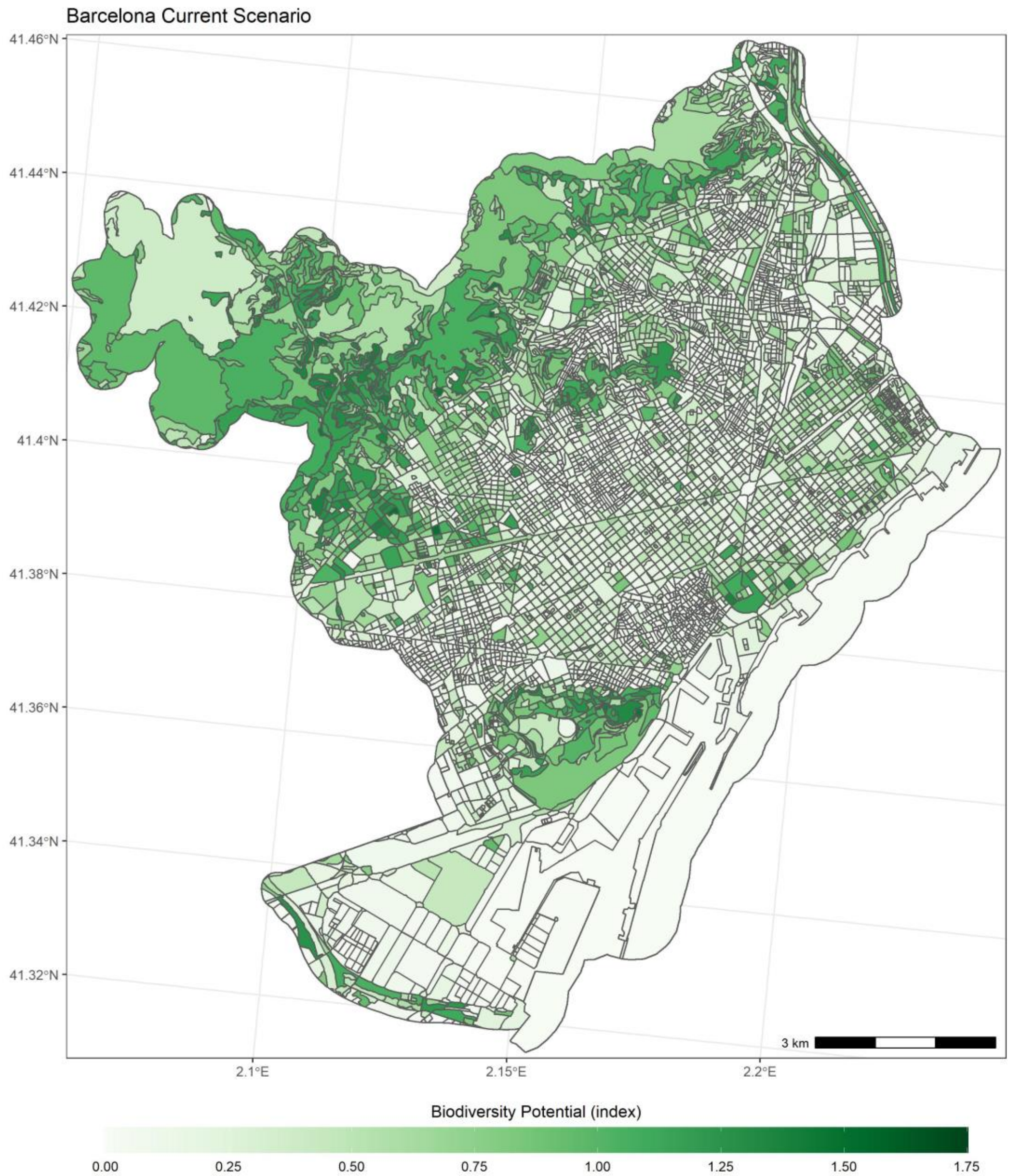

Figure M19. Barcelona Current scenario Biodiversity Potential (index)

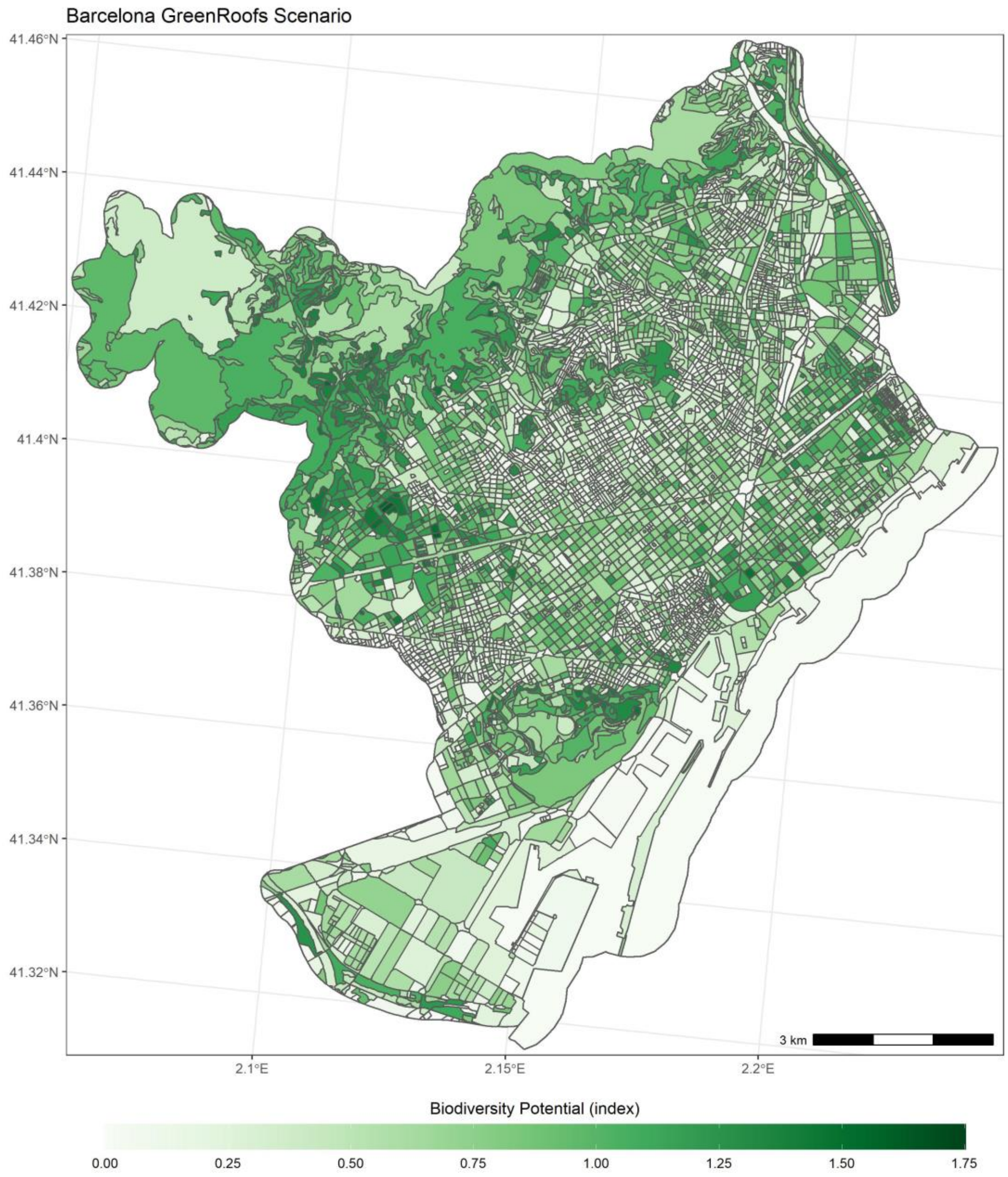

Figure M20. Barcelona GreenRoofs scenario Biodiversity Potential (index)

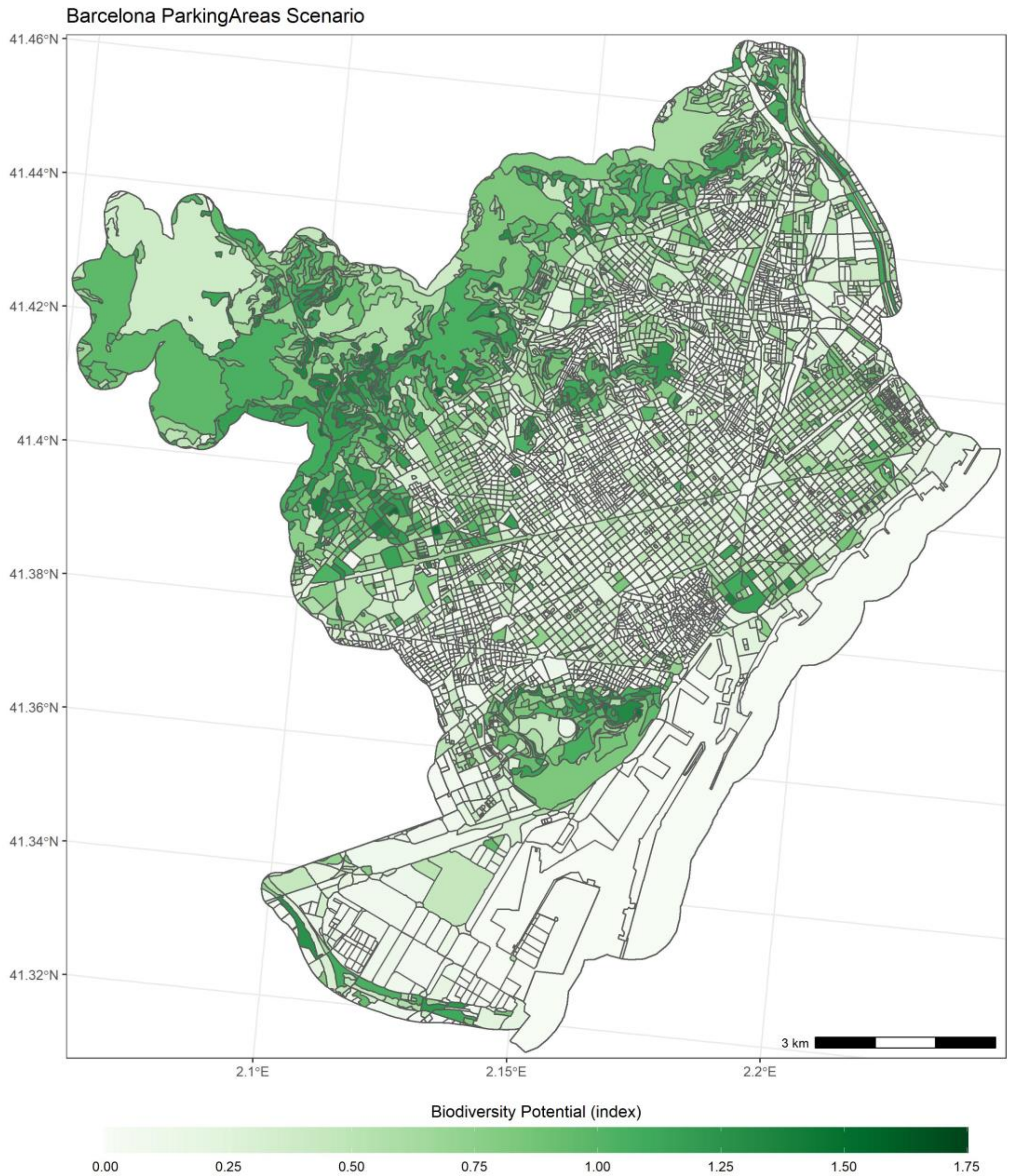

Figure M21. Barcelona ParkingAreas scenario Biodiversity Potential (index)

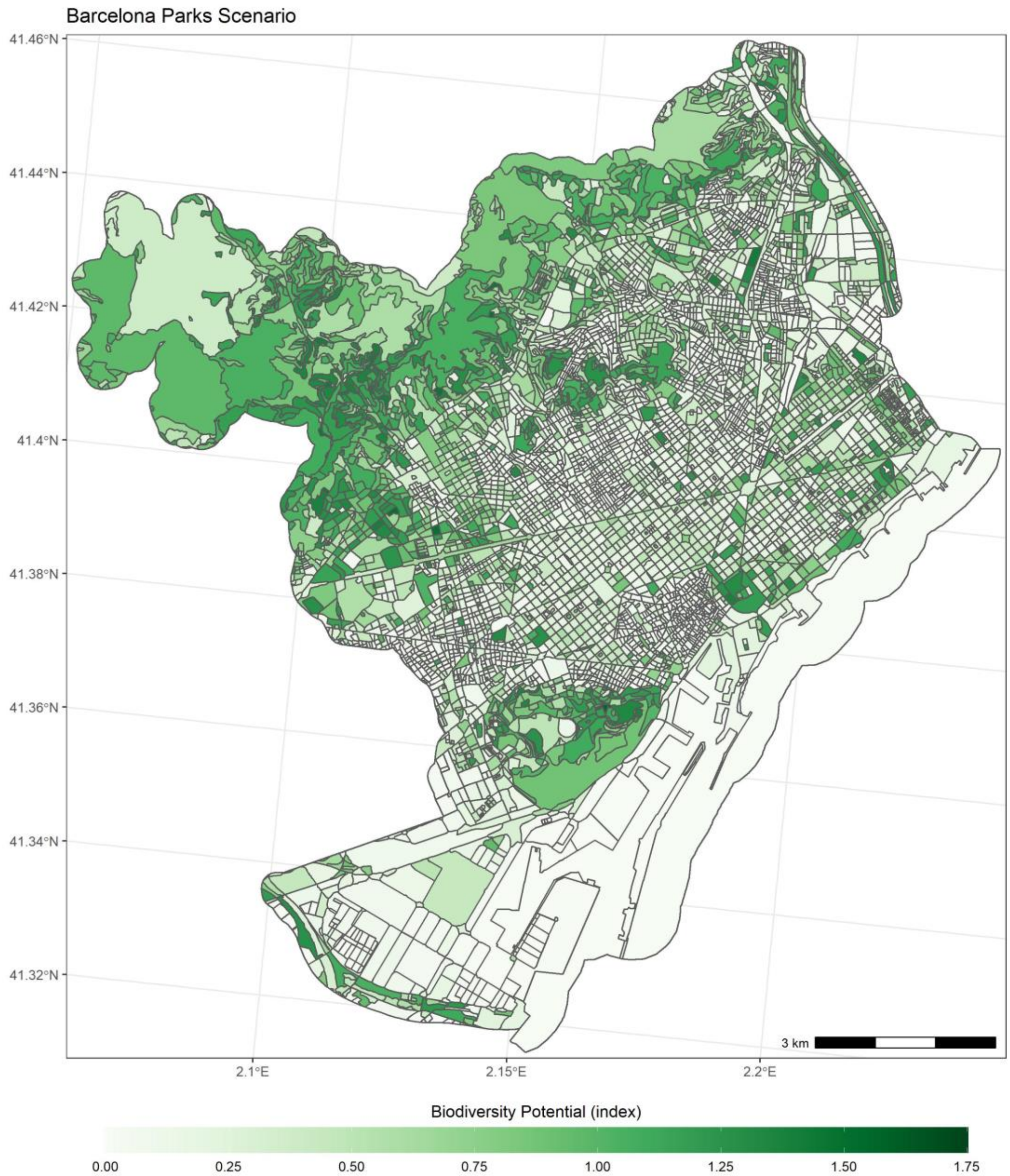

Figure M22. Barcelona Parks scenario Biodiversity Potential (index)

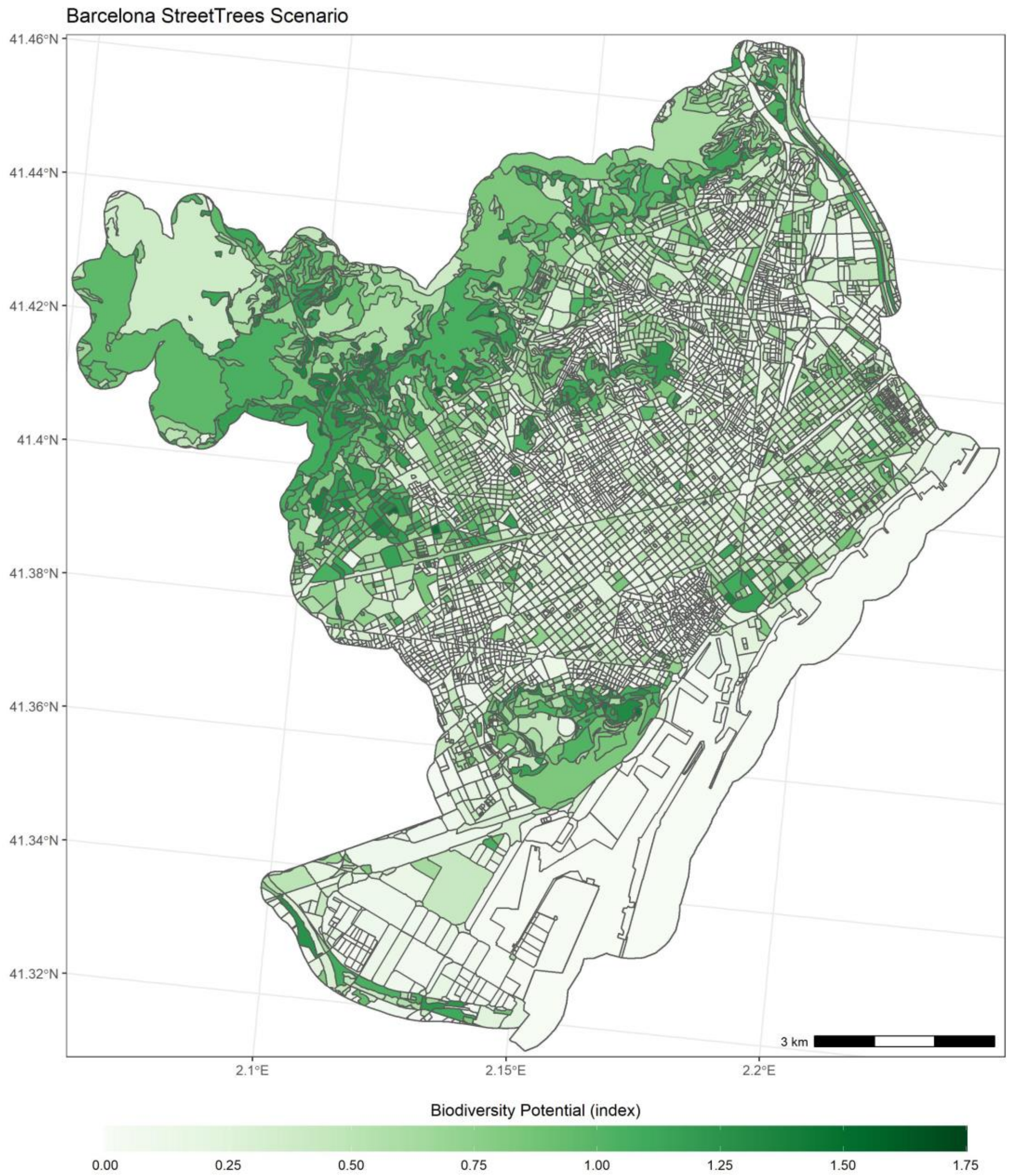

Figure M23. Barcelona StreetTrees scenario Biodiversity Potential (index)

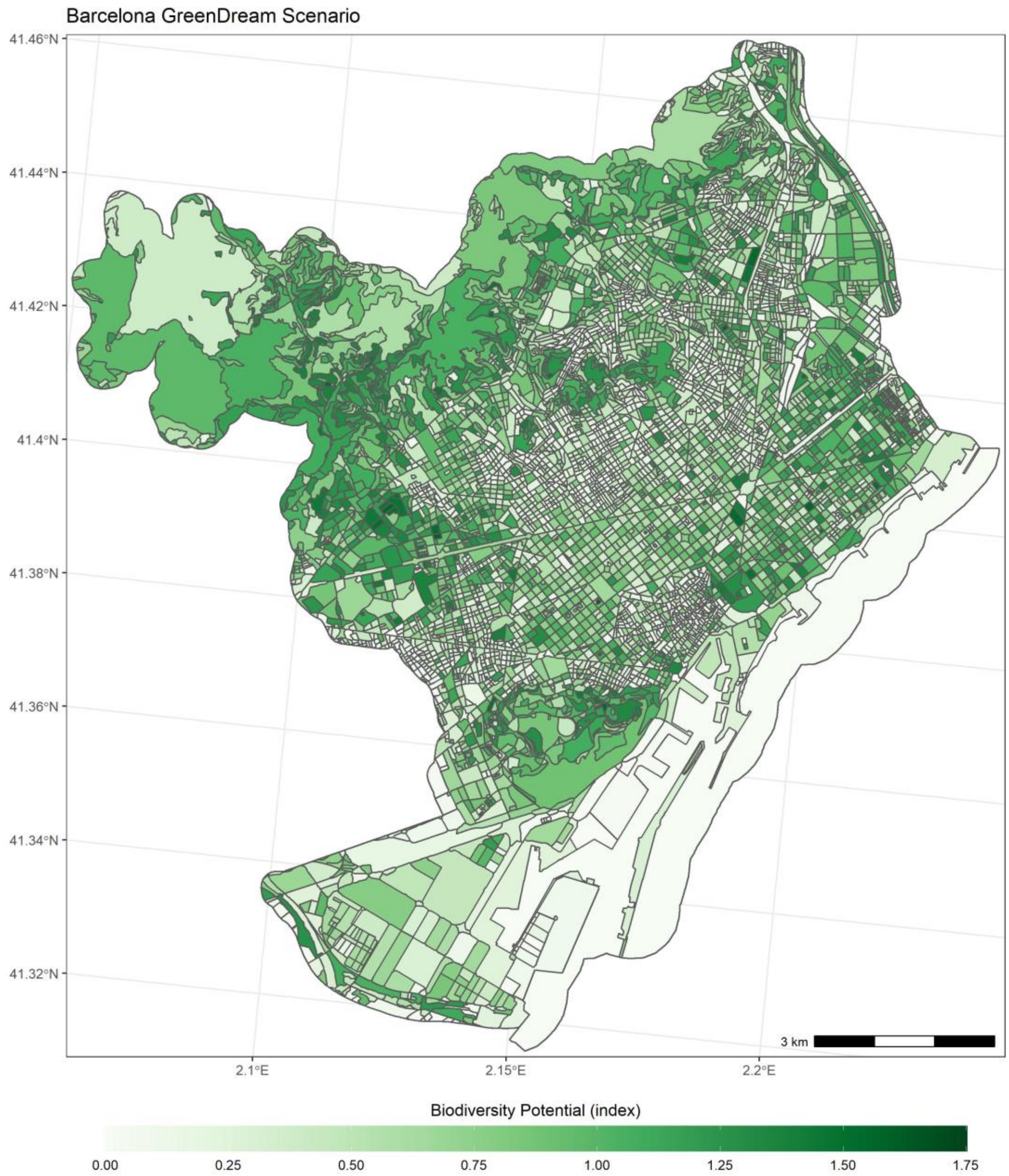

Figure M24. Barcelona GreenDream scenario Biodiversity Potential (index)

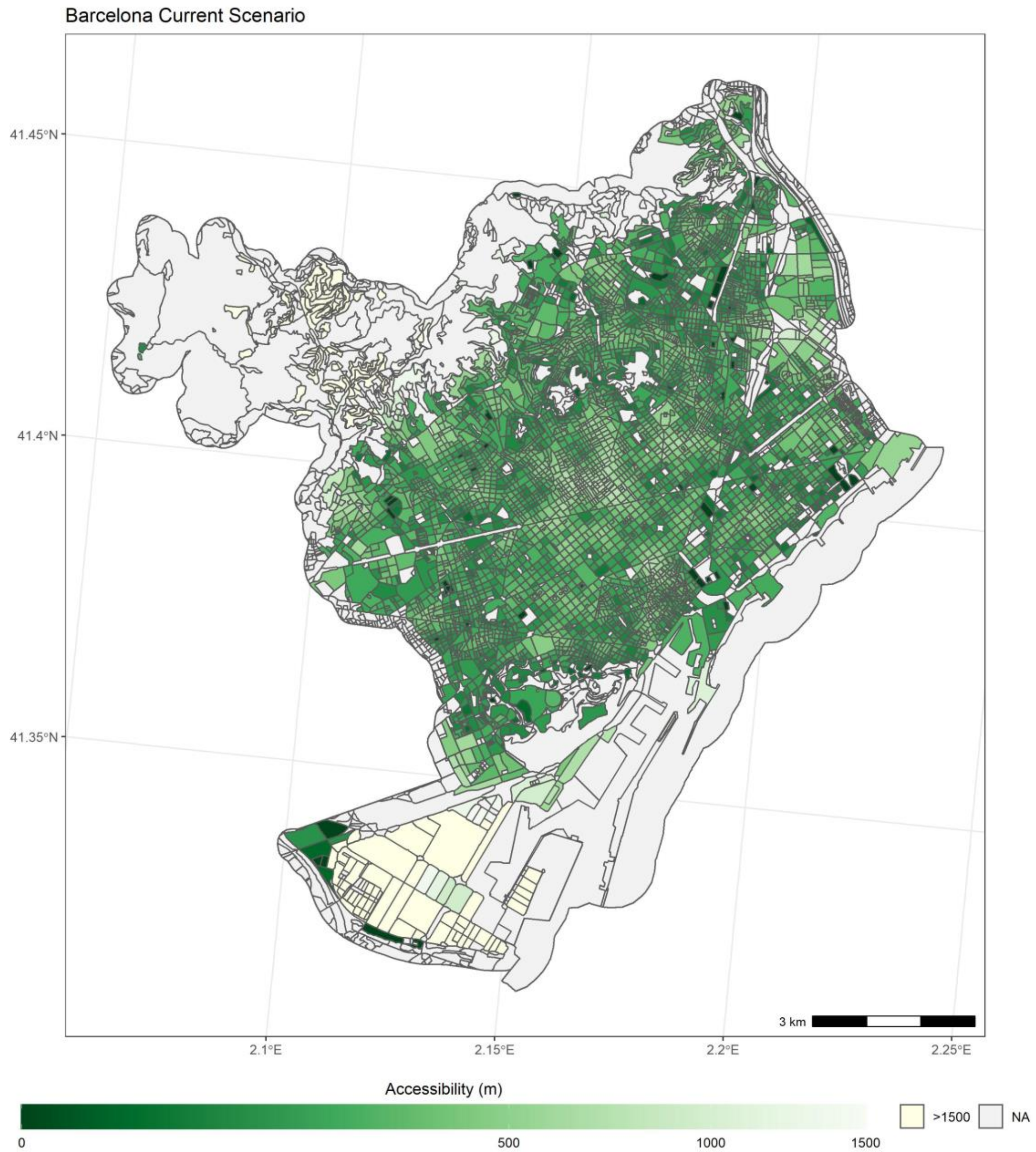

Figure M25. Barcelona Current scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

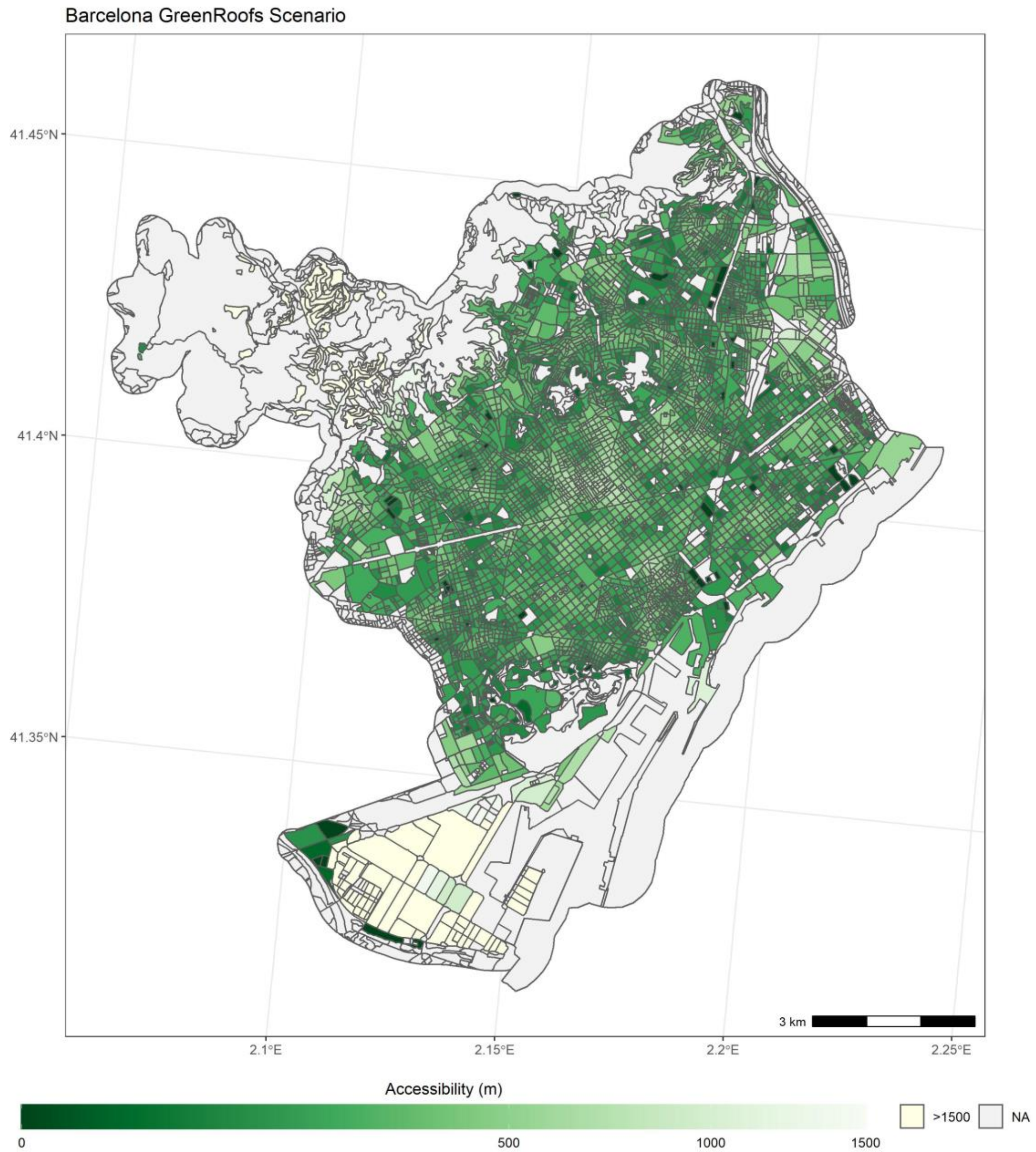

Figure M26. Barcelona GreenRoofs scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

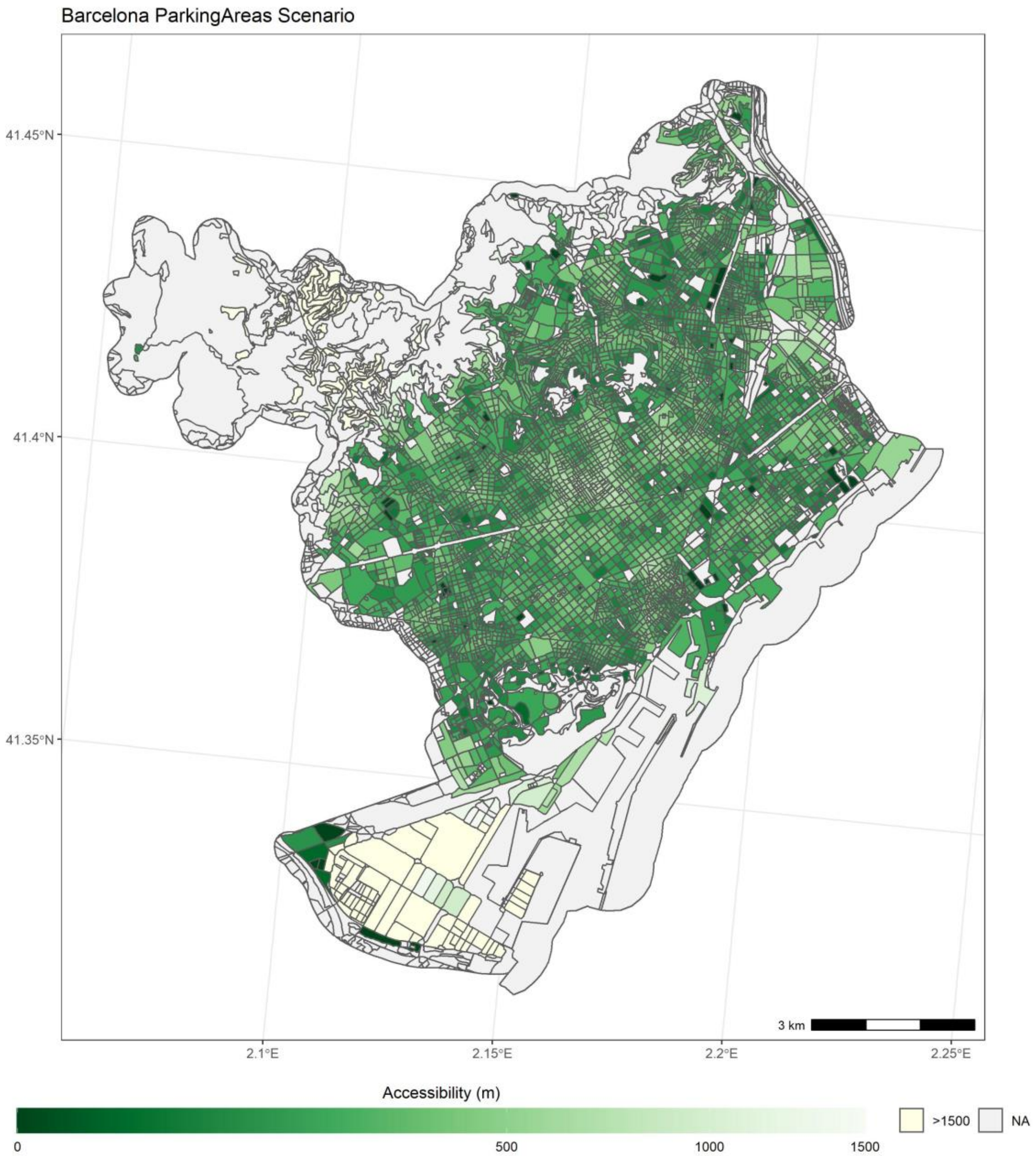

Figure M27. Barcelona ParkingAreas scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

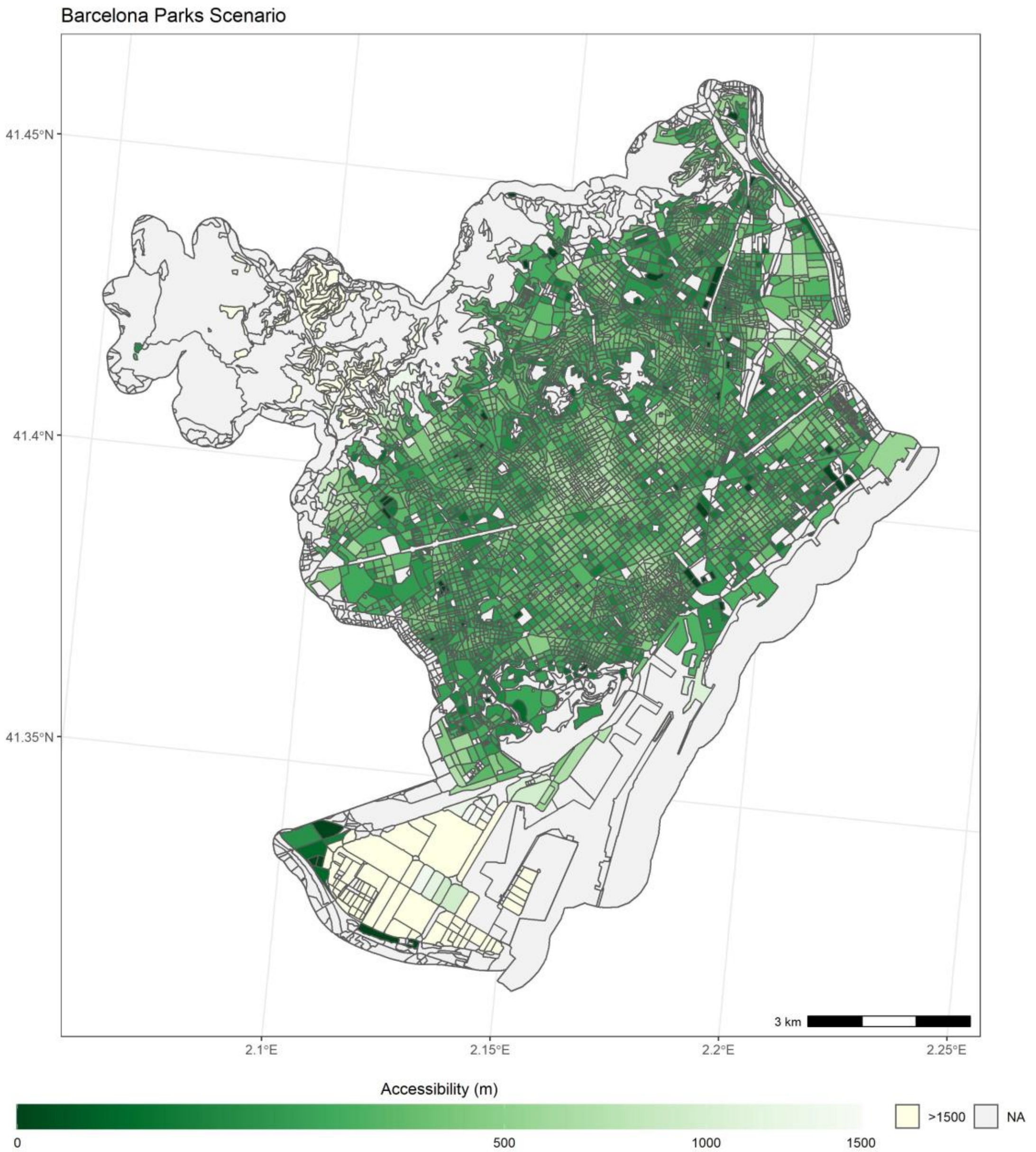

Figure M28. Barcelona Parks scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

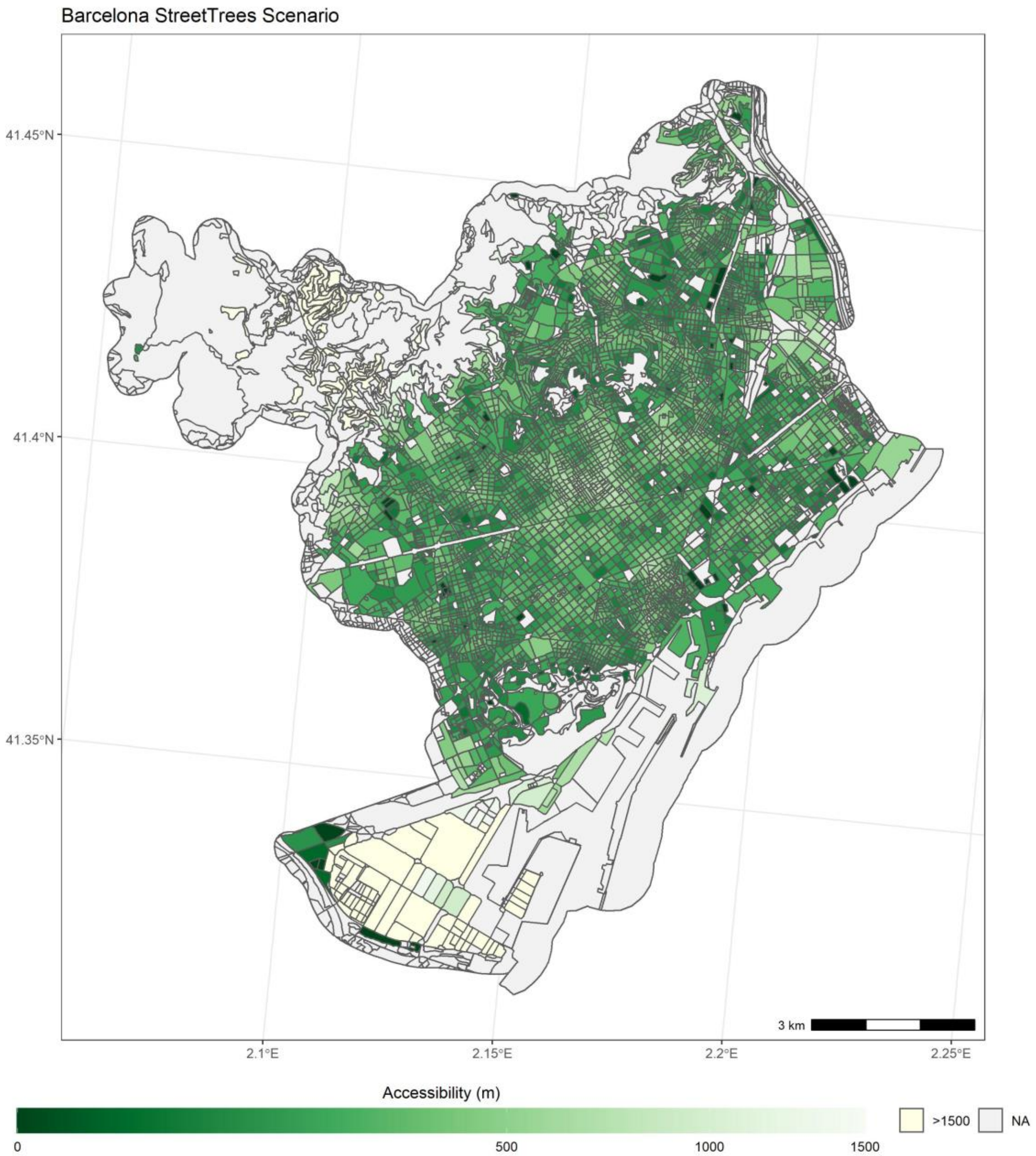

Figure M29. Barcelona StreetTrees scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

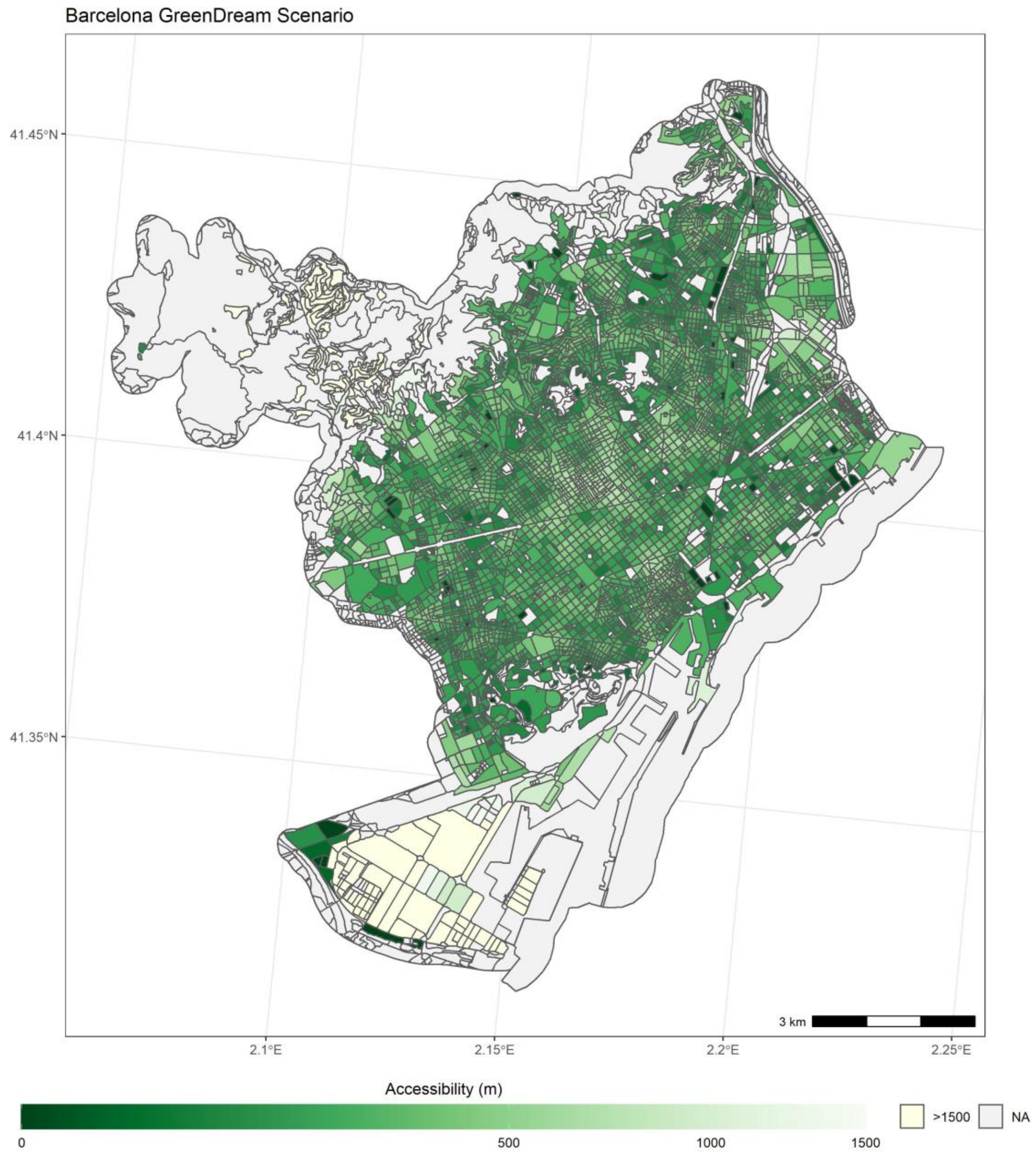

Figure M30. Barcelona GreenDream scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

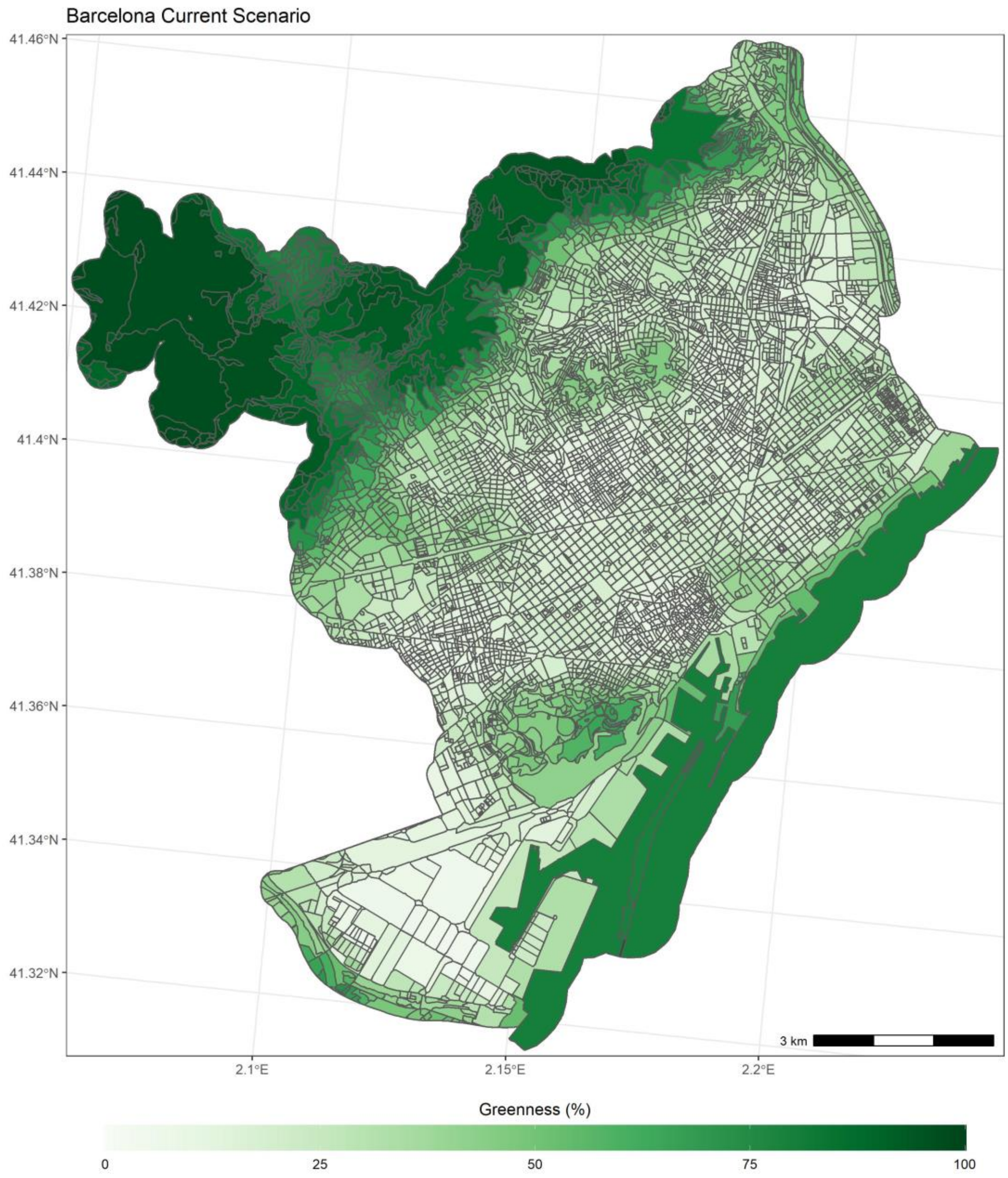

Figure M31. Barcelona Current scenario Greenness (%)

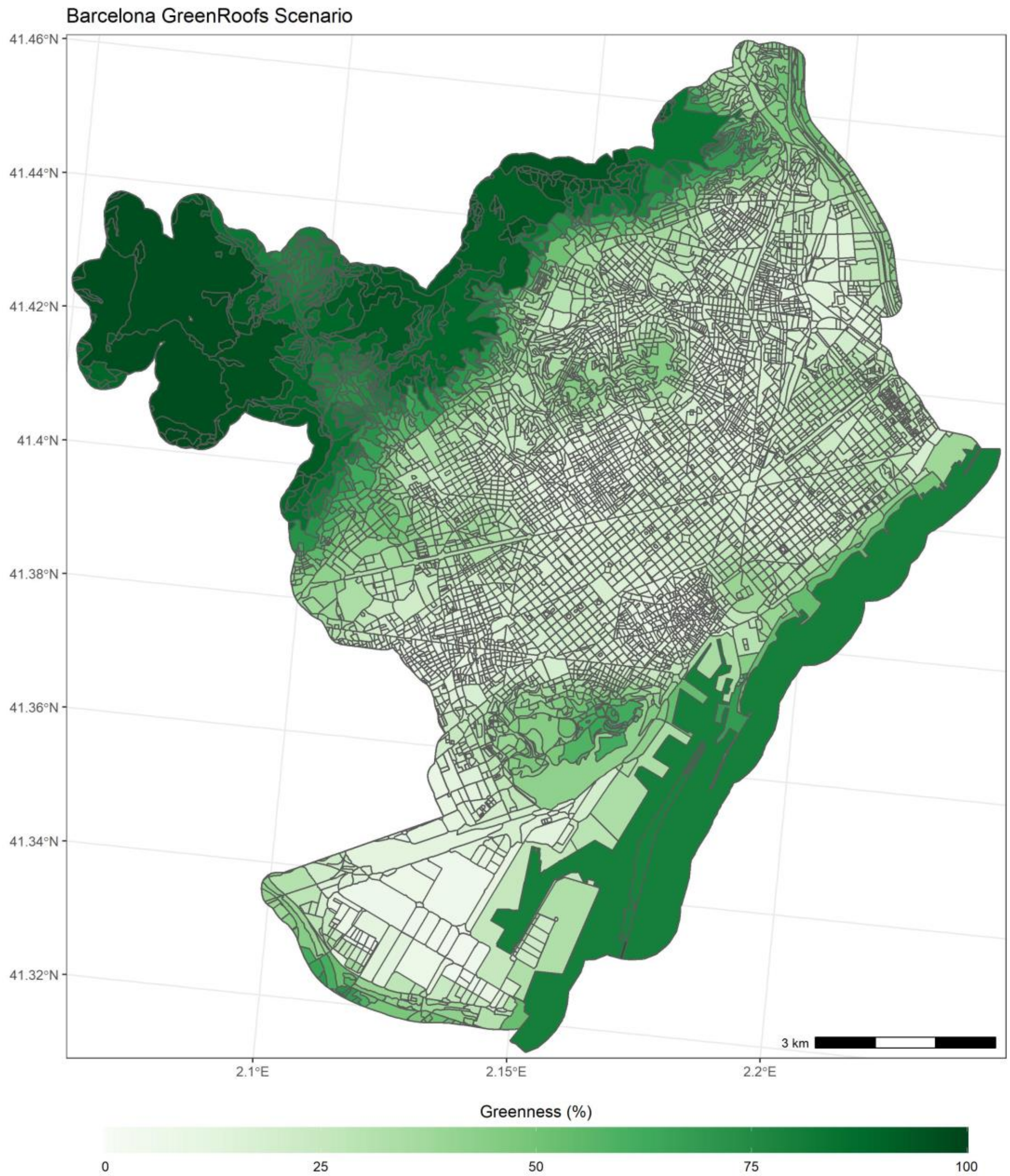

Figure M32. Barcelona GreenRoofs scenario Greenness (%)

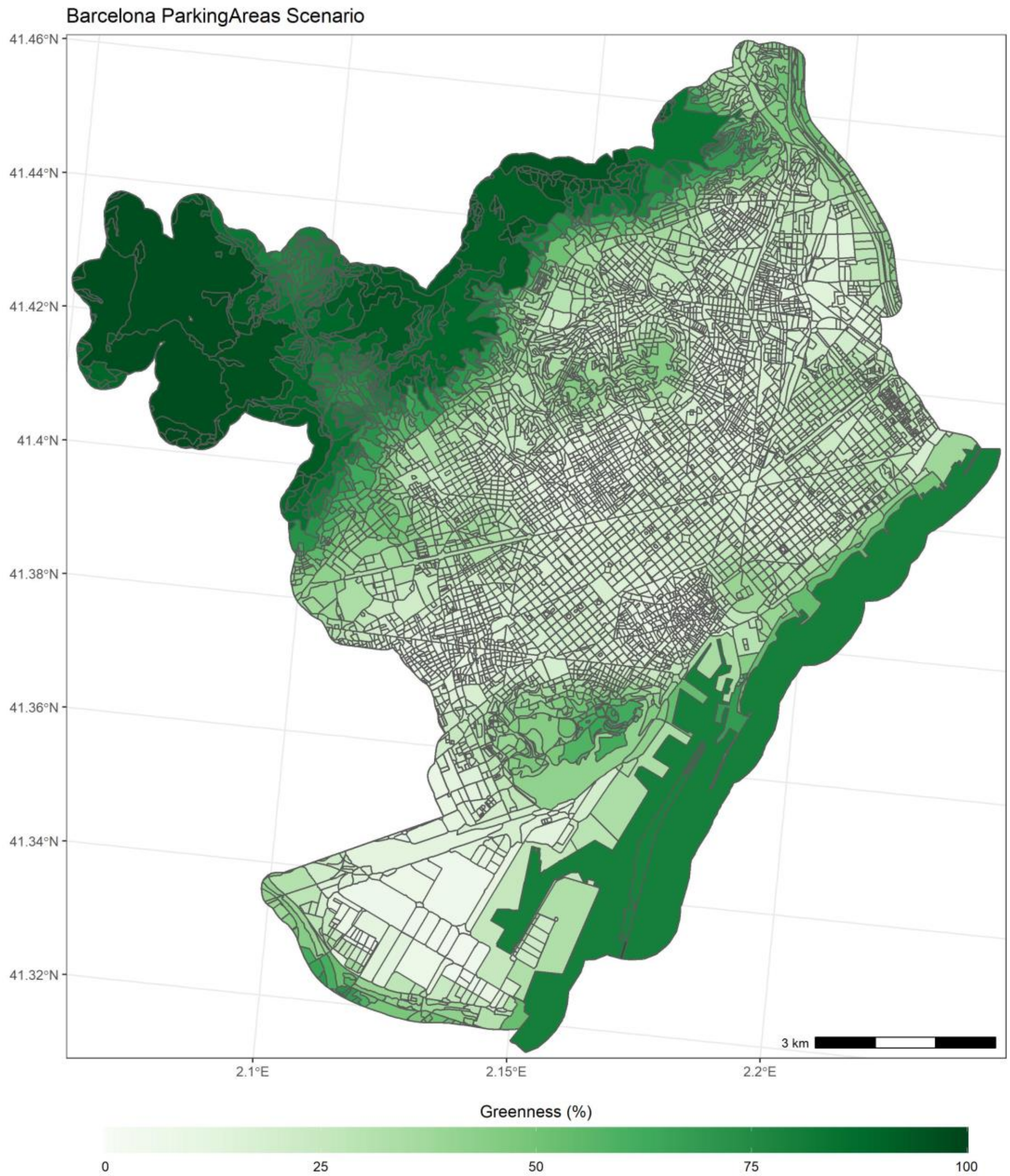

Figure M33. Barcelona ParkingAreas scenario Greenness (%)

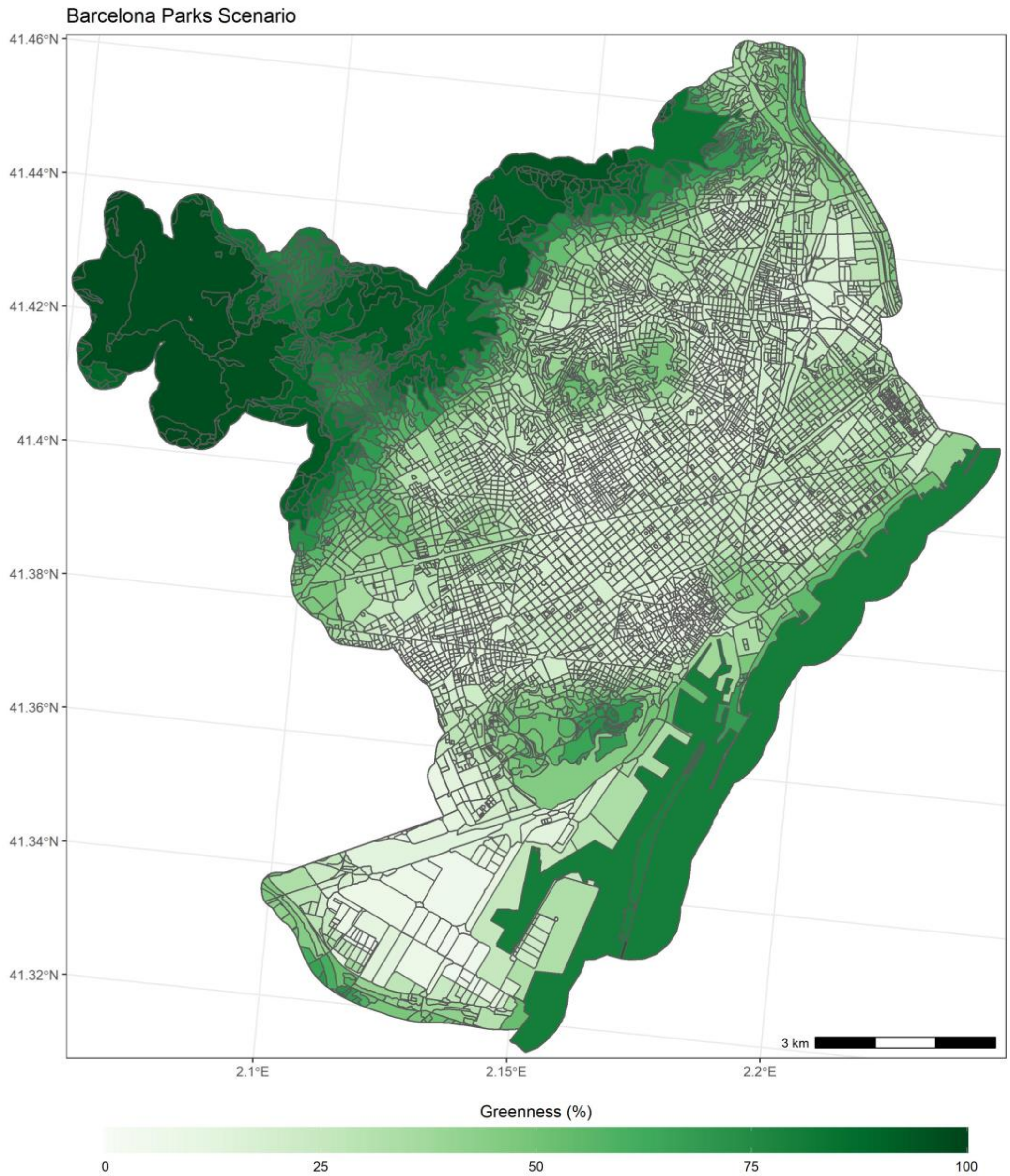

Figure M34. Barcelona Parks scenario Greenness (%)

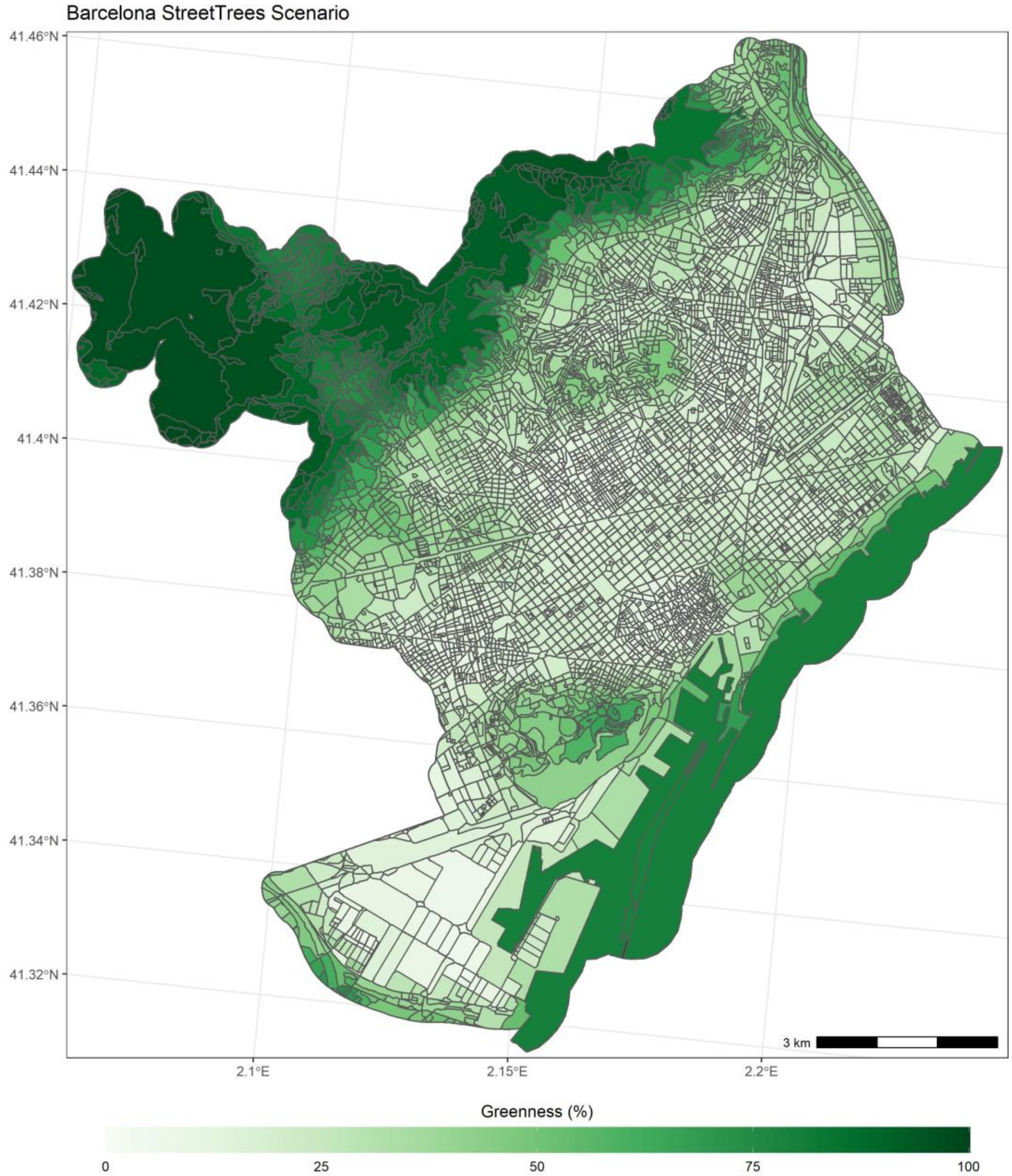

Figure M35. Barcelona StreetTrees scenario Greenness (%)

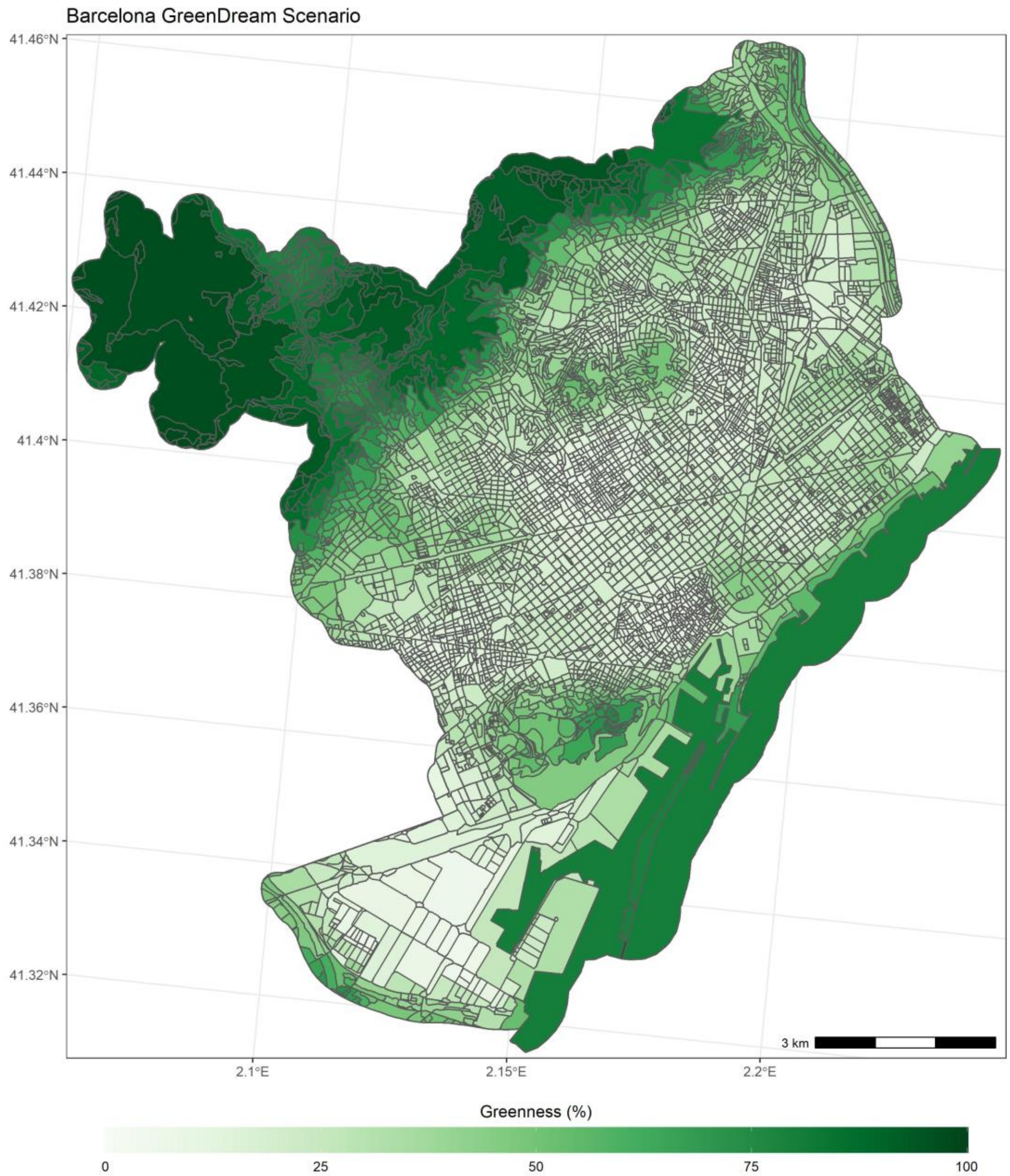

Figure M36. Barcelona GreenDream scenario Greenness (%)

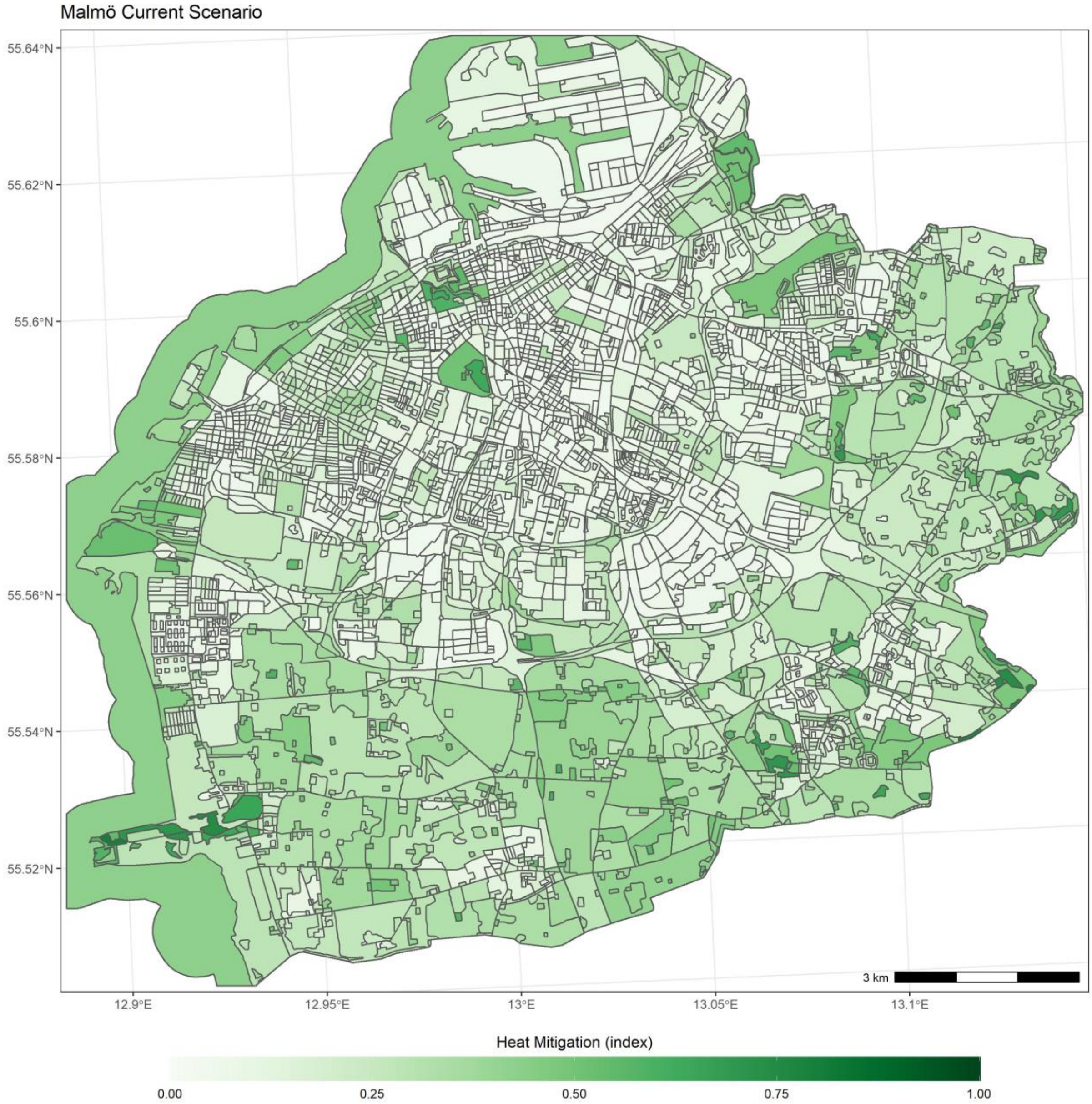

Figure M37. Malmö Current scenario Heat Mitigation (index)

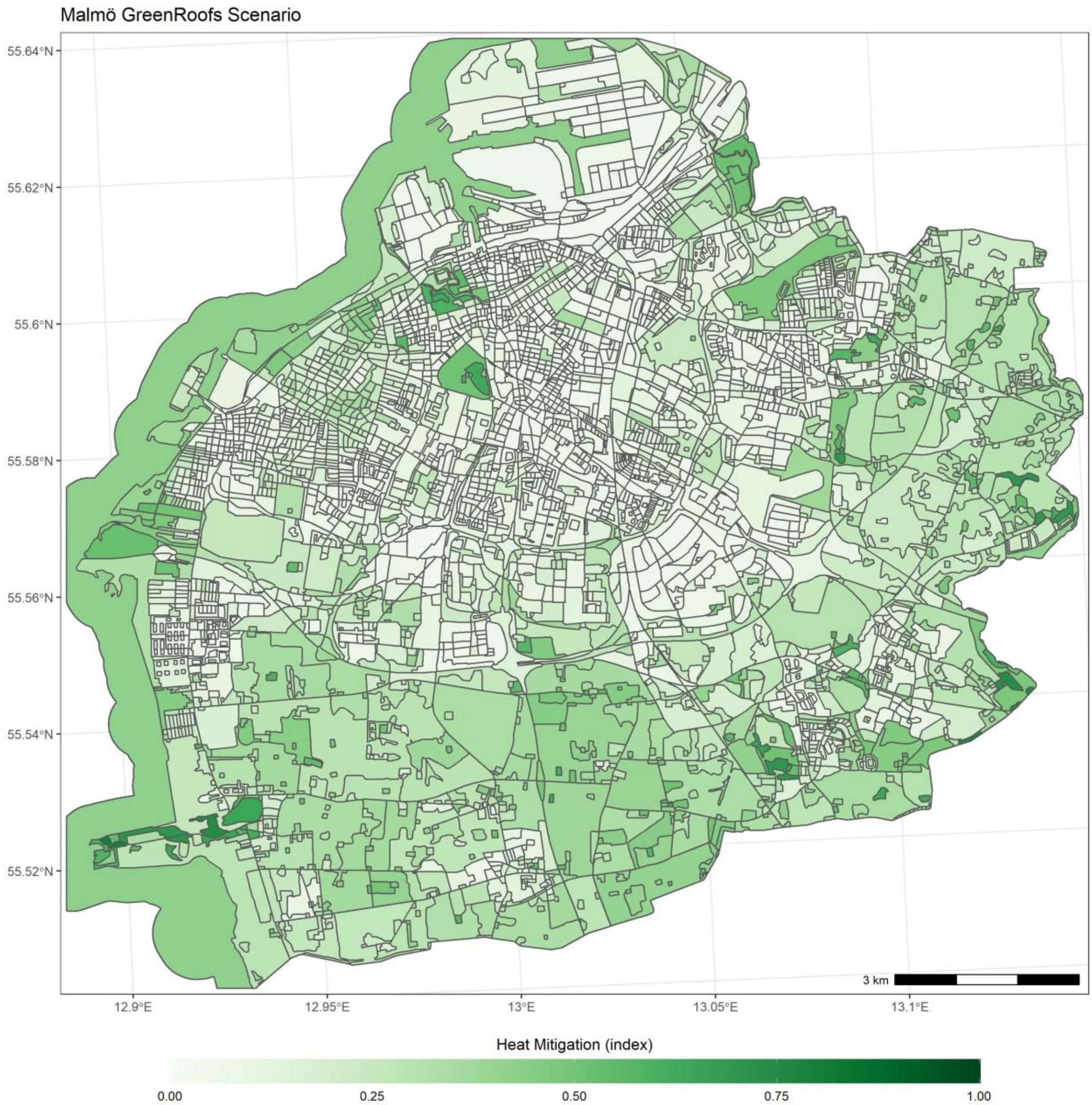

Figure M38. Malmö GreenRoofs scenario Heat Mitigation (index)

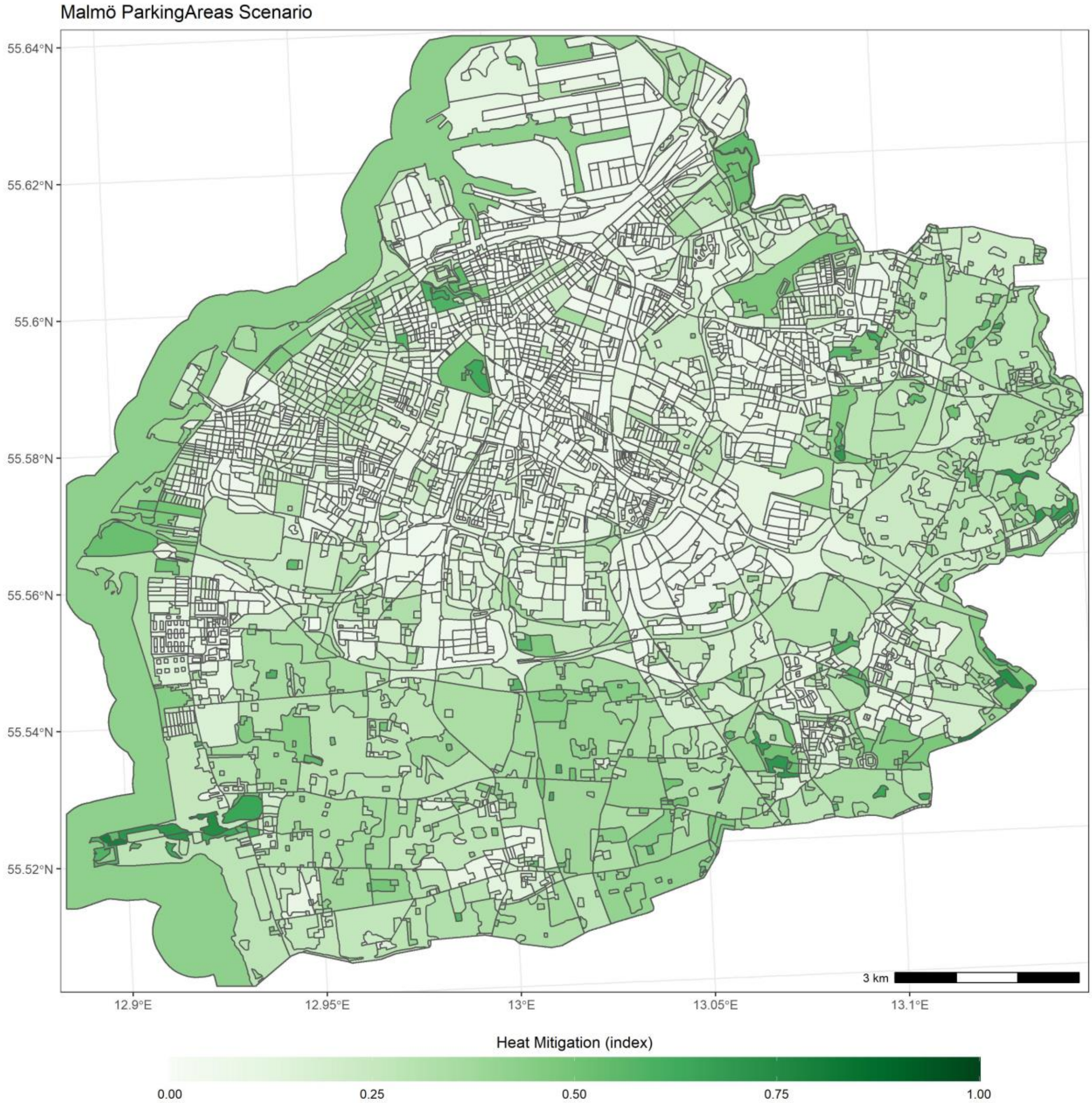

Figure M39. Malmö ParkingAreas scenario Heat Mitigation (index)

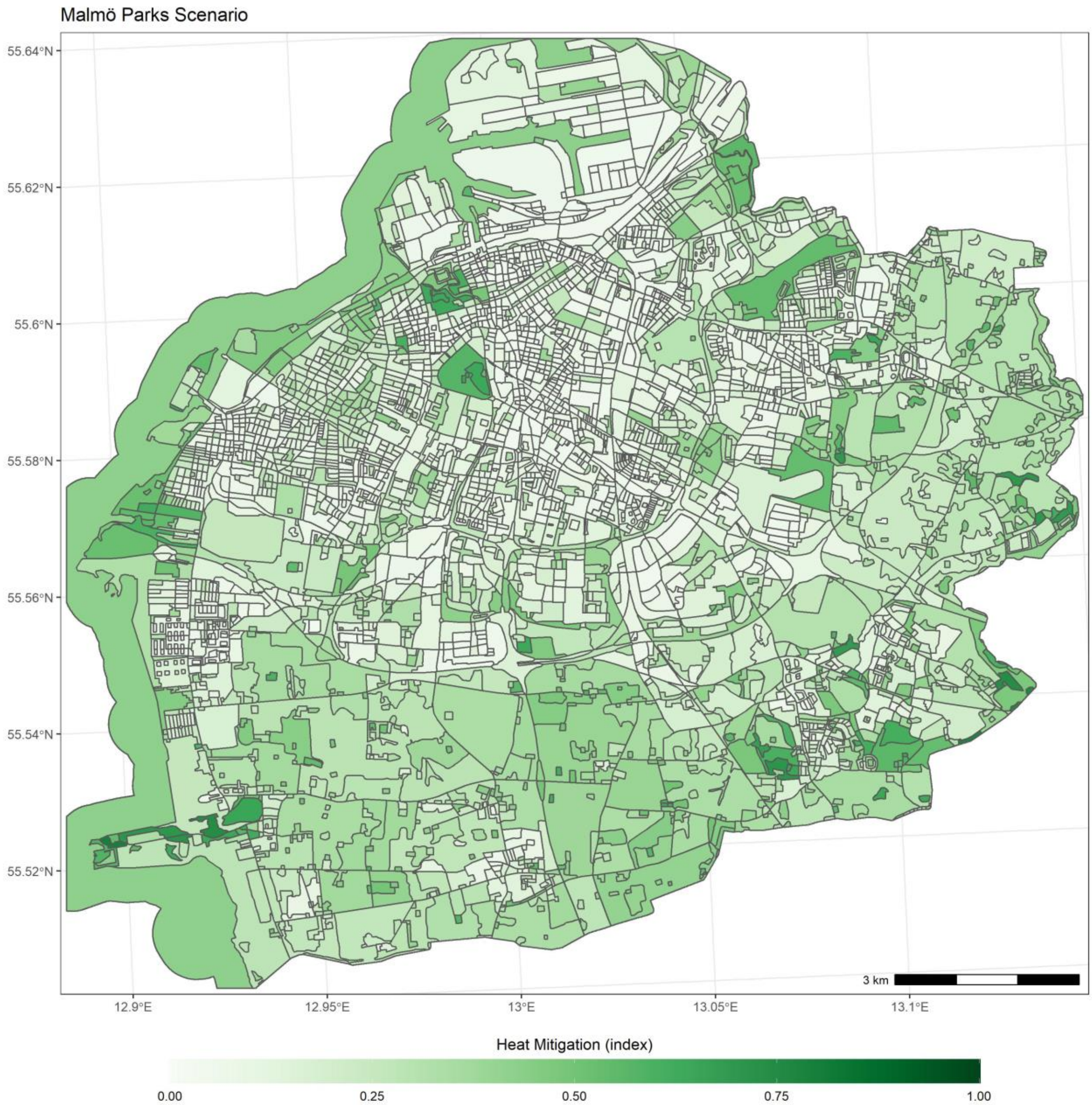

Figure M40. Malmö Parks scenario Heat Mitigation (index)

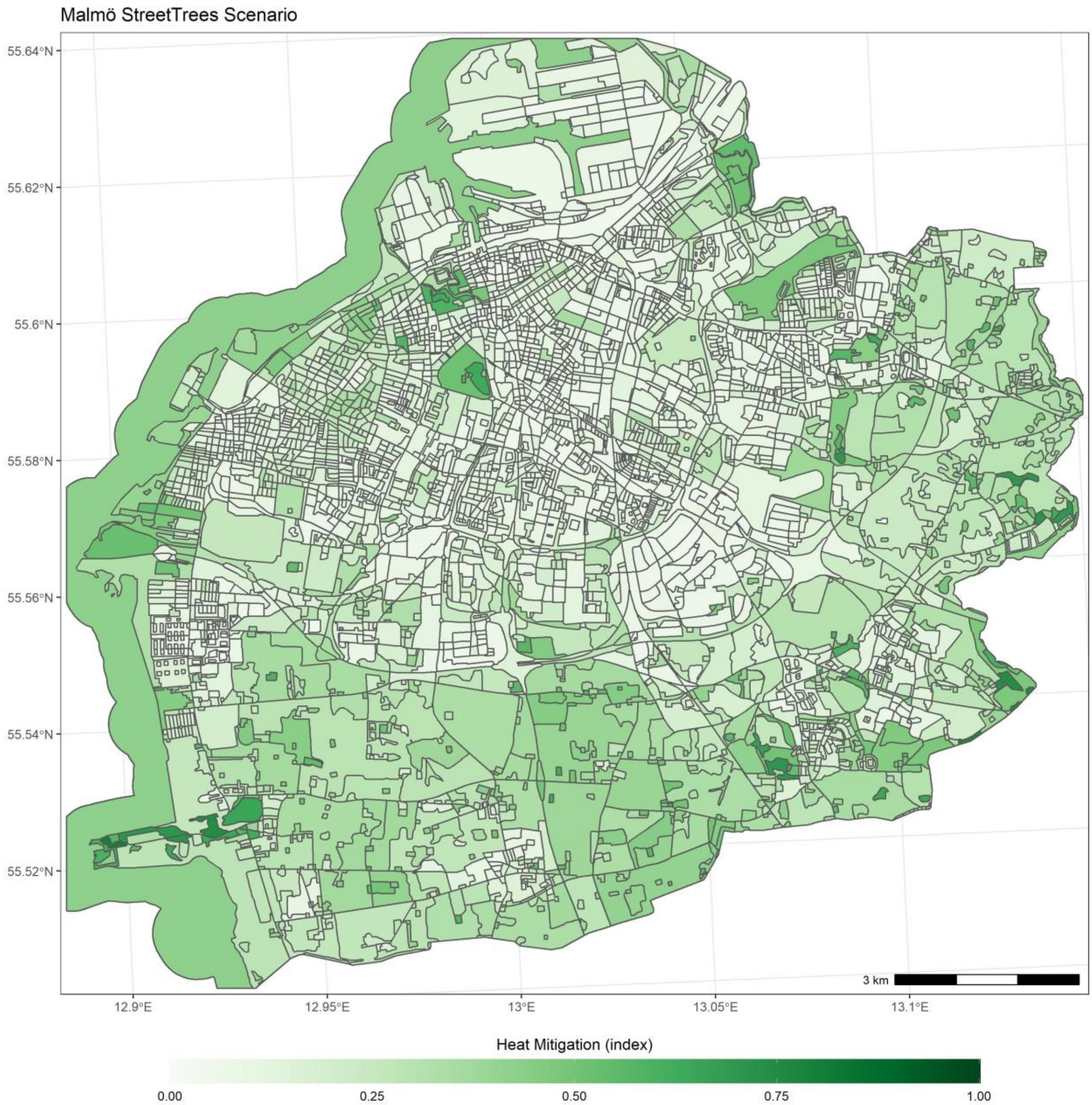

Figure M41. Malmö StreetTrees scenario Heat Mitigation (index)

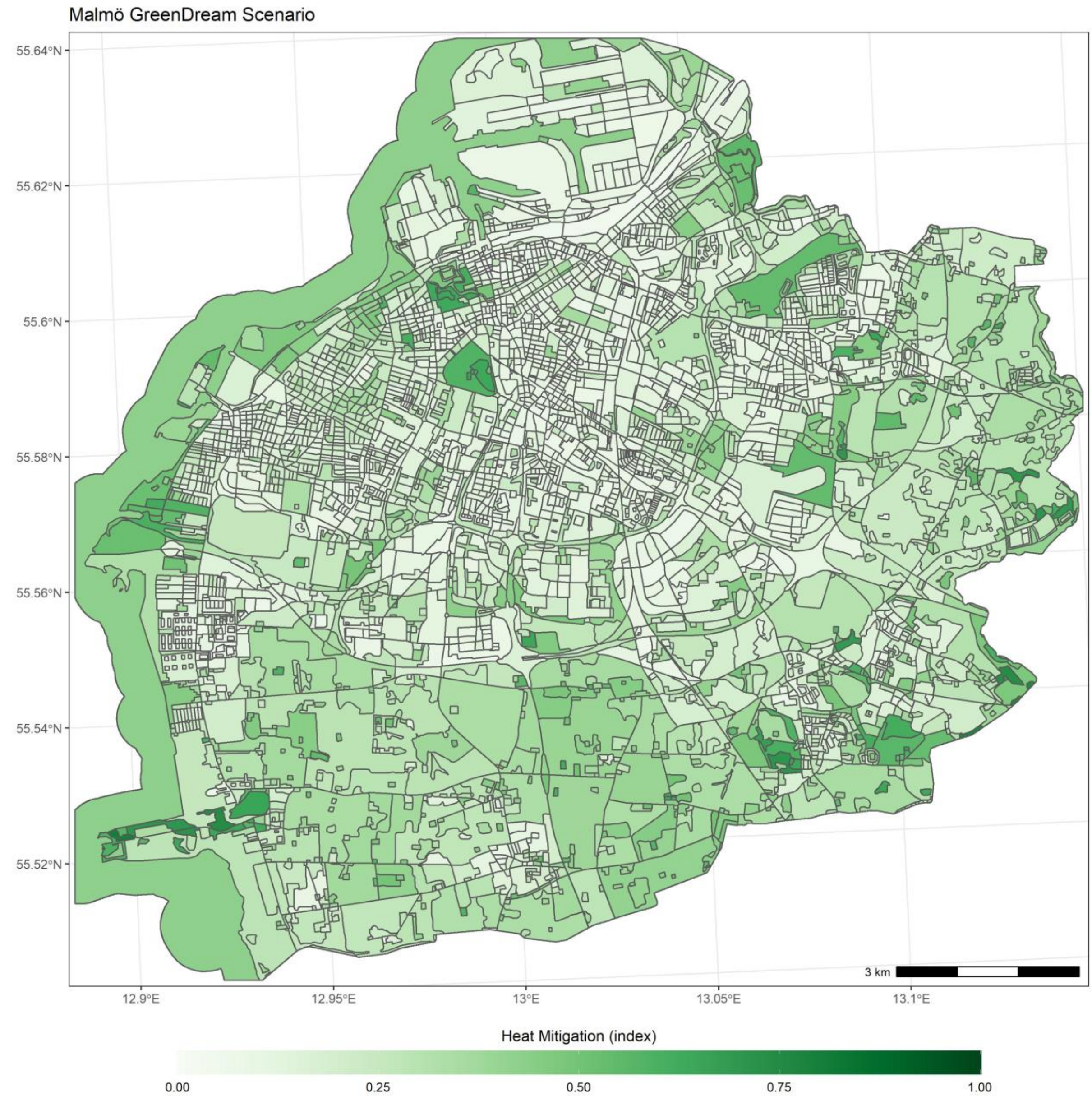

Figure M42. Malmö GreenDream scenario Heat Mitigation (index)

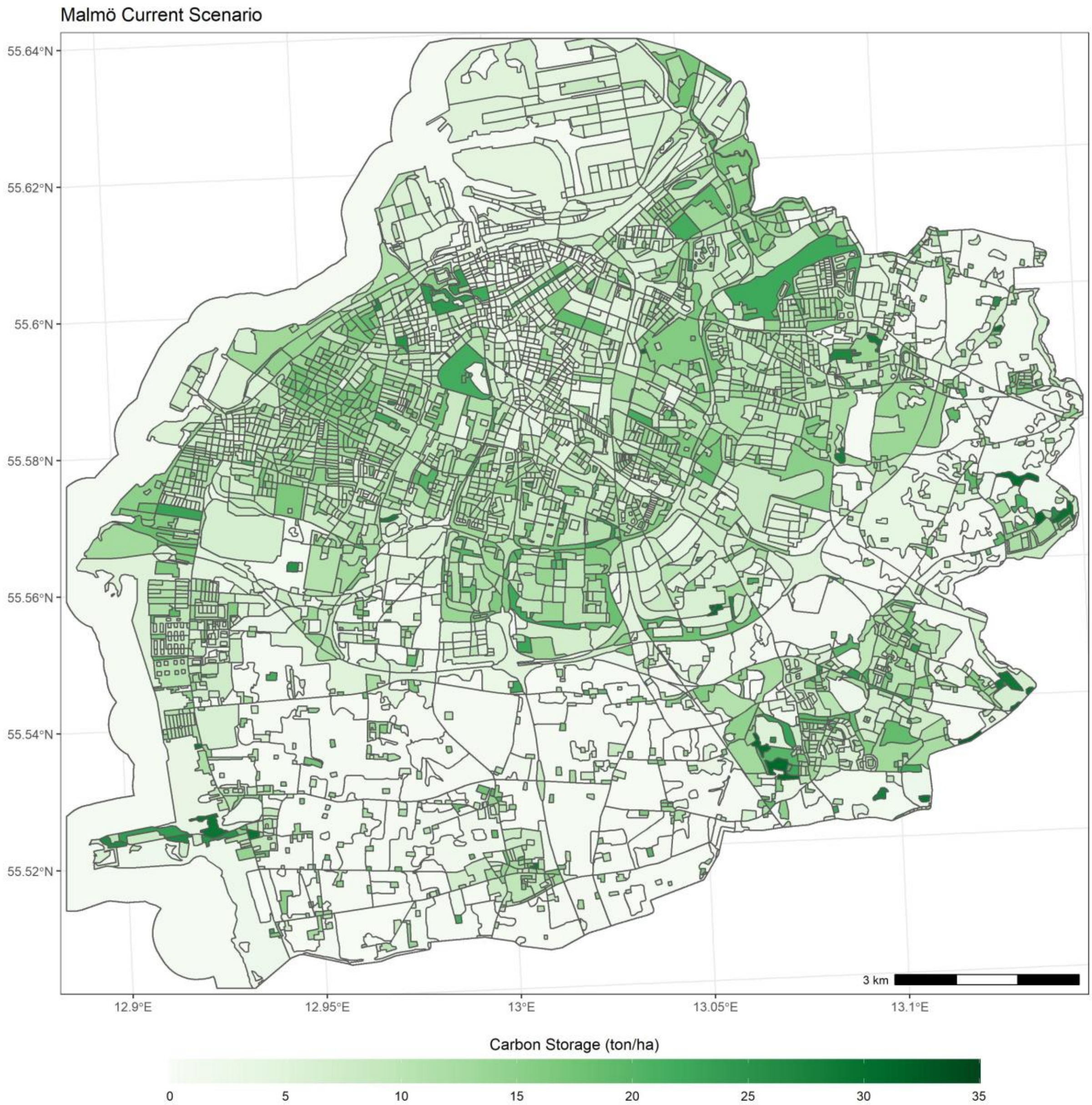

Figure M43. Malmö Current scenario Carbon Storage (ton/ha)

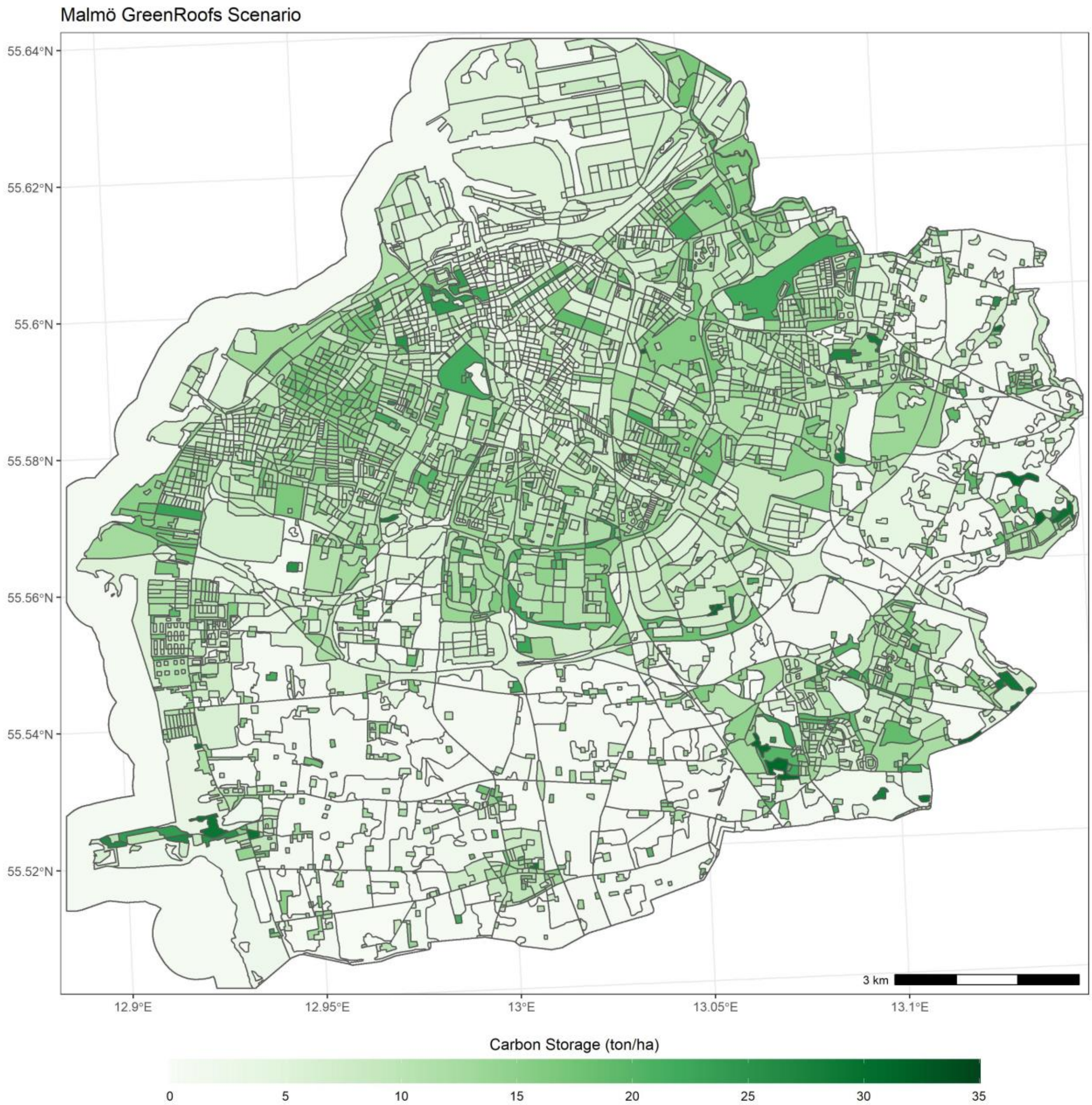

Figure M44. Malmö GreenRoofs scenario Carbon Storage (ton/ha)

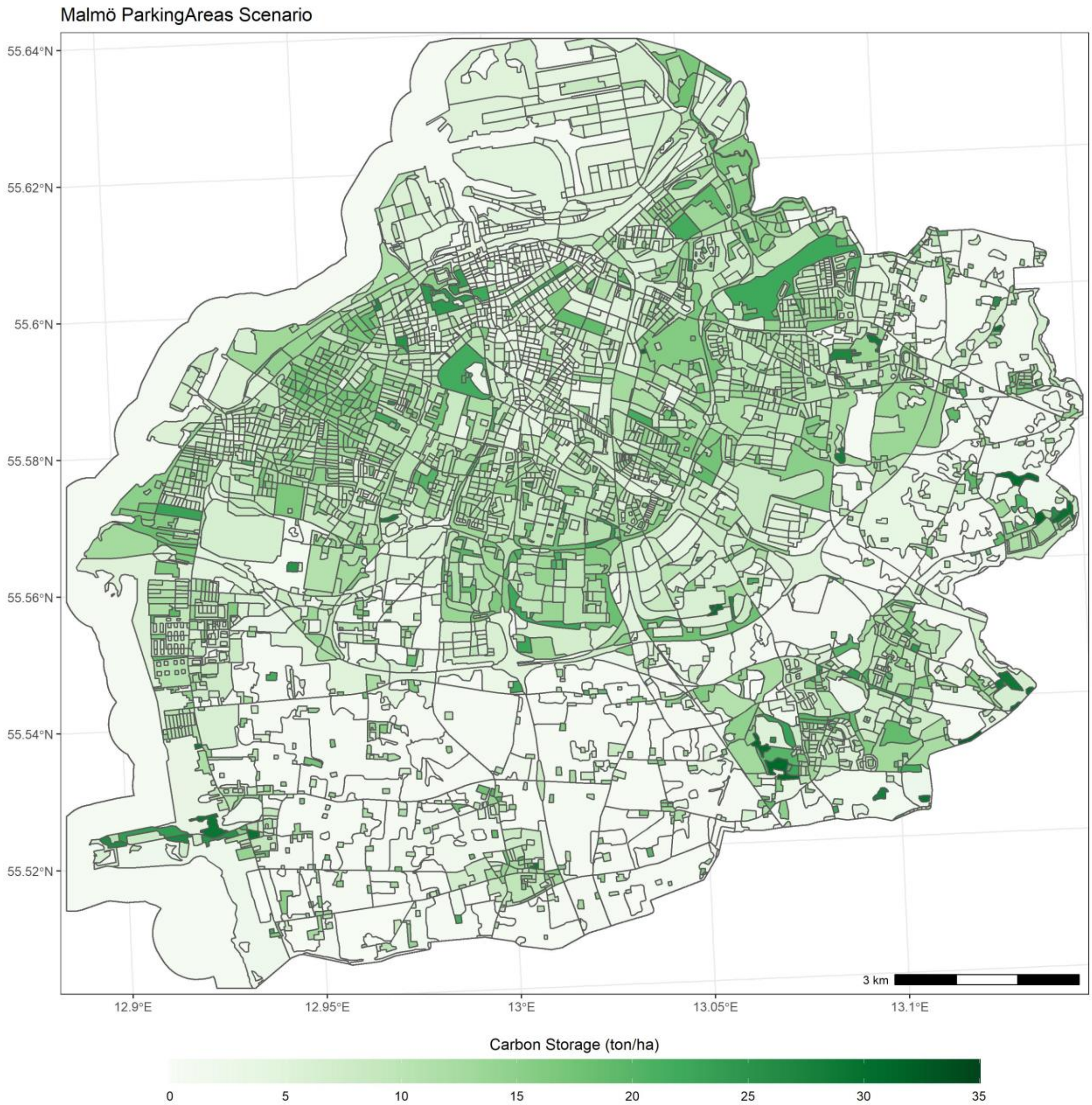

Figure M45. Malmö ParkingAreas scenario Carbon Storage (ton/ha)

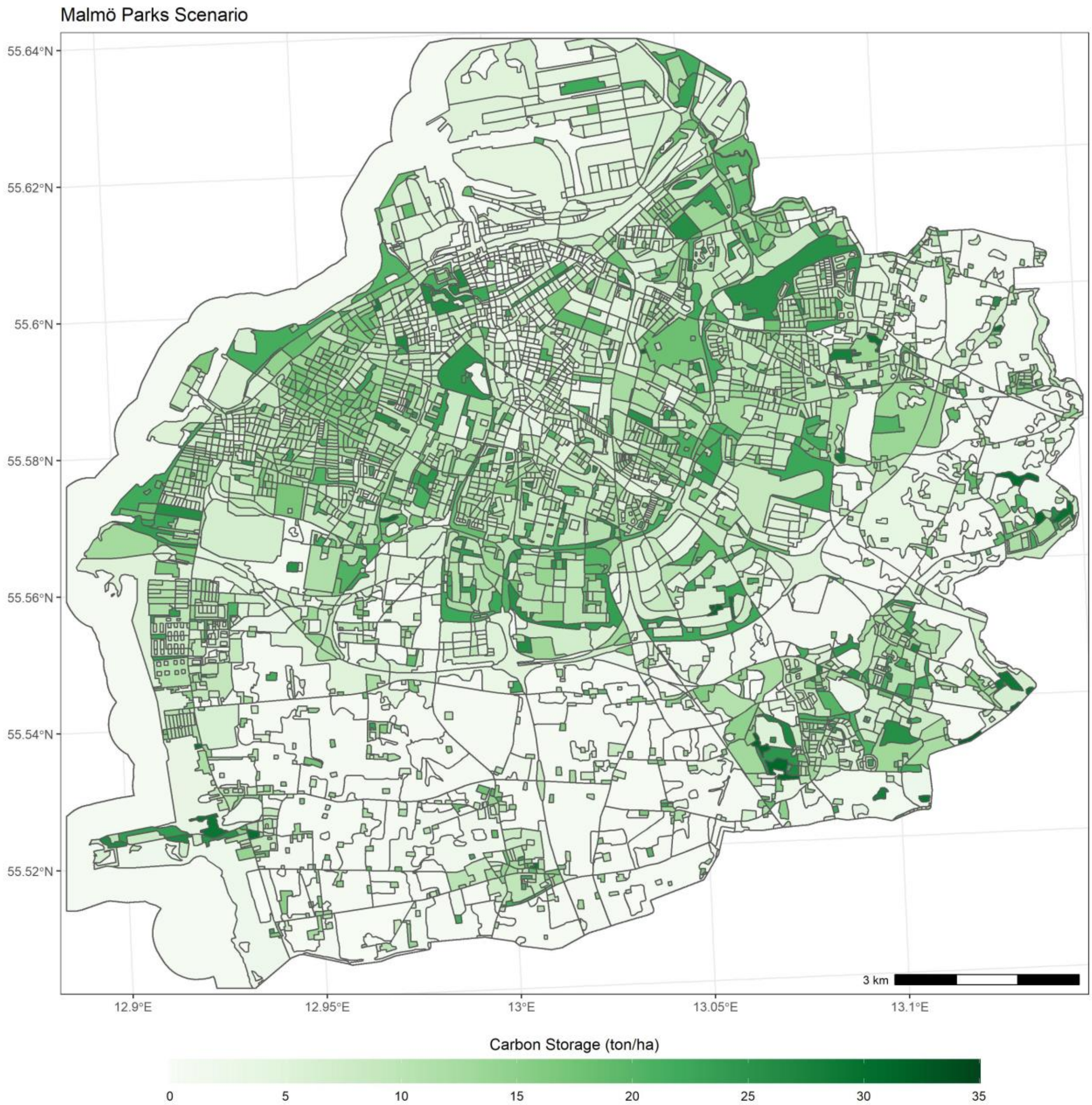

Figure M46. Malmö Parks scenario Carbon Storage (ton/ha)

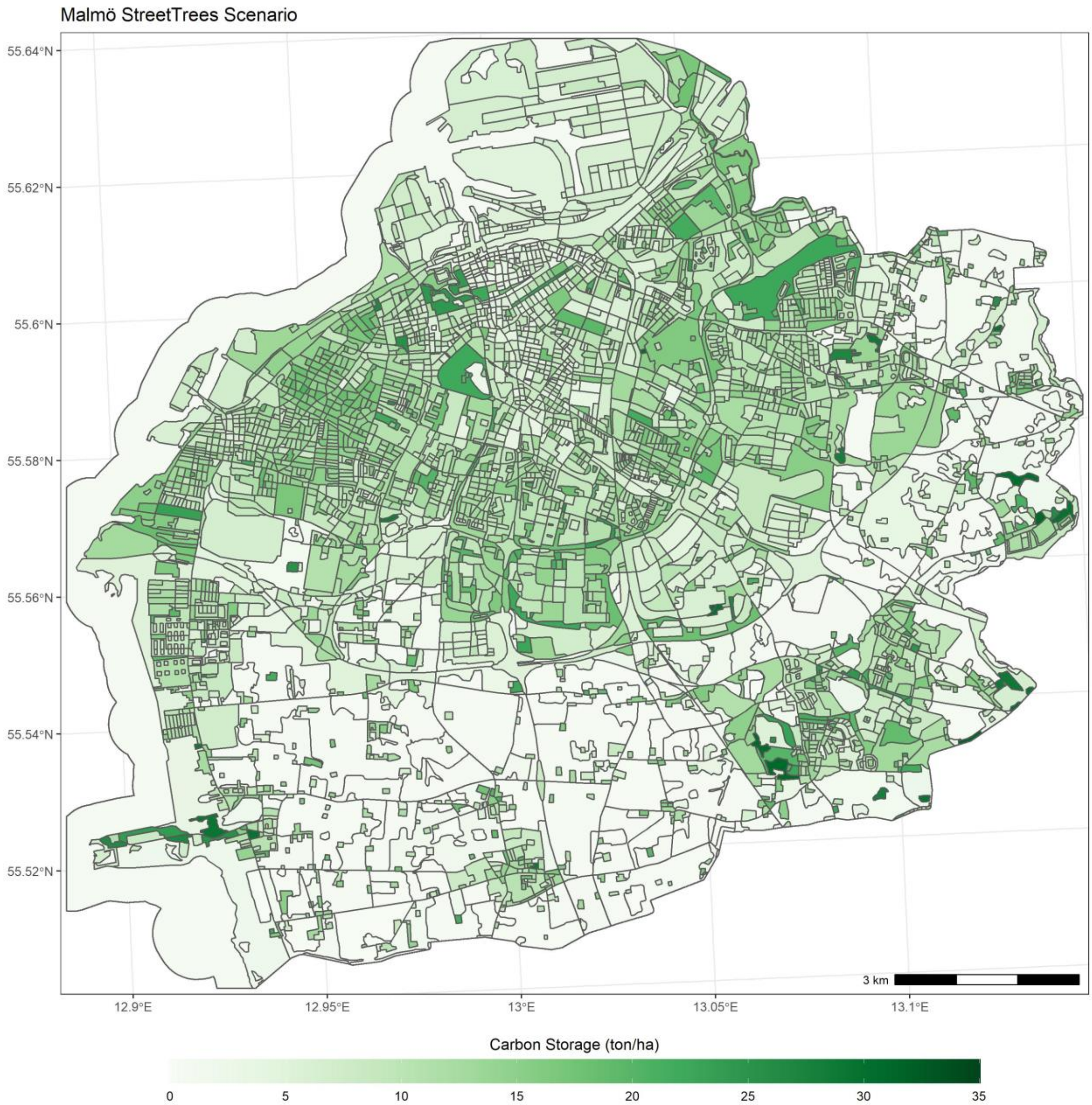

Figure M47. Malmö StreetTrees scenario Carbon Storage (ton/ha)

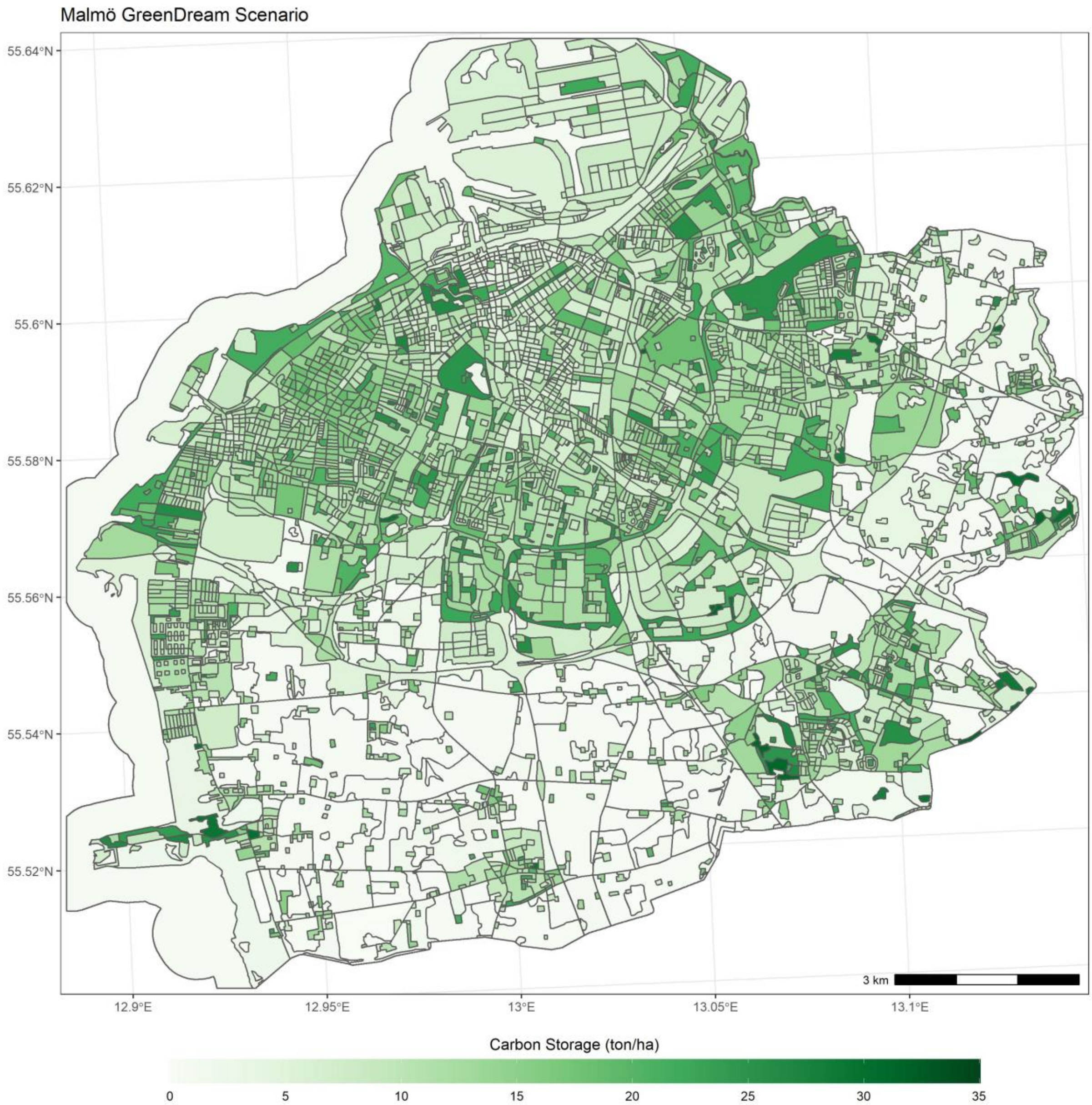

Figure M48. Malmö GreenDream scenario Carbon Storage (ton/ha)

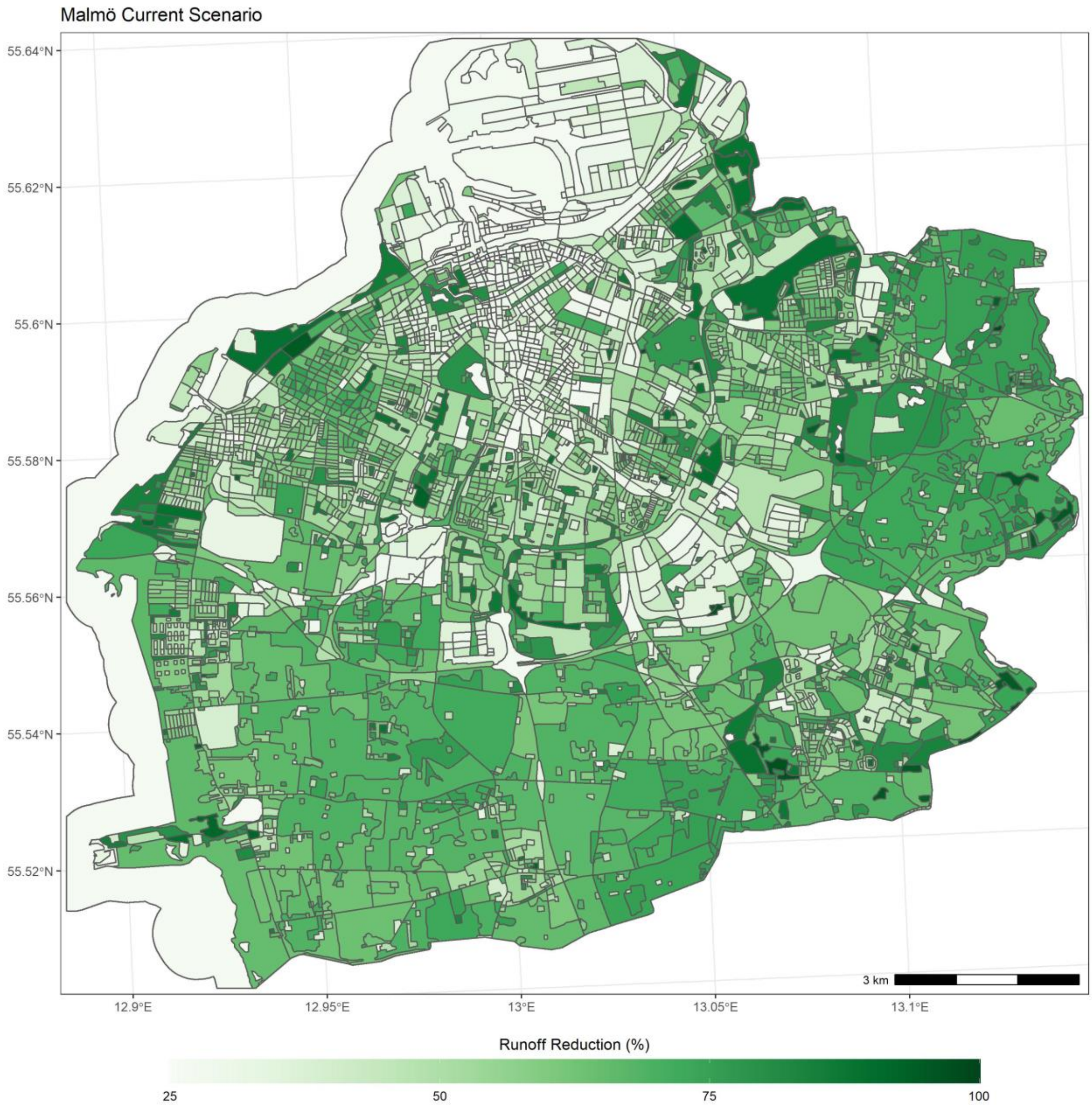

Figure M49. Malmö Current scenario Runoff Reduction (%)

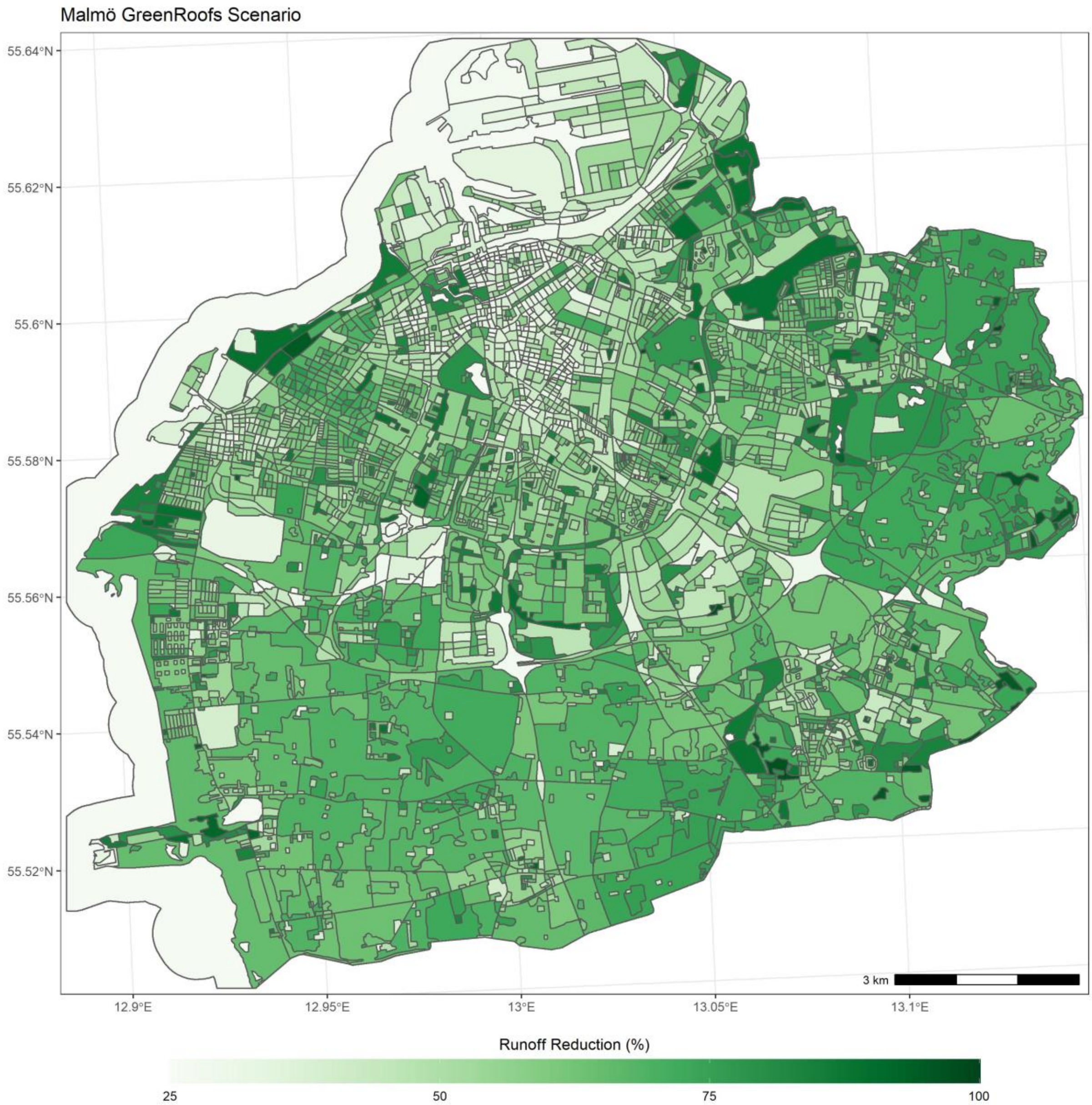

Figure M50. Malmö GreenRoofs scenario Runoff Reduction (%)

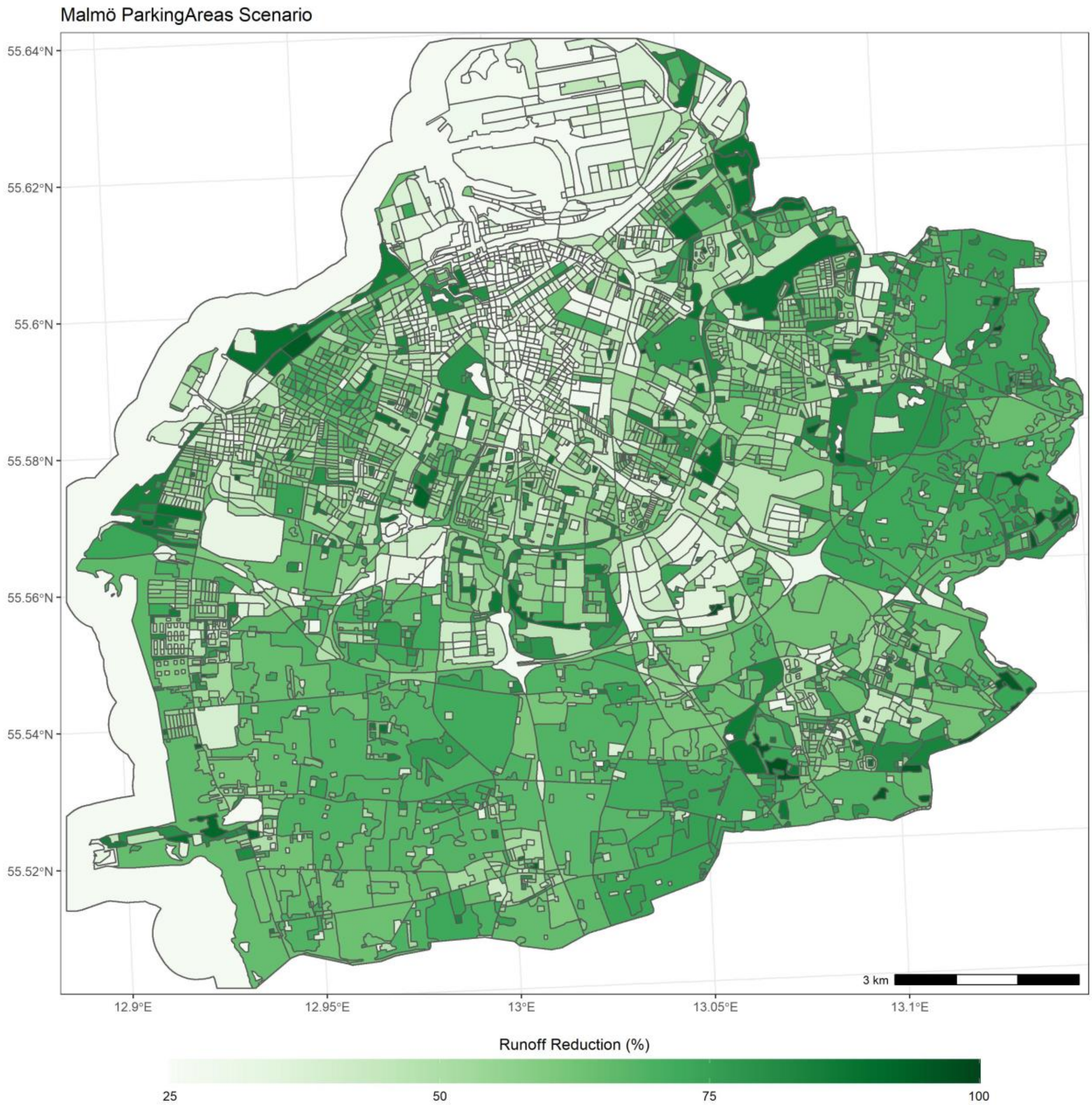

Figure M51. Malmö ParkingAreas scenario Runoff Reduction (%)

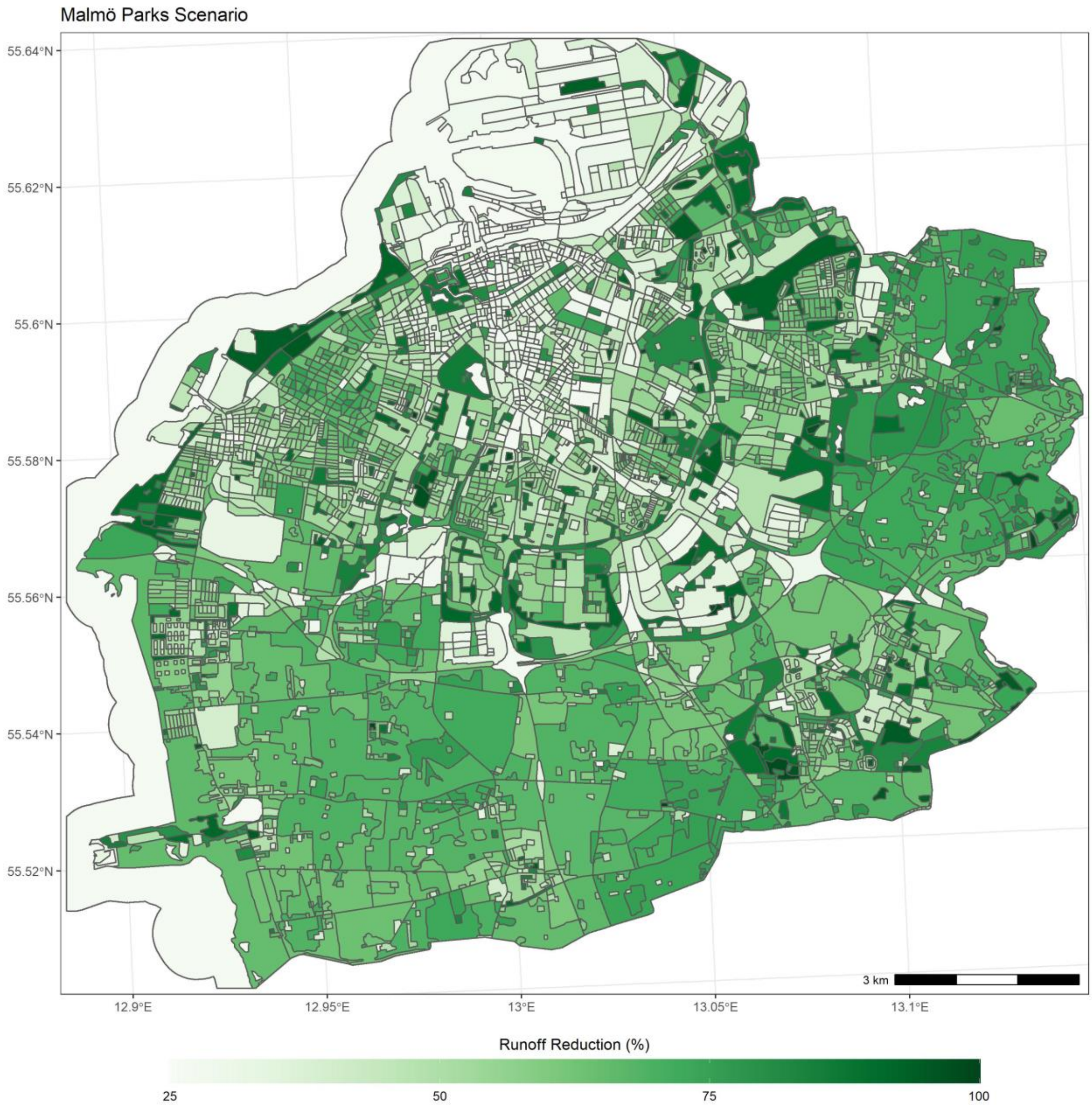

Figure M52. Malmö Parks scenario Runoff Reduction (%)

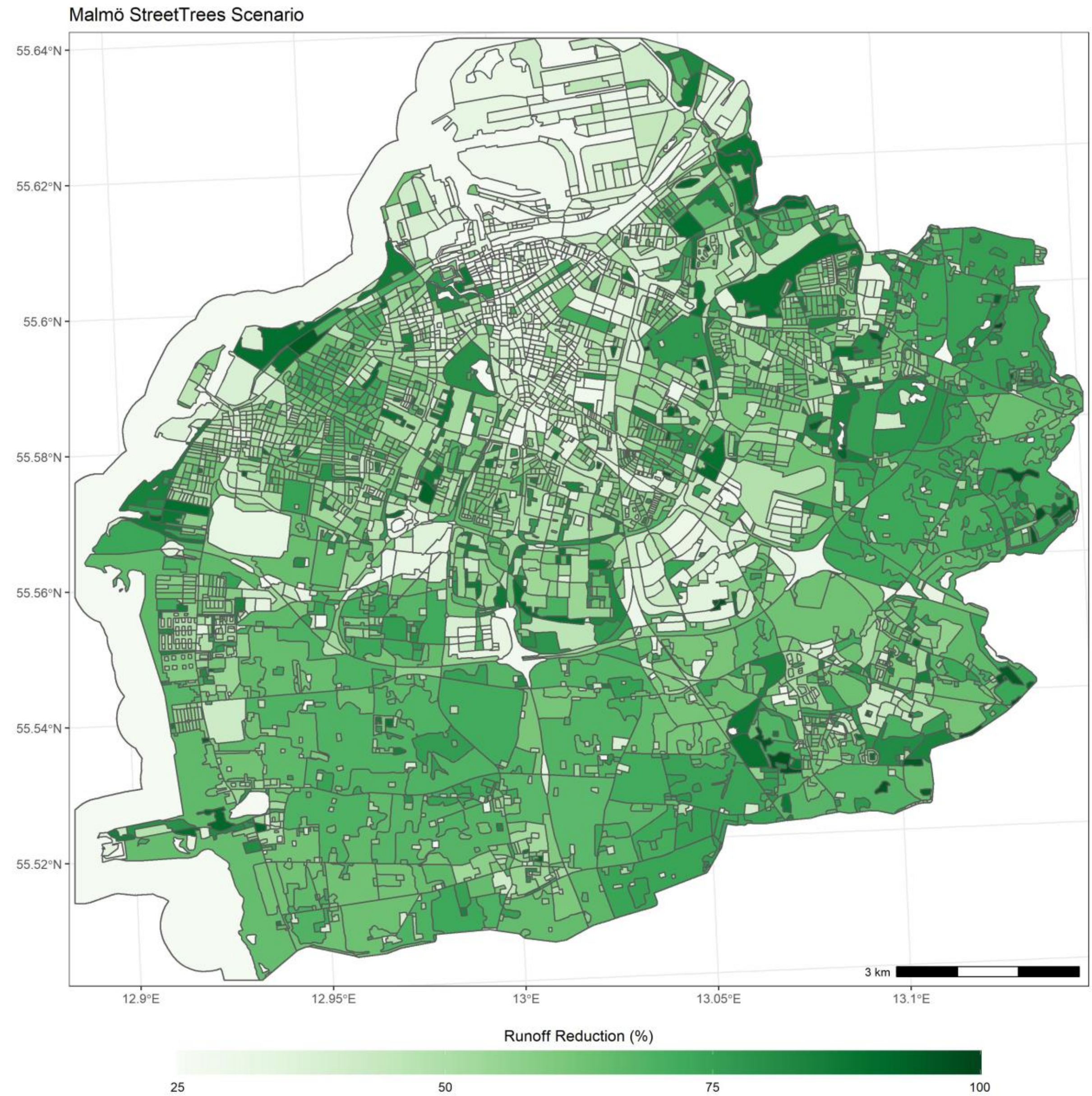

Figure M53. Malmö StreetTrees scenario Runoff Reduction (%)

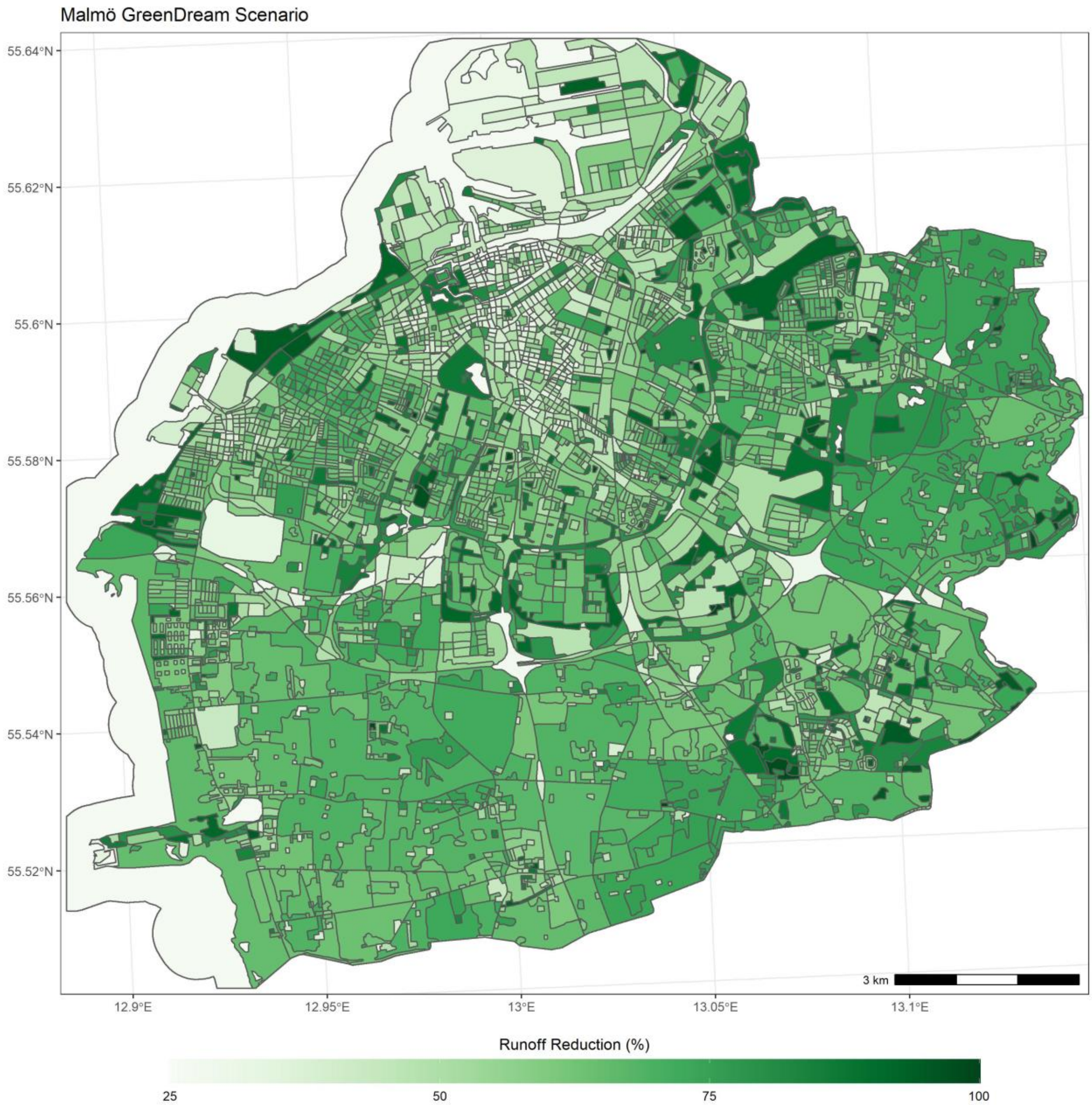

Figure M54. Malmö GreenDream scenario Runoff Reduction (%)

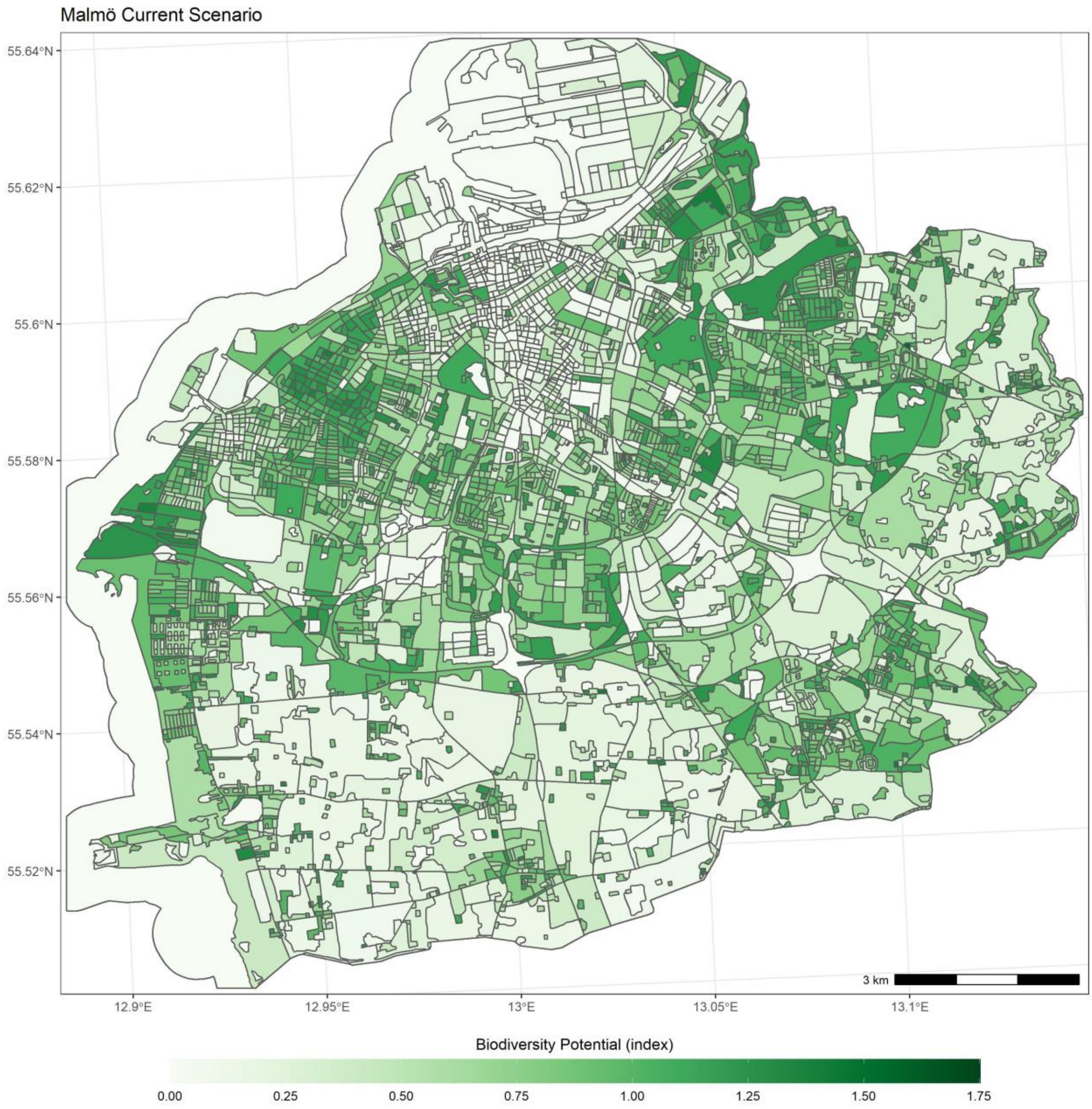

Figure M55. Malmö Current scenario Biodiversity Potential (index)

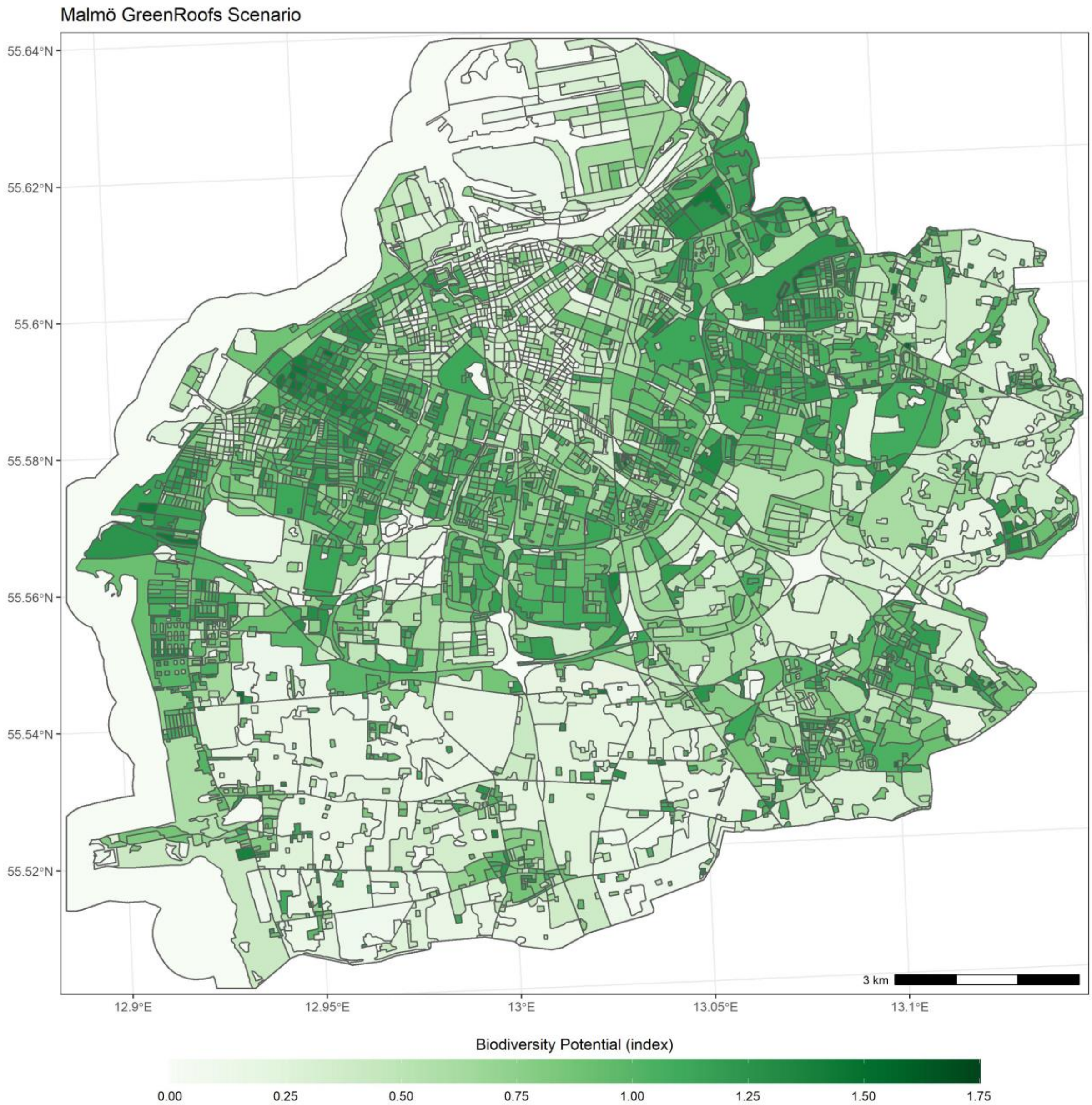

Figure M56. Malmö GreenRoofs scenario Biodiversity Potential (index)

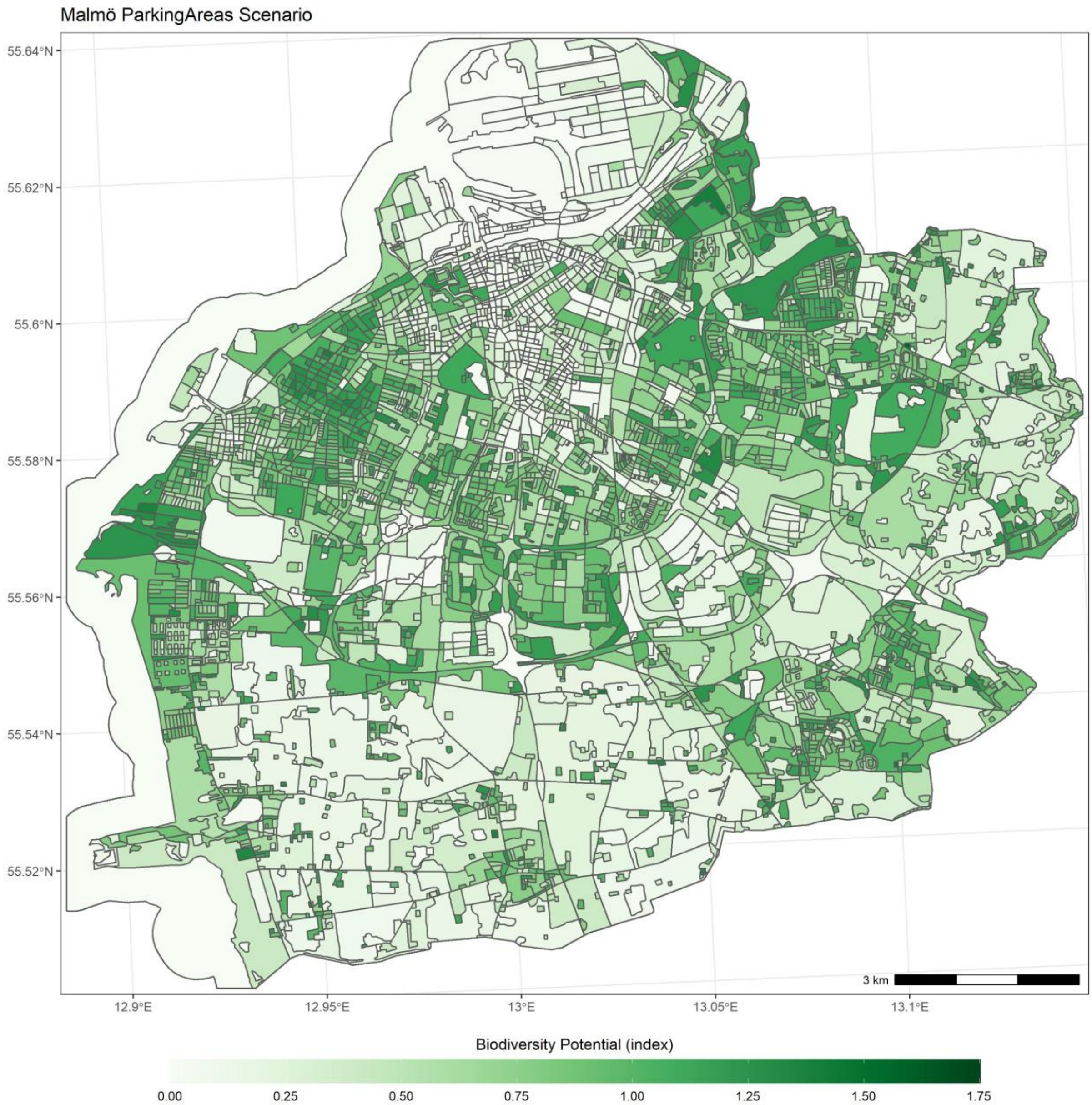

Figure M57. Malmö ParkingAreas scenario Biodiversity Potential (index)

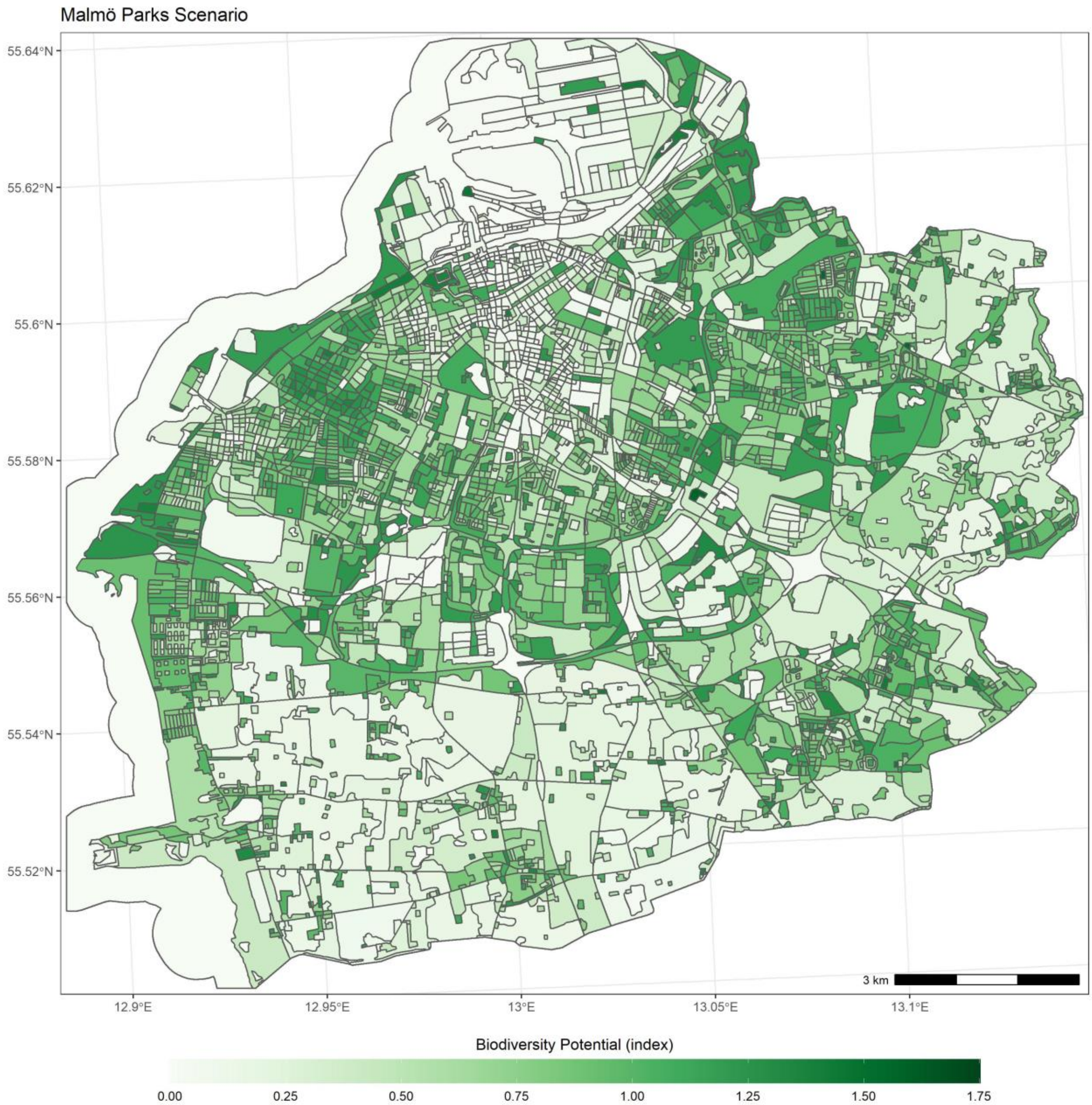

Figure M58. Malmö Parks scenario Biodiversity Potential (index)

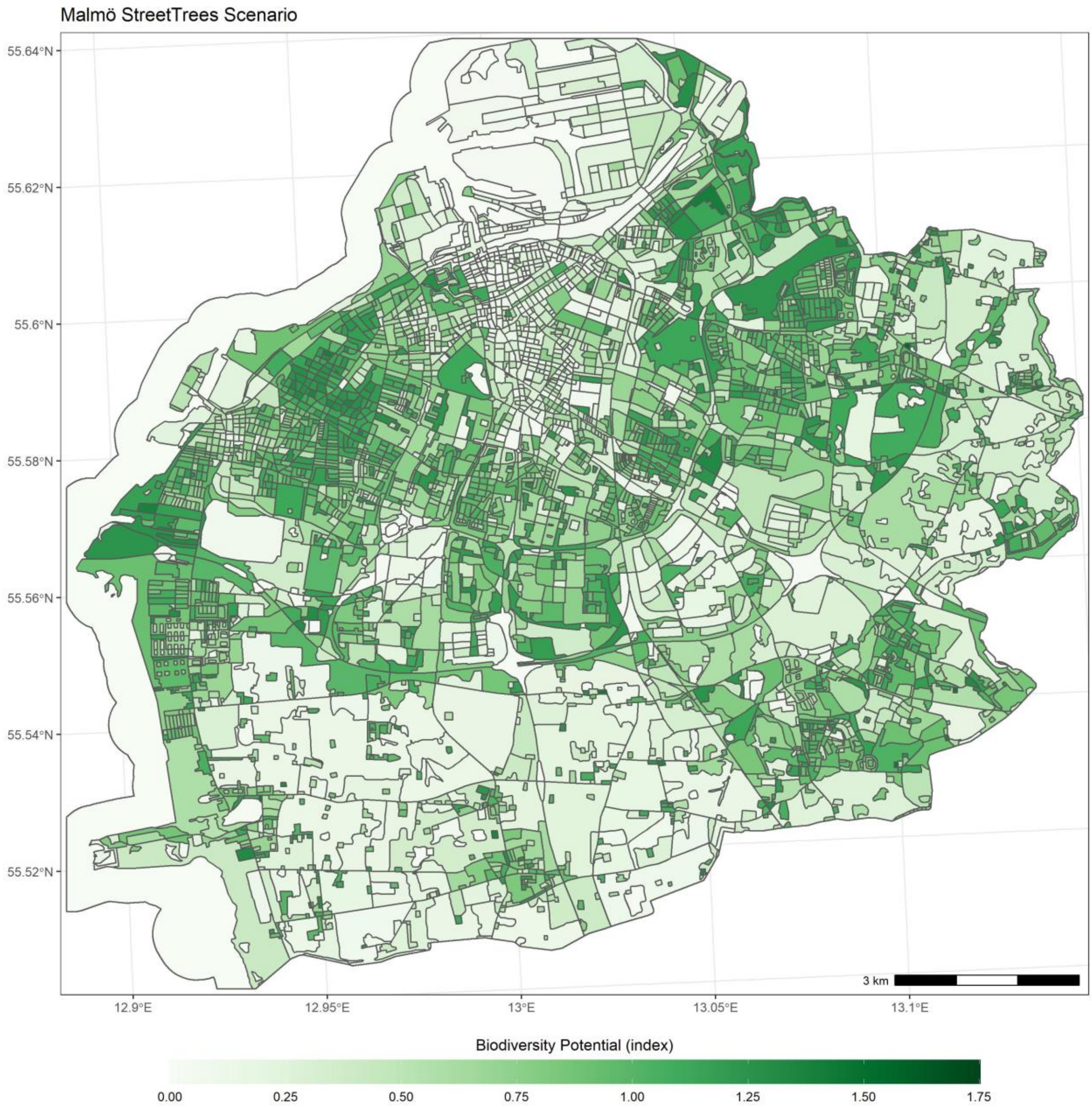

Figure M59. Malmö StreetTrees scenario Biodiversity Potential (index)

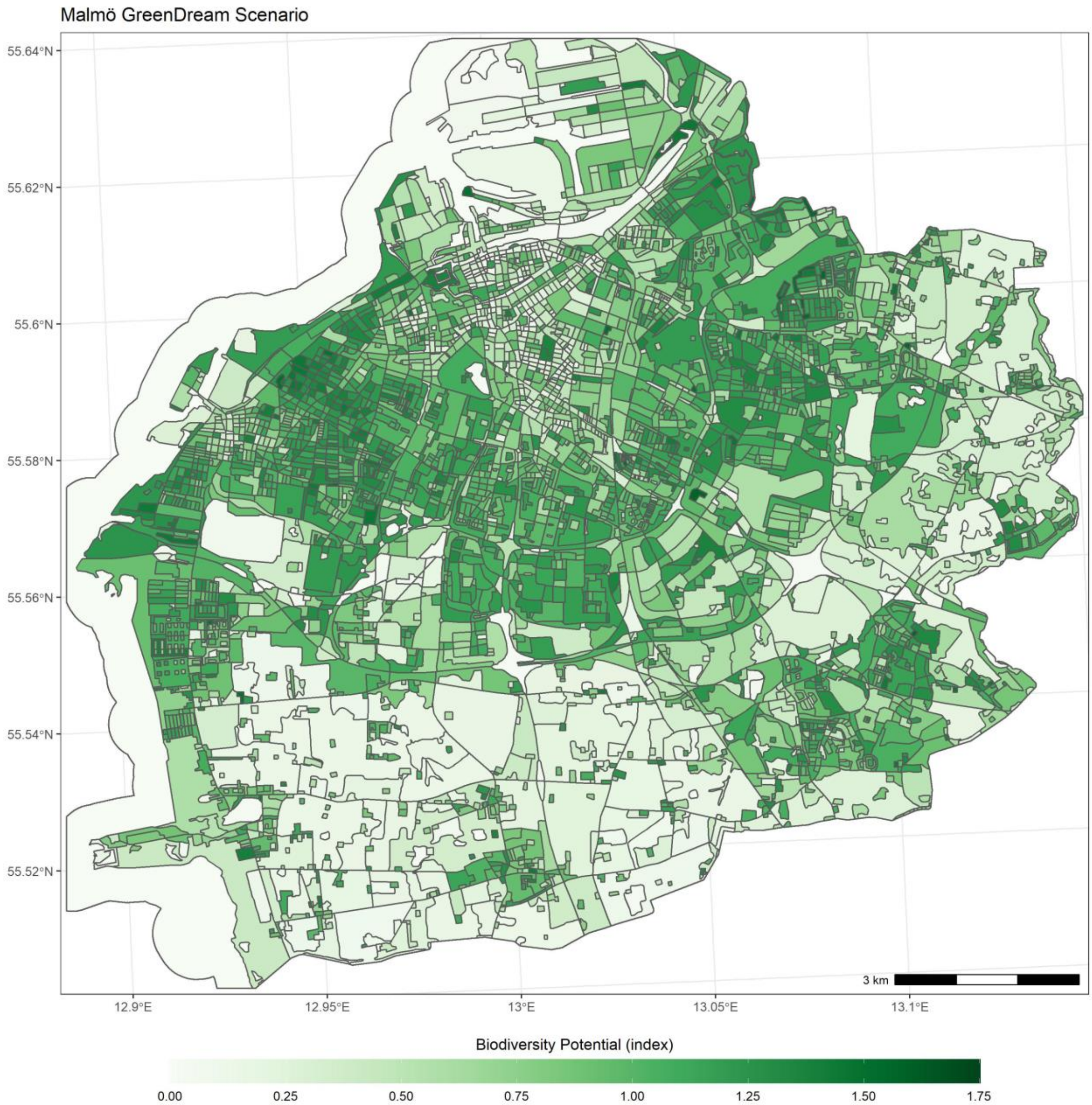

Figure M60. Malmö GreenDream scenario Biodiversity Potential (index)

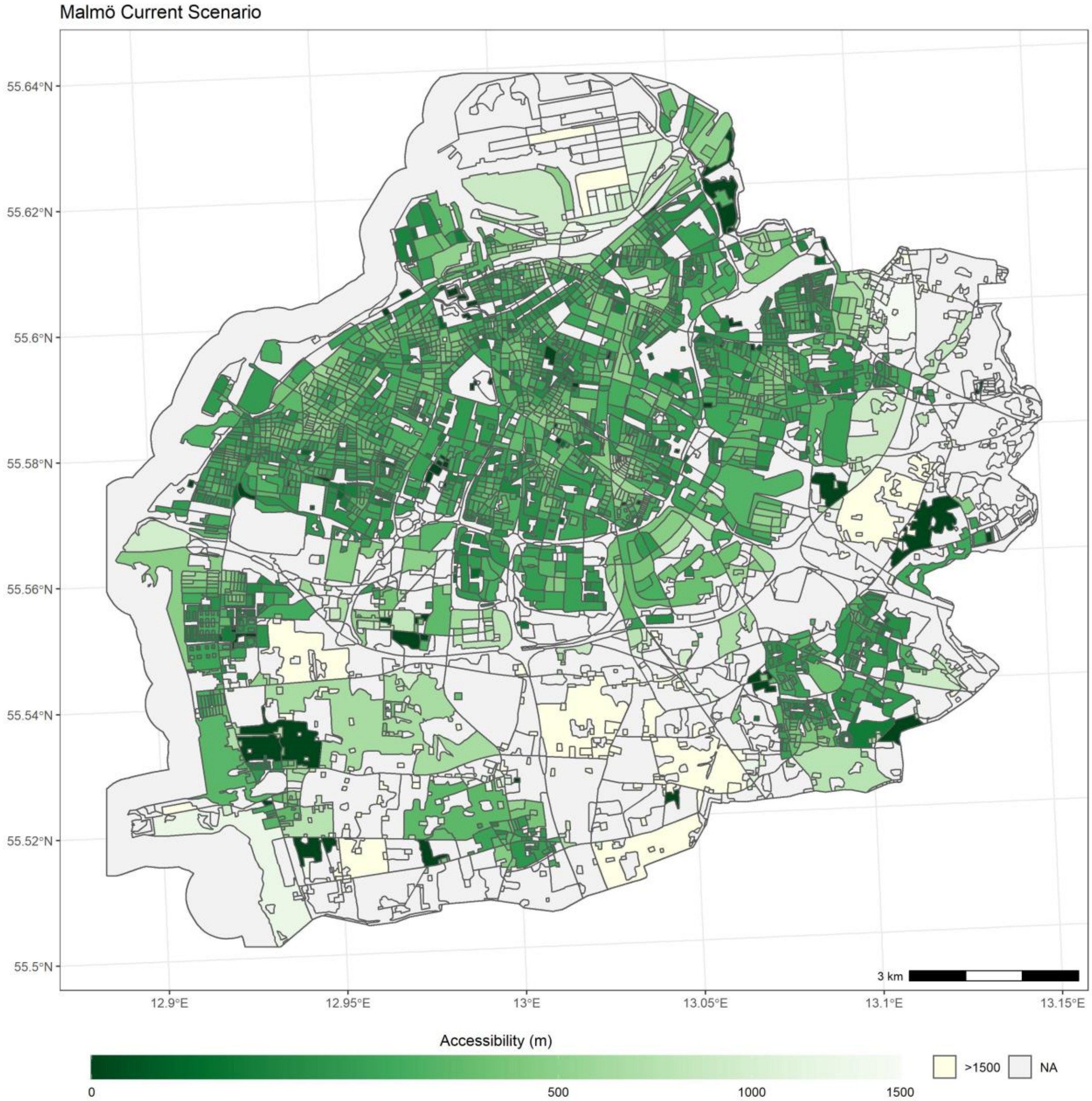

Figure M61. Malmö Current scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

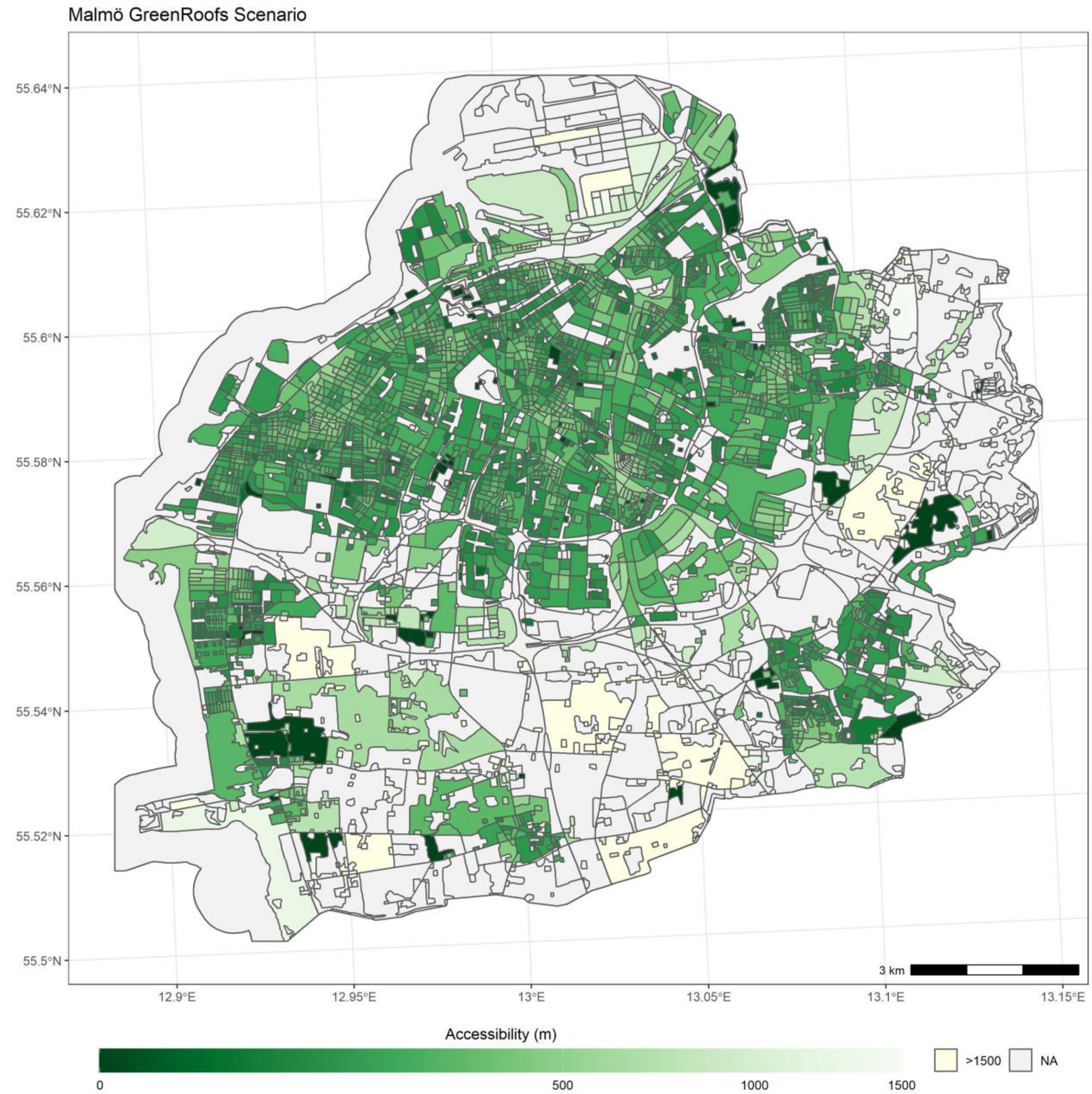

Figure M62. Malmö GreenRoofs scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

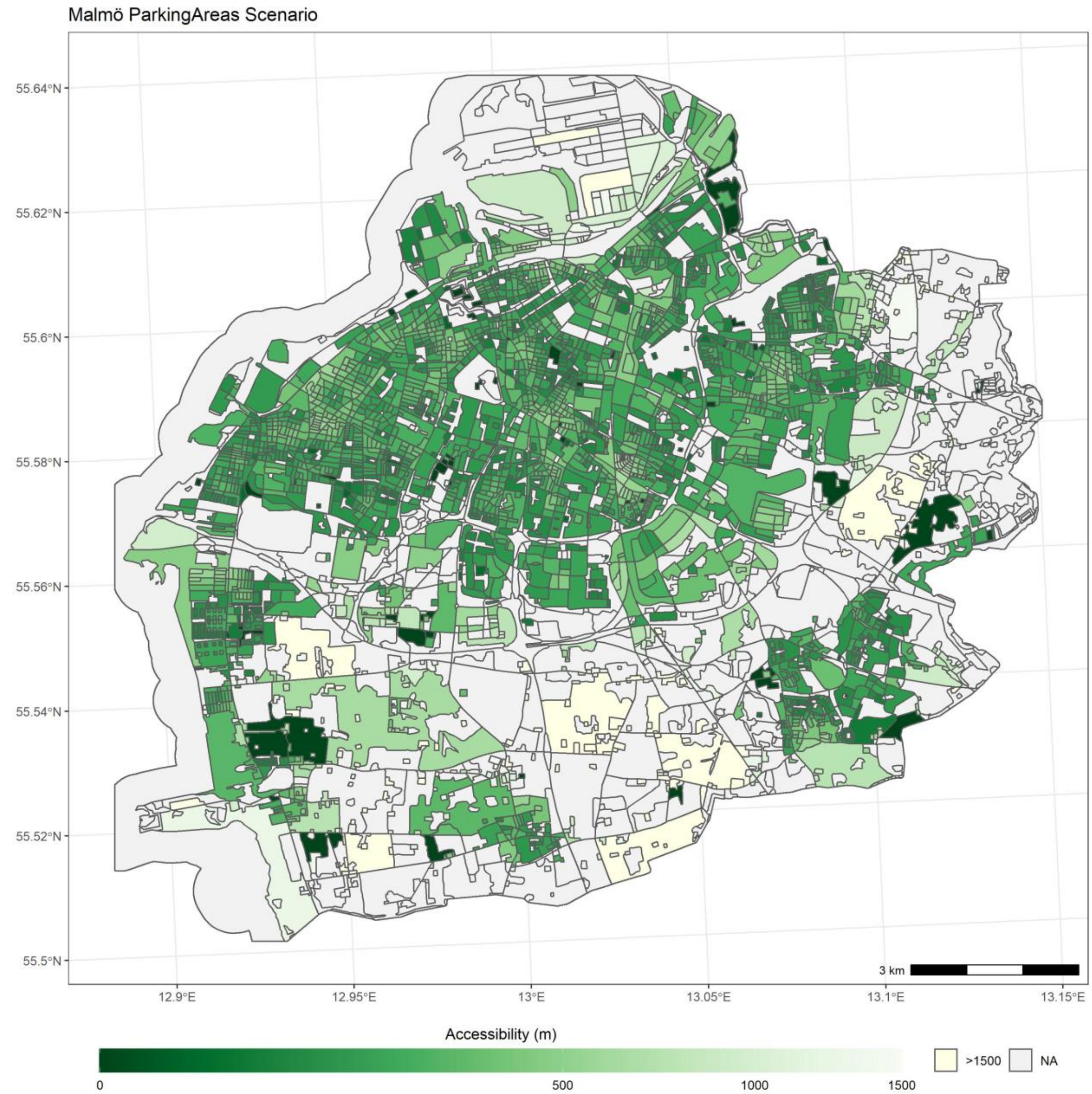

Figure M63. Malmö ParkingAreas scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

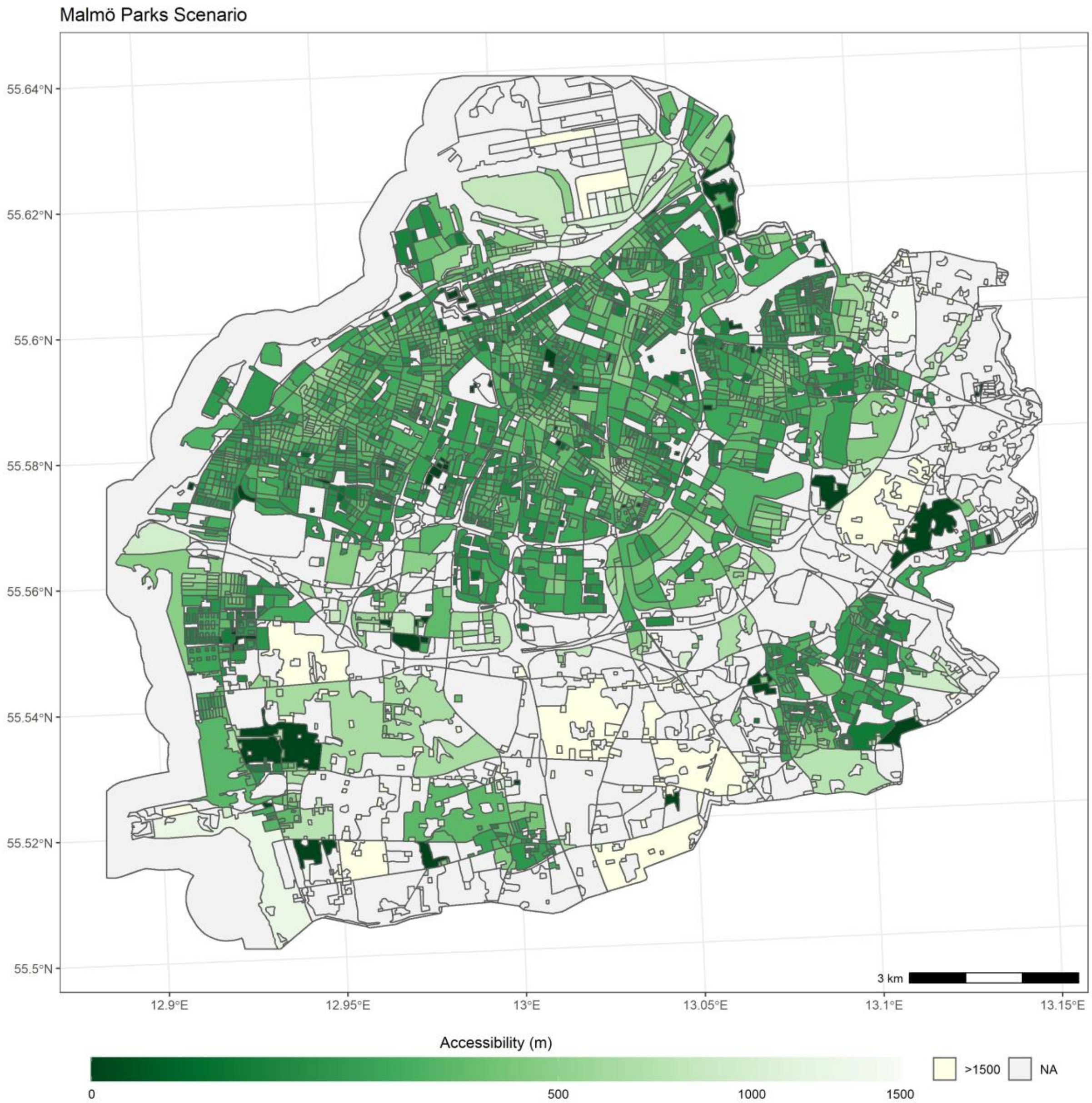

Figure M64. Malmö Parks scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

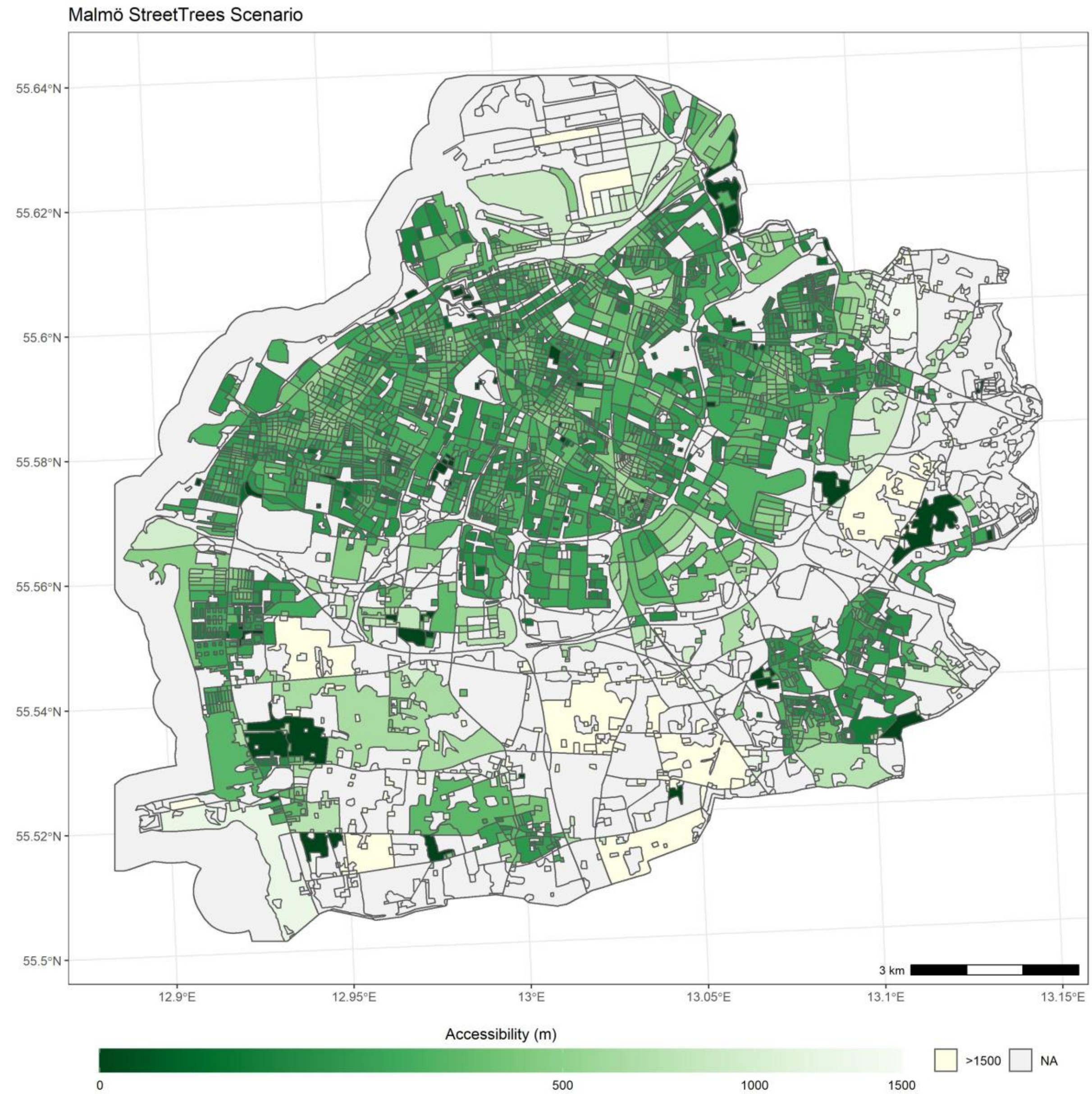

Figure M65. Malmö StreetTrees scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

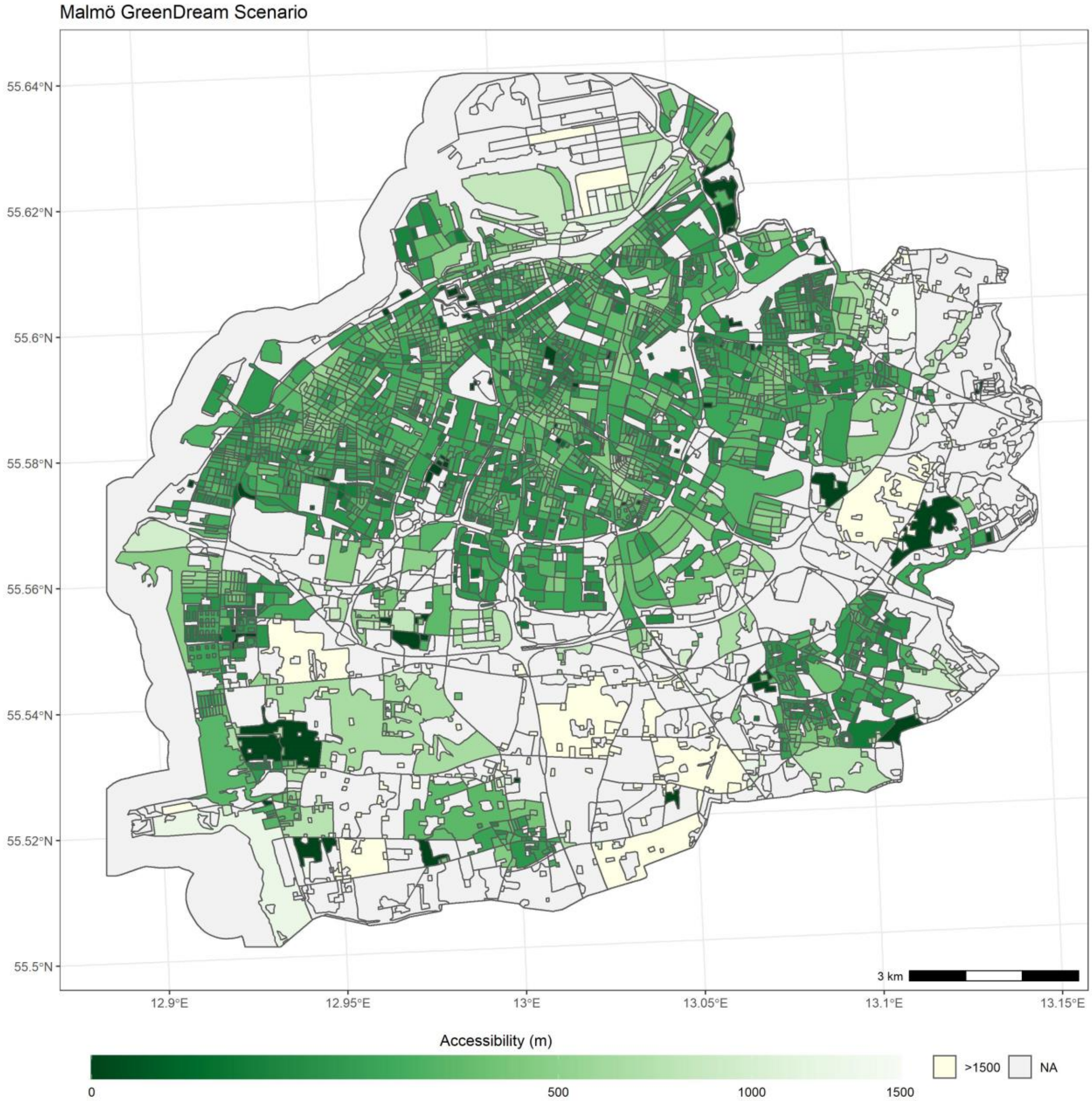

Figure M66. Malmö GreenDream scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

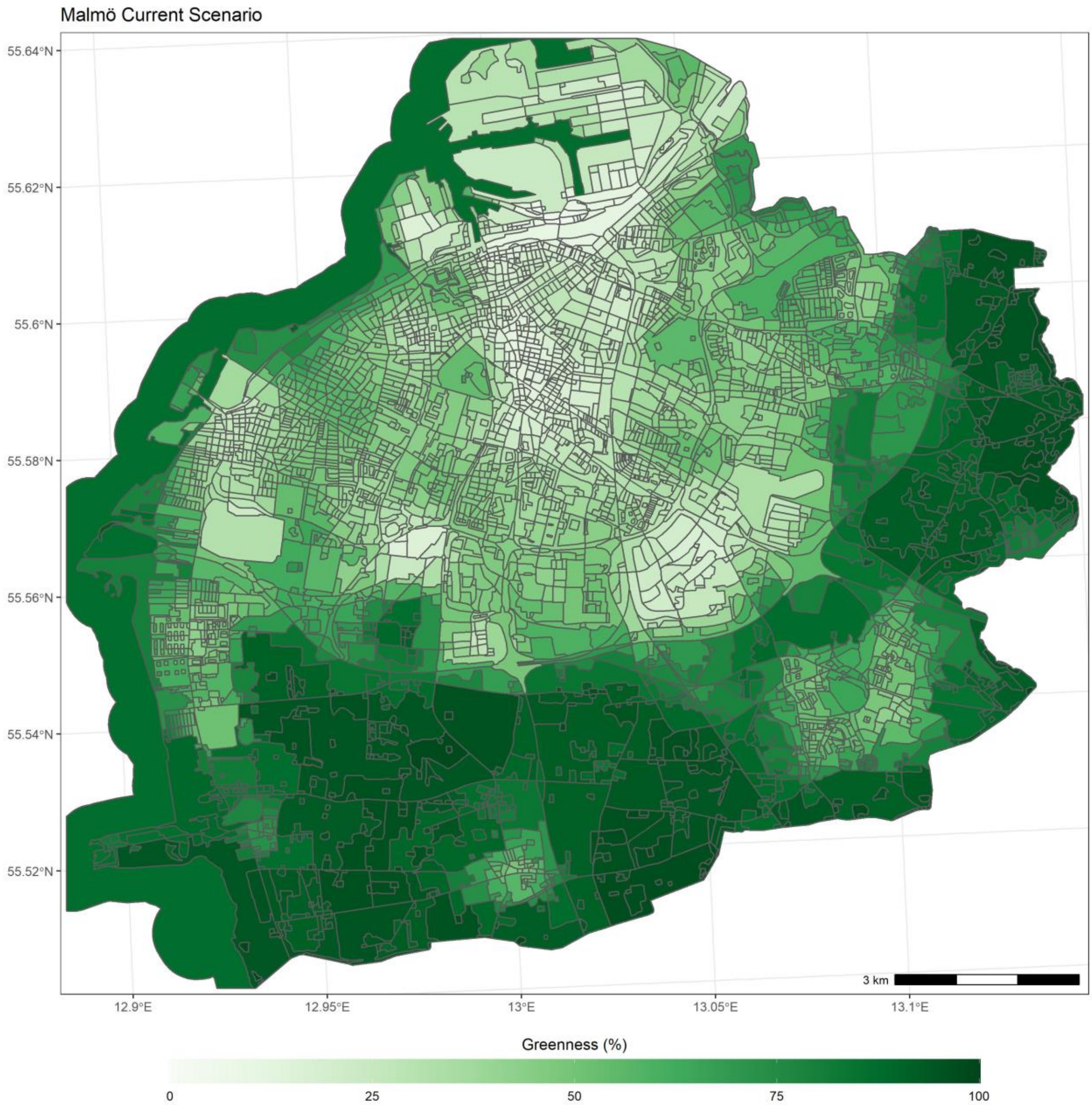

Figure M67. Malmö Current scenario Greenness (%)

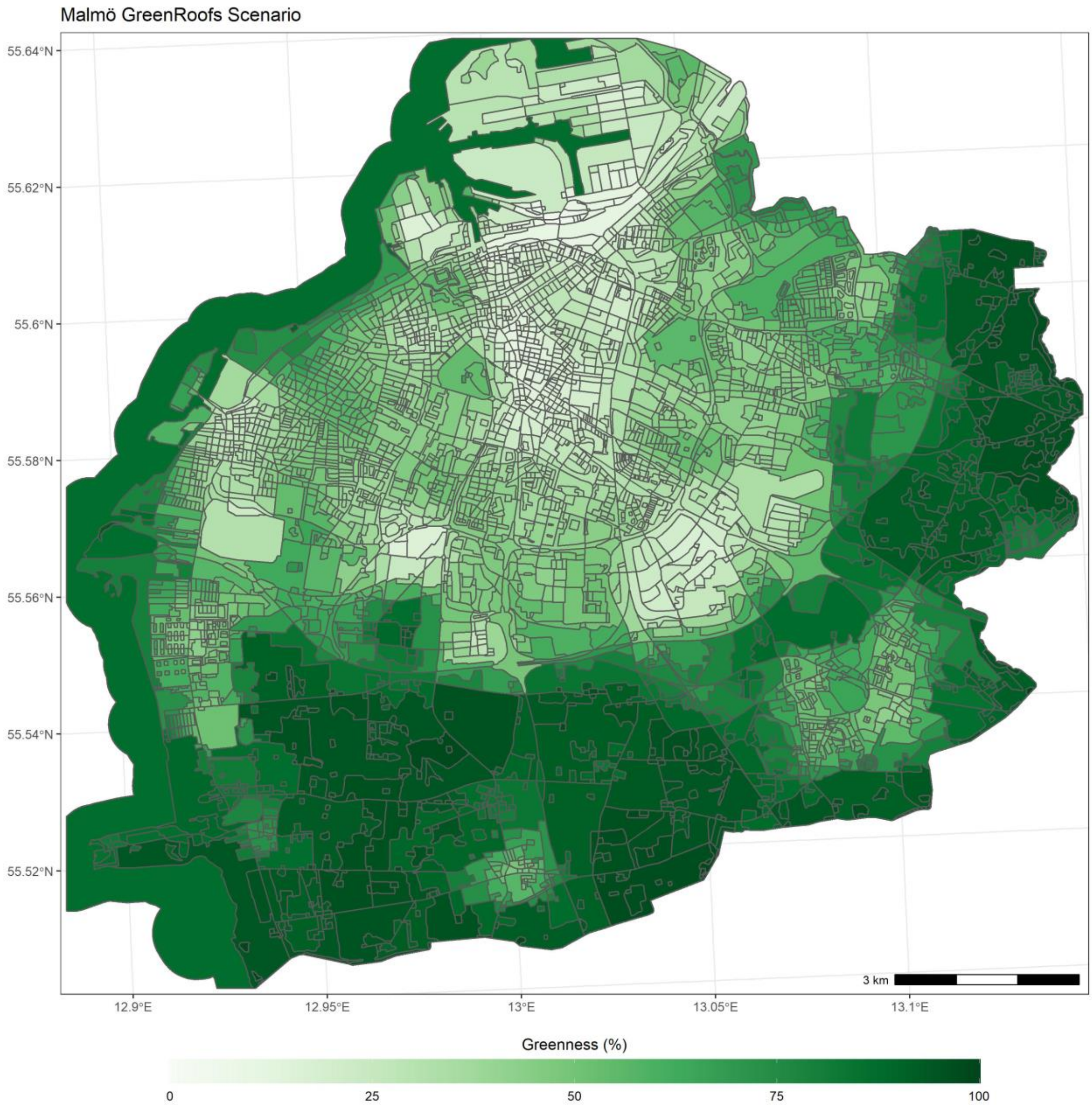

Figure M68. Malmö GreenRoofs scenario Greenness (%)

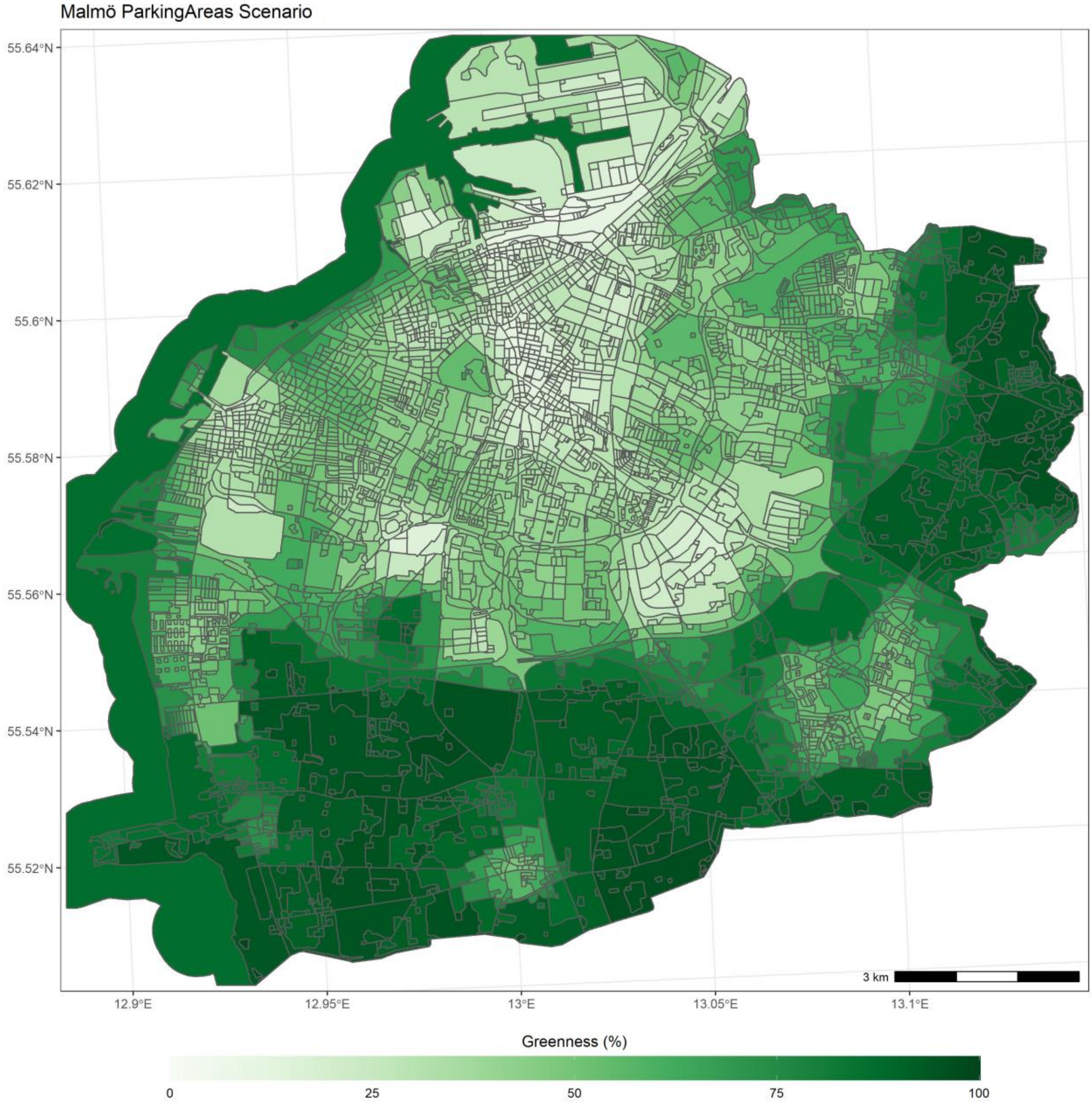

Figure M69. Malmö ParkingAreas scenario Greenness (%)

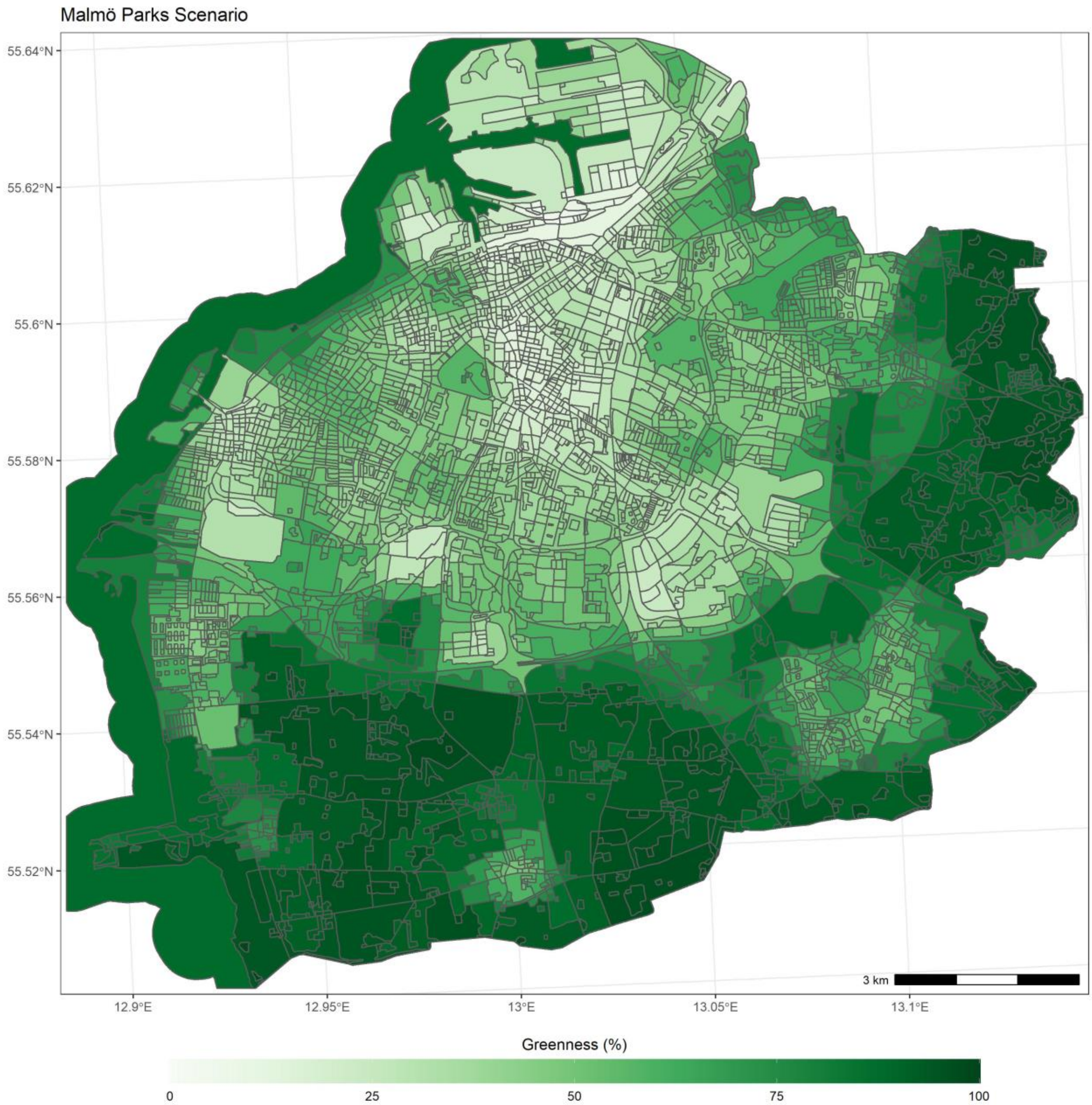

Figure M70. Malmö Parks scenario Greenness (%)

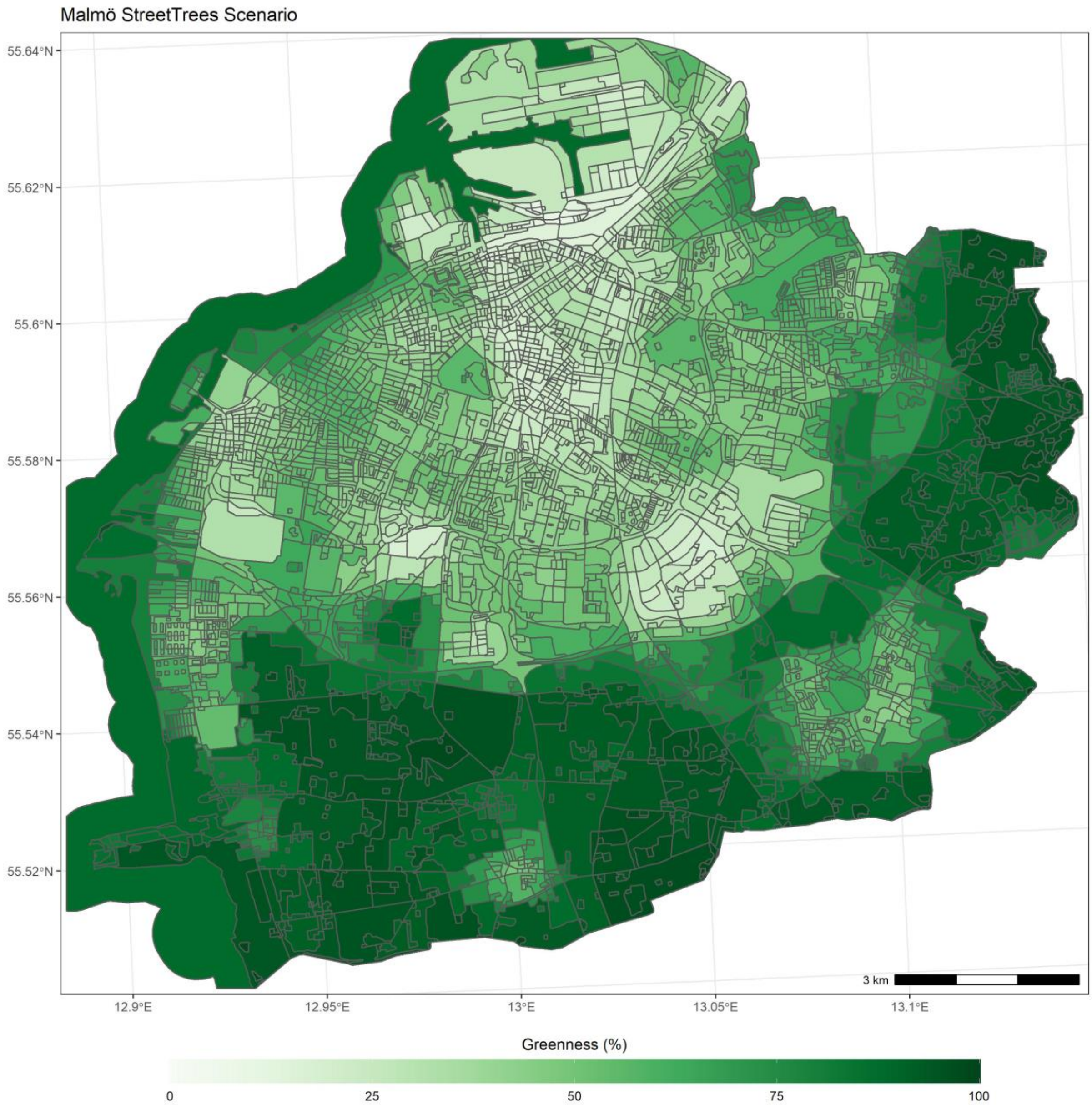

Figure M71. Malmö StreetTrees scenario Greenness (%)

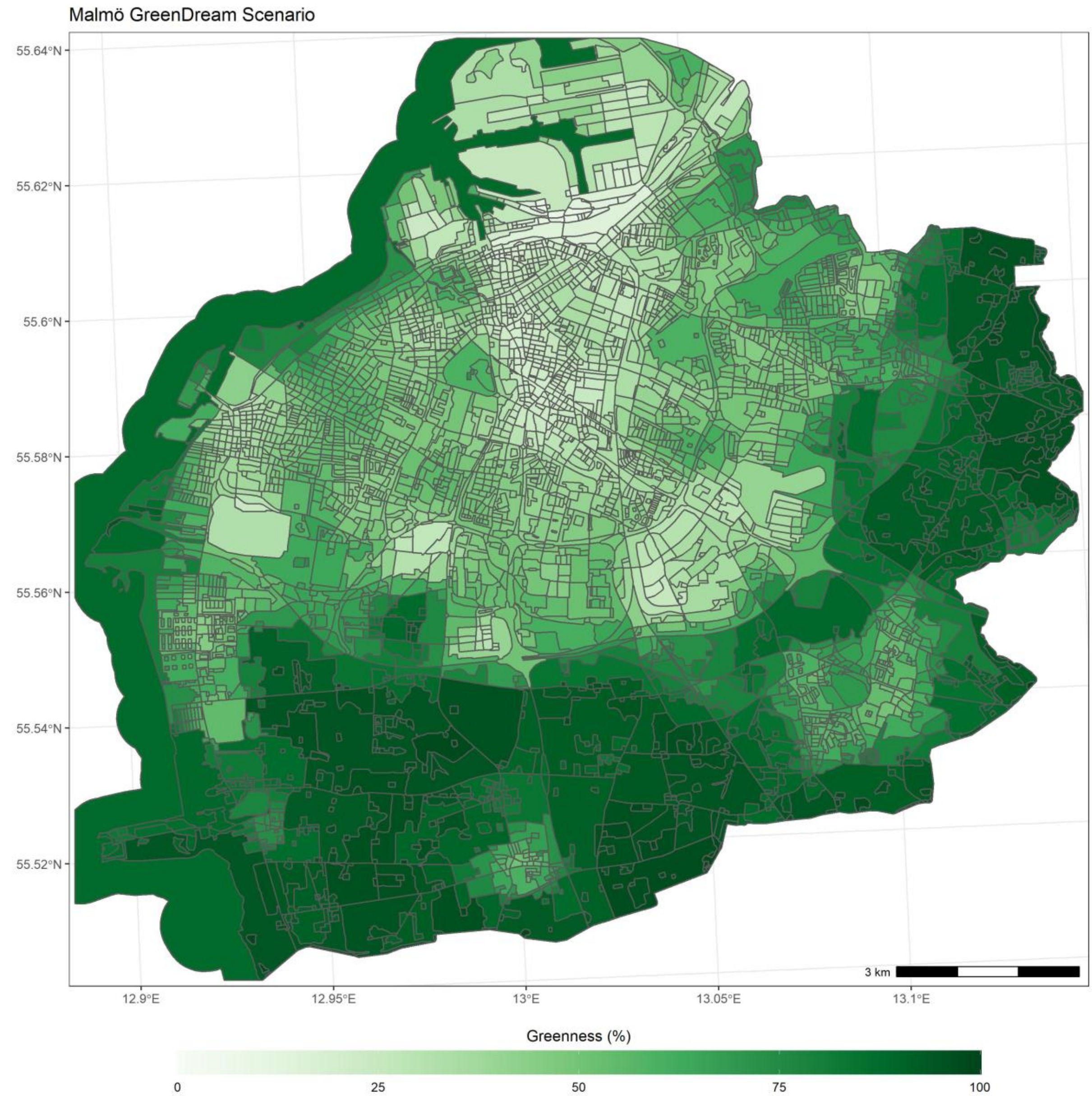

Figure M72. Malmö GreenDream scenario Greenness (%)

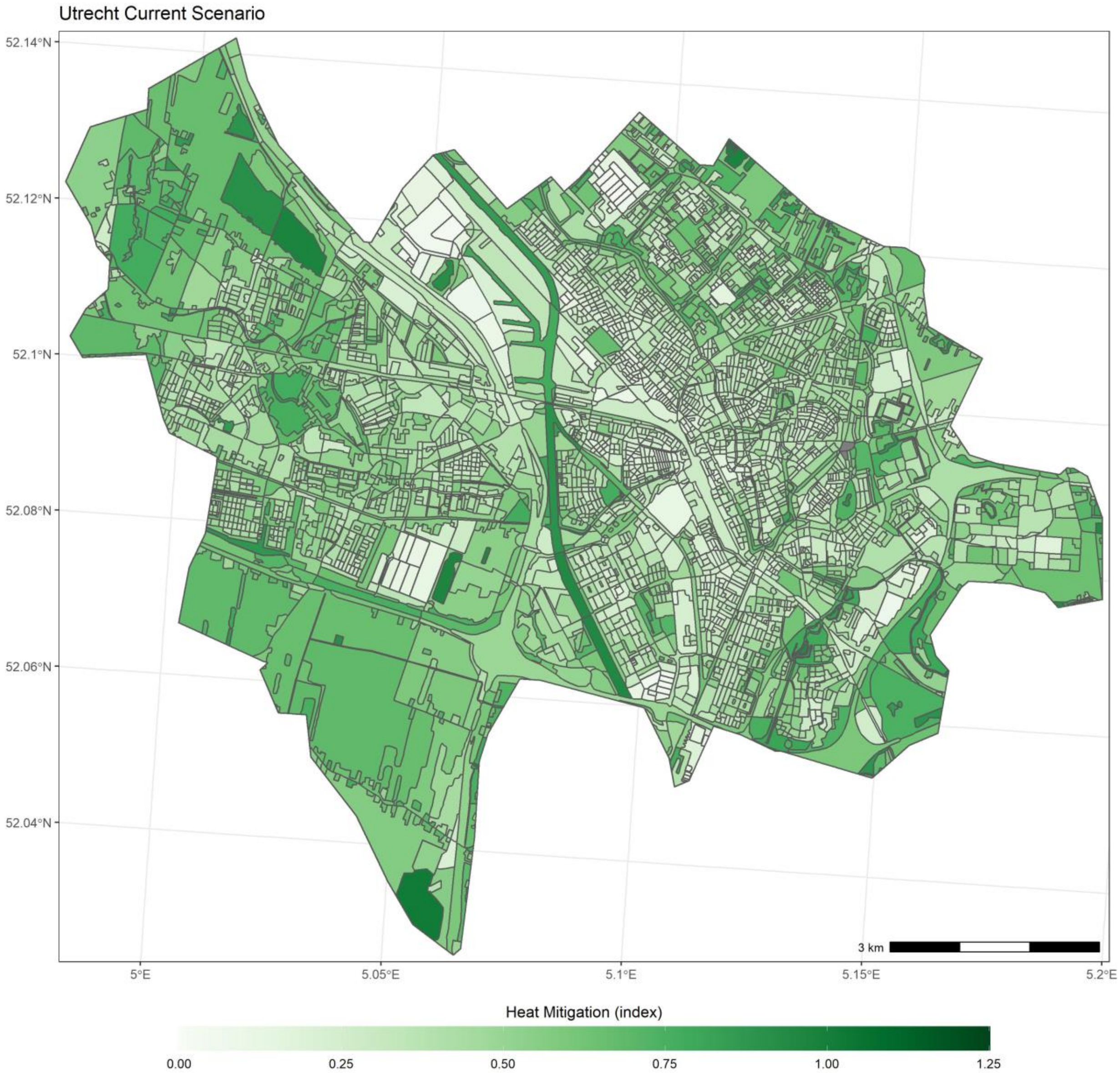

Figure M73. Utrecht Current scenario Heat Mitigation (index)

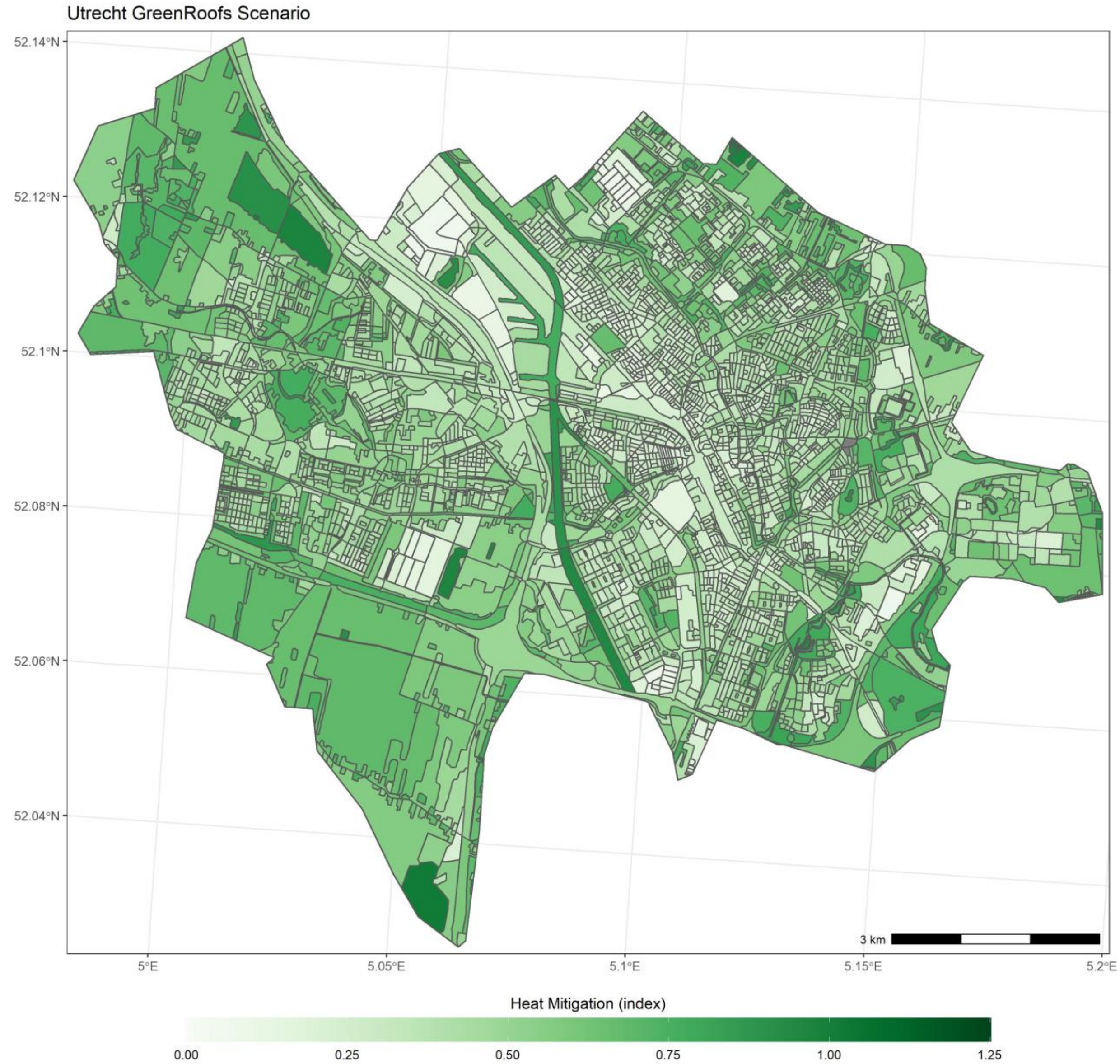

Figure M74. Utrecht GreenRoofs scenario Heat Mitigation (index)

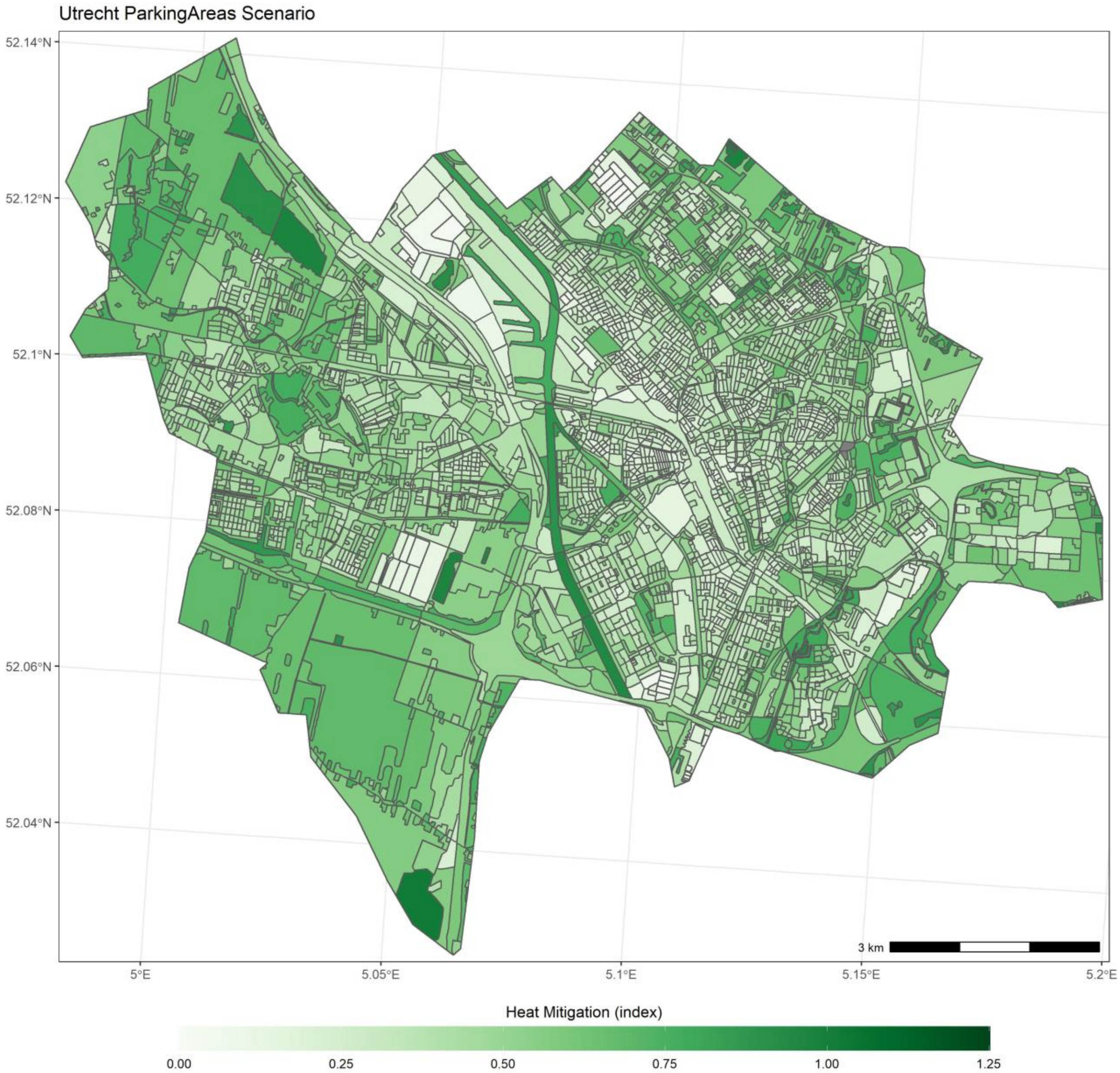

Figure M75. Utrecht ParkingAreas scenario Heat Mitigation (index)

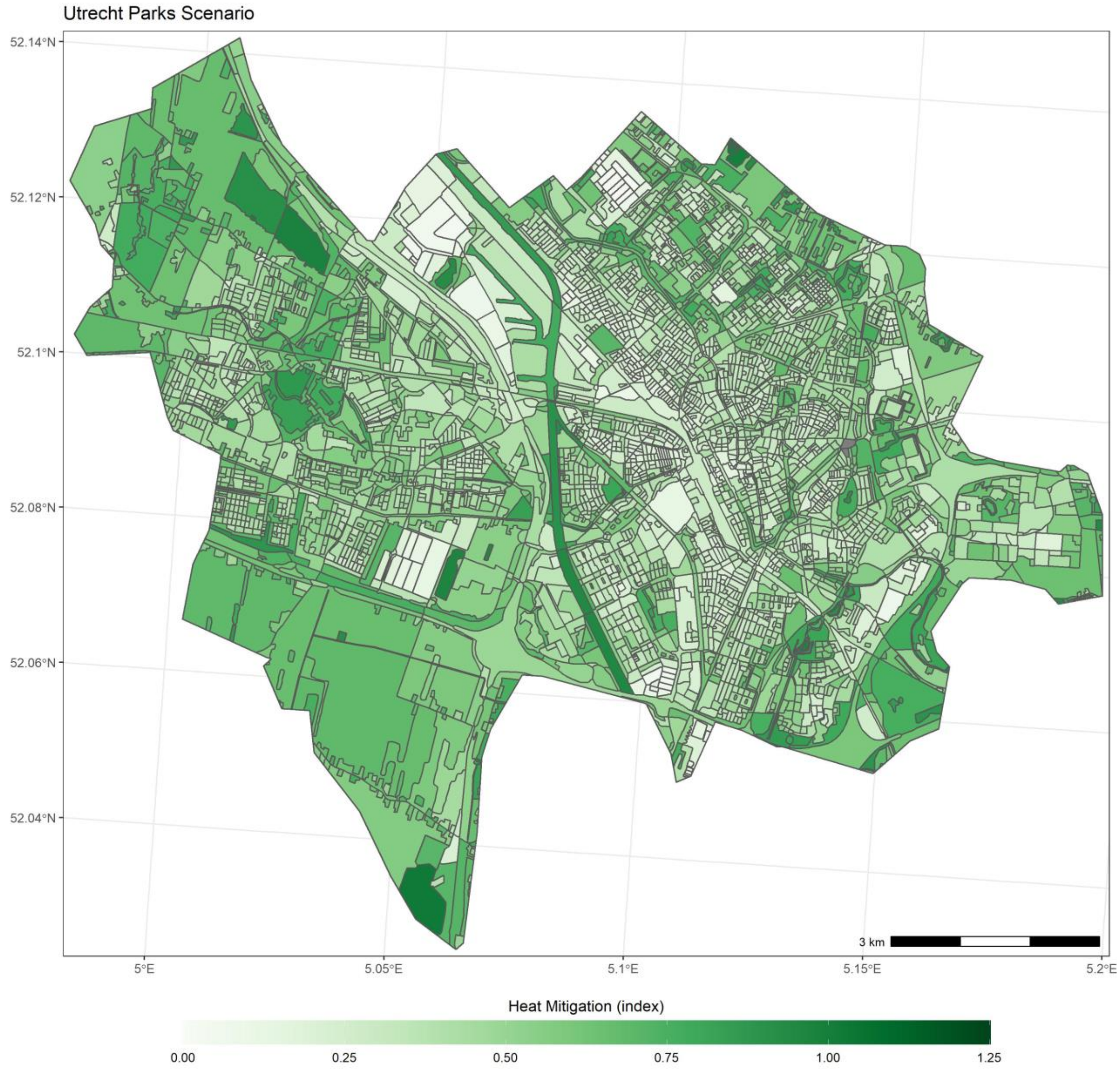

Figure M76. Utrecht Parks scenario Heat Mitigation (index)

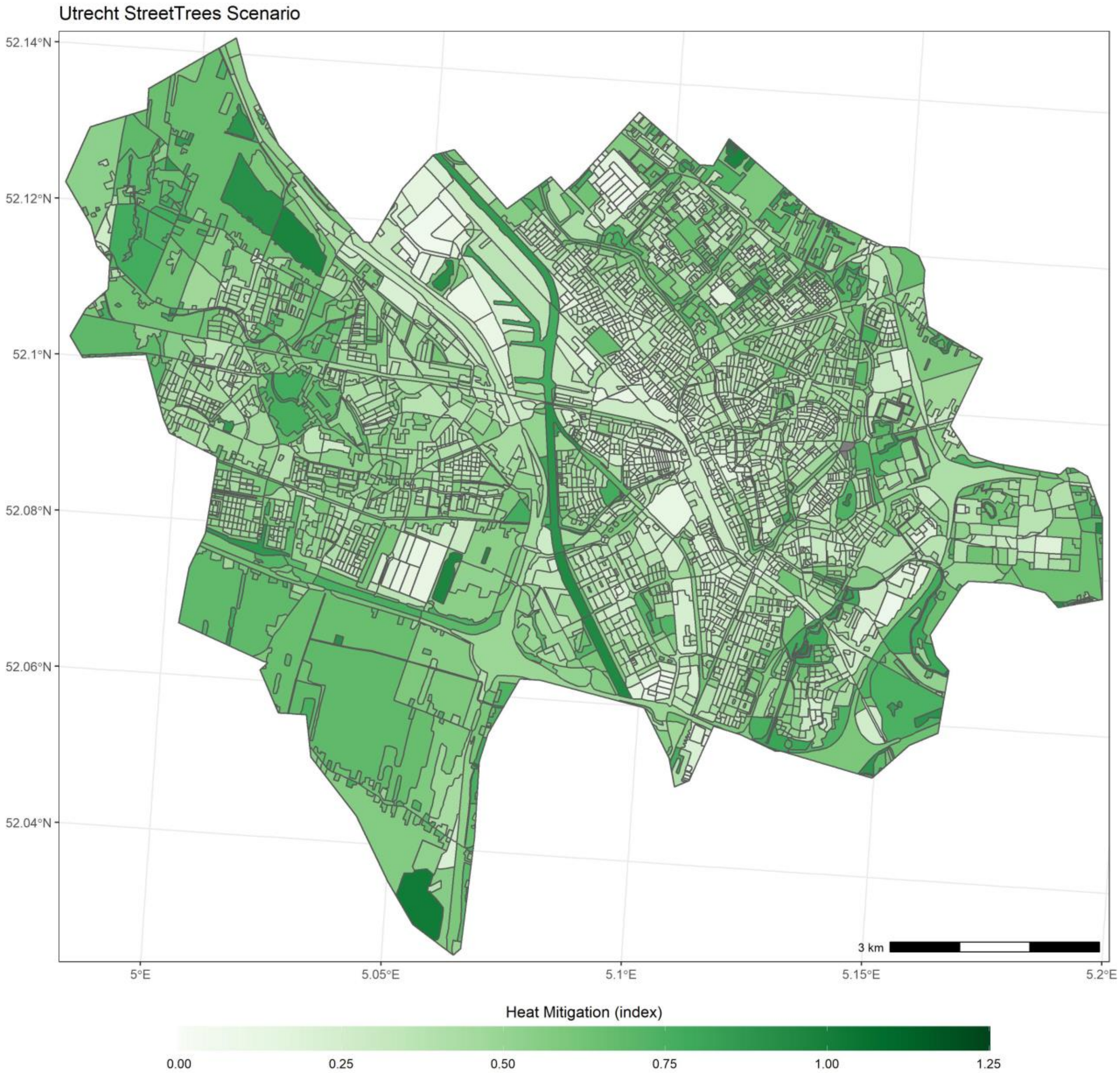

Figure M77. Utrecht StreetTrees scenario Heat Mitigation (index)

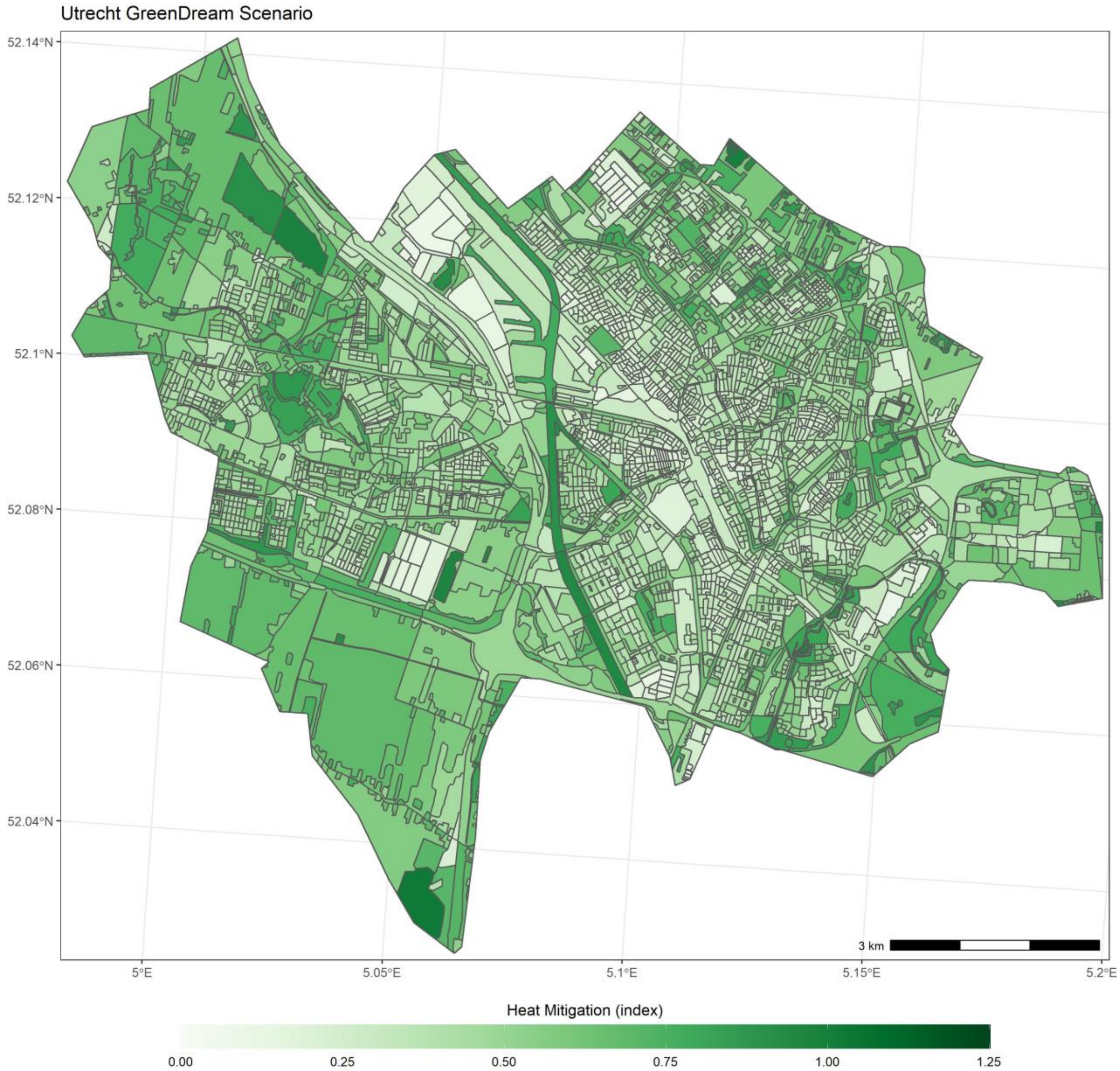

Figure M78. Utrecht GreenDream scenario Heat Mitigation (index)

Figure M79. Utrecht Current scenario Carbon Storage (ton/ha)

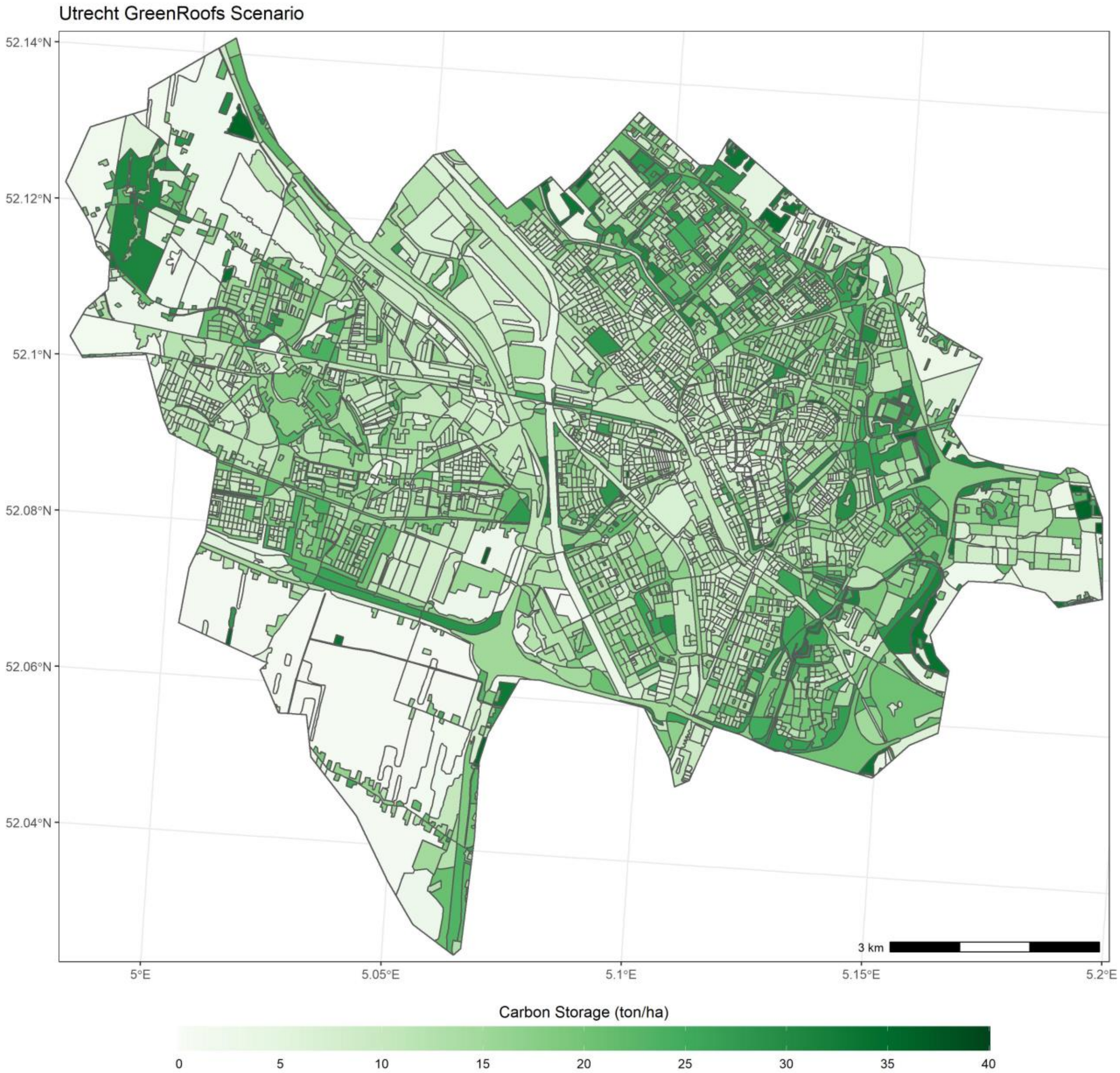

Figure M80. Utrecht GreenRoofs scenario Carbon Storage (ton/ha)

Figure M81. Utrecht ParkingAreas scenario Carbon Storage (ton/ha)

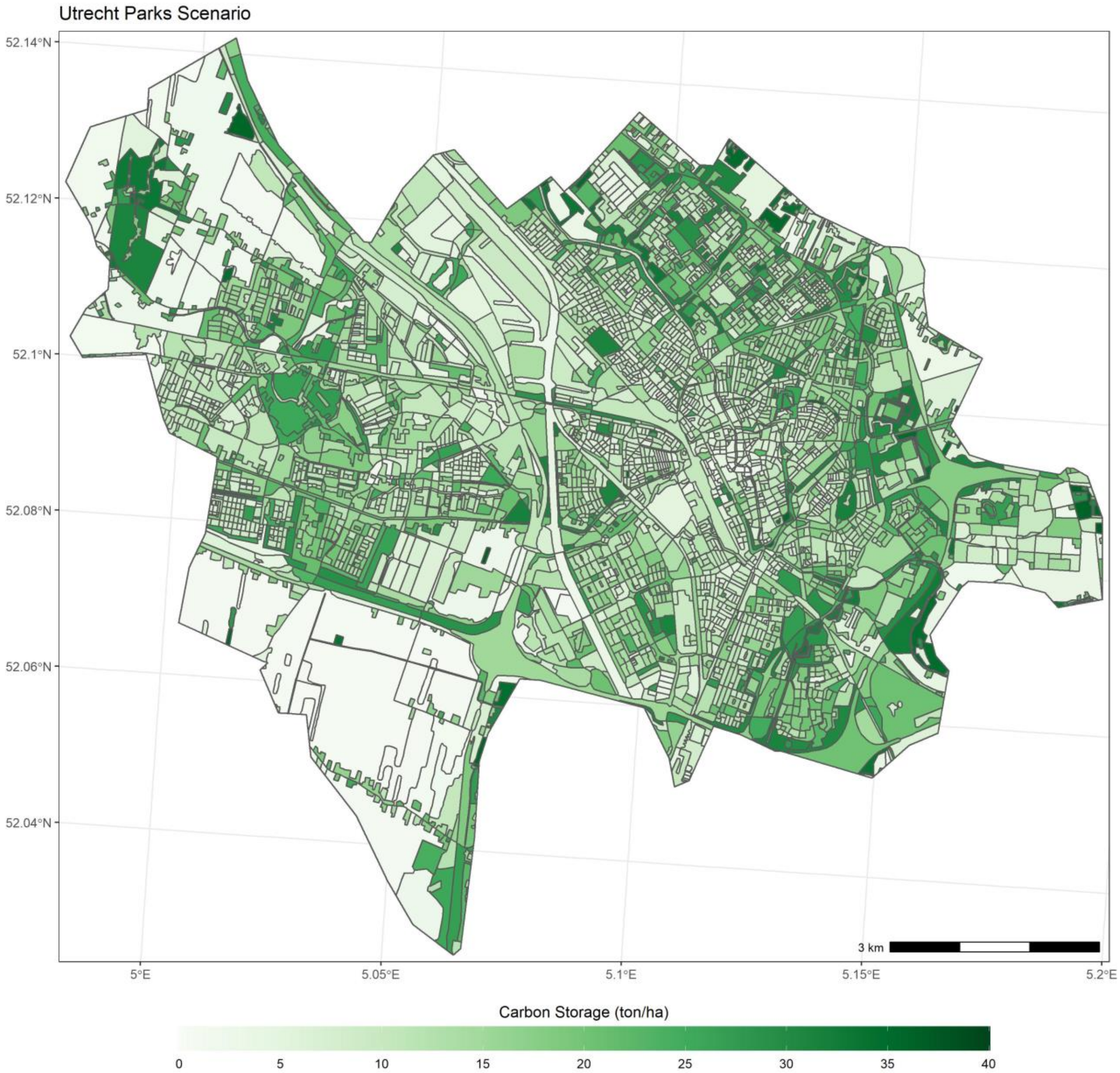

Figure M82. Utrecht Parks scenario Carbon Storage (ton/ha)

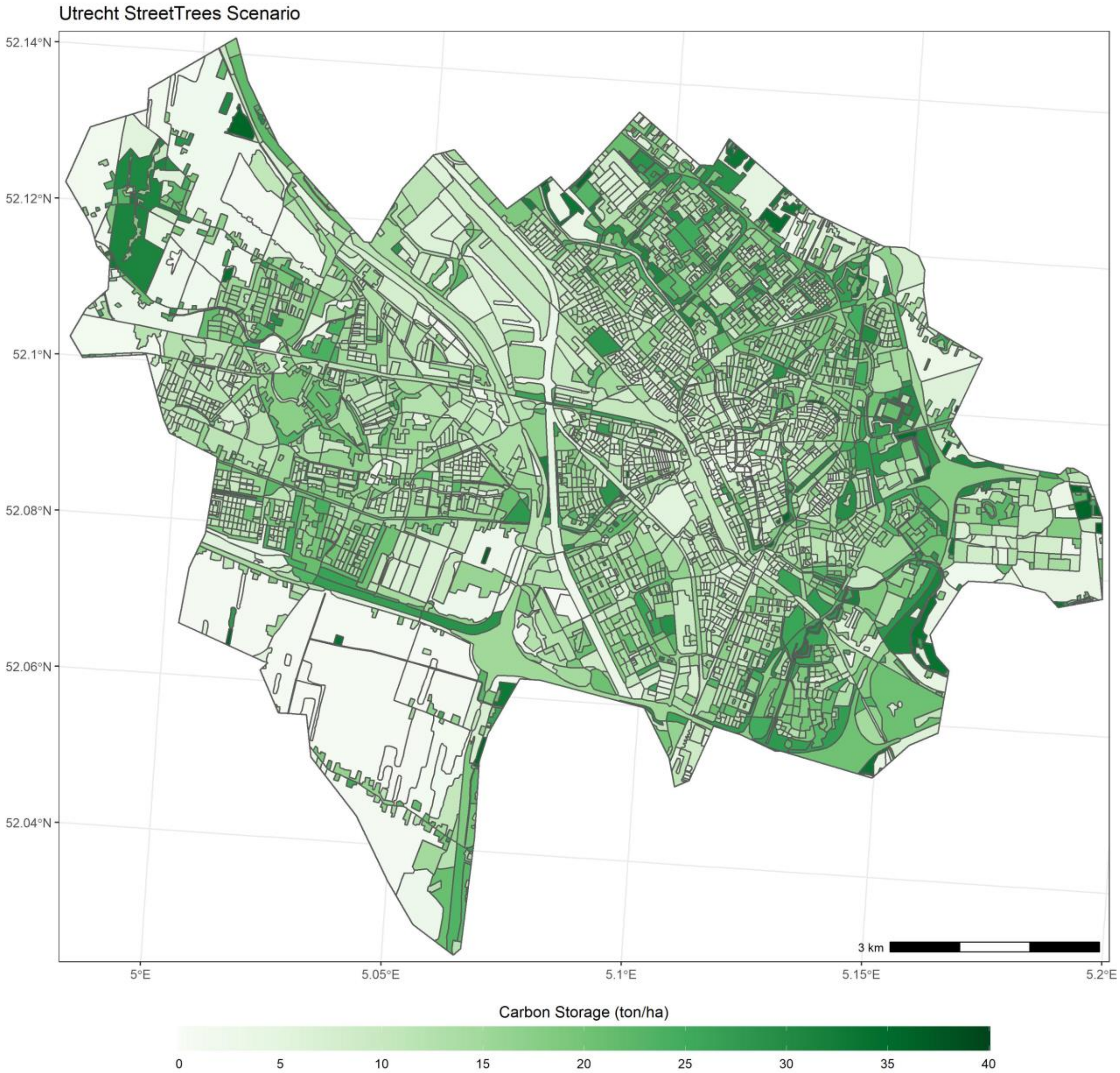

Figure M83. Utrecht StreetTrees scenario Carbon Storage (ton/ha)

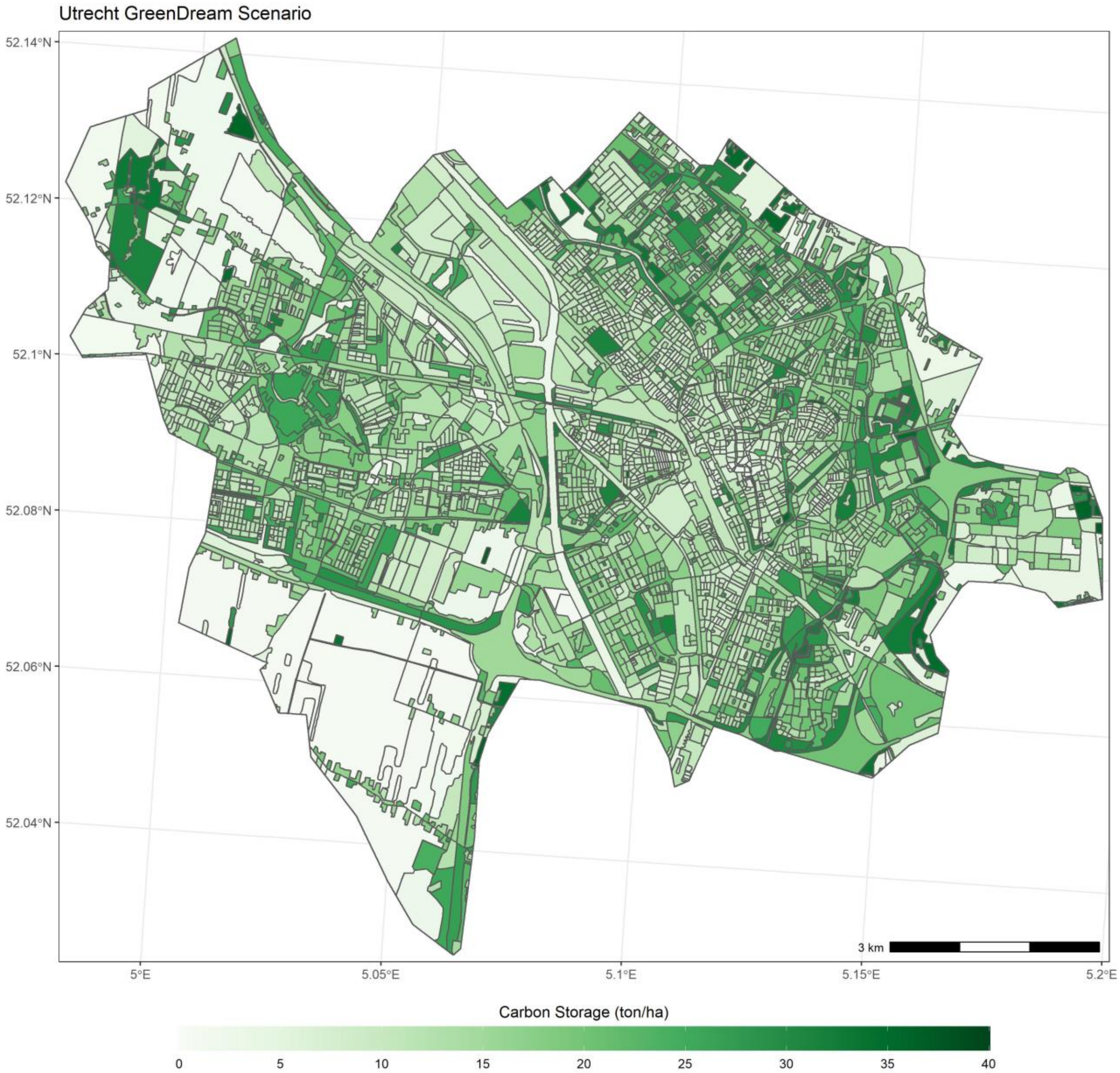

Figure M84. Utrecht GreenDream scenario Carbon Storage (ton/ha)

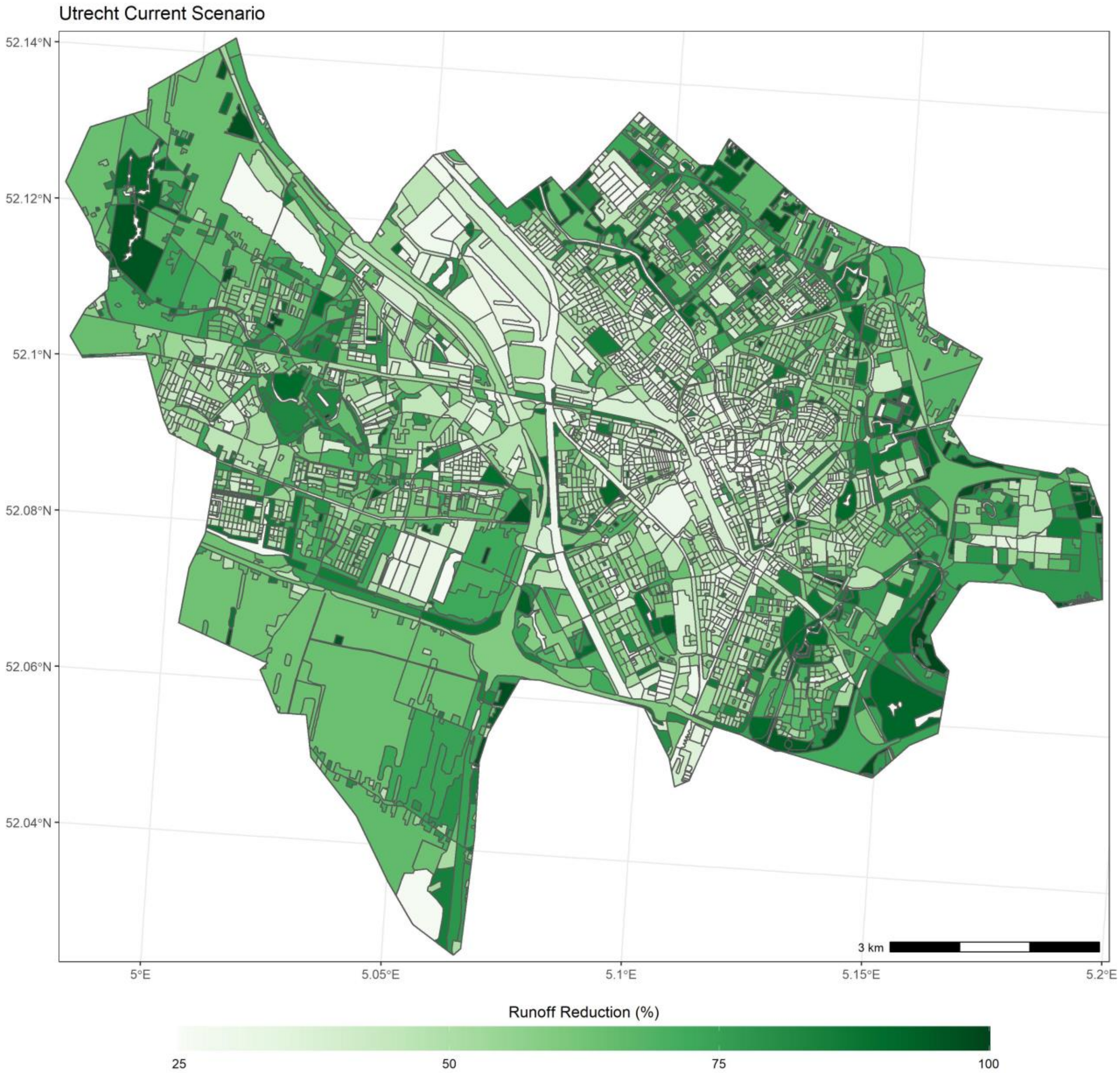

Figure M85. Utrecht Current scenario Runoff Reduction (%)

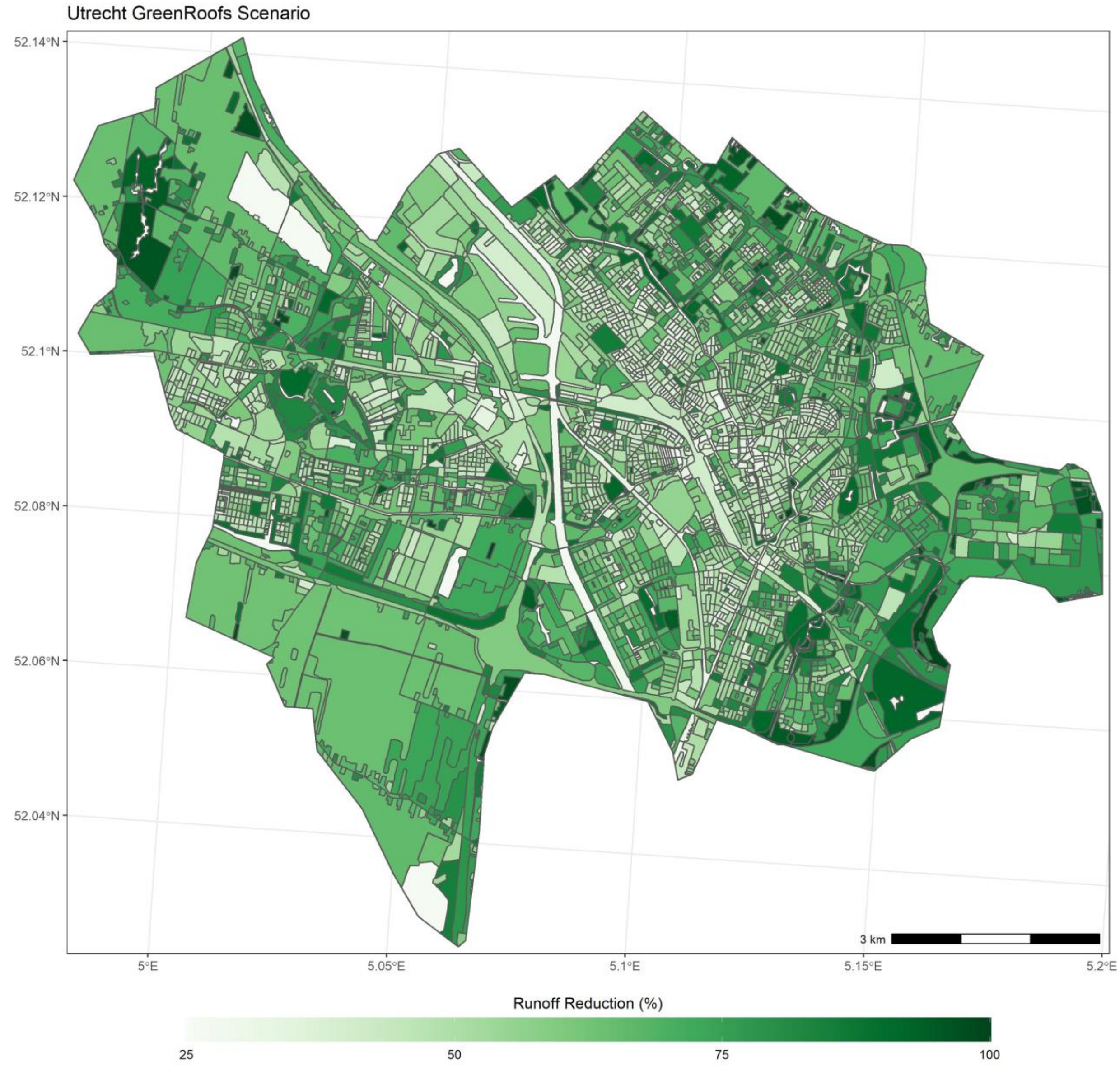

Figure M86. Utrecht GreenRoofs scenario Runoff Reduction (%)

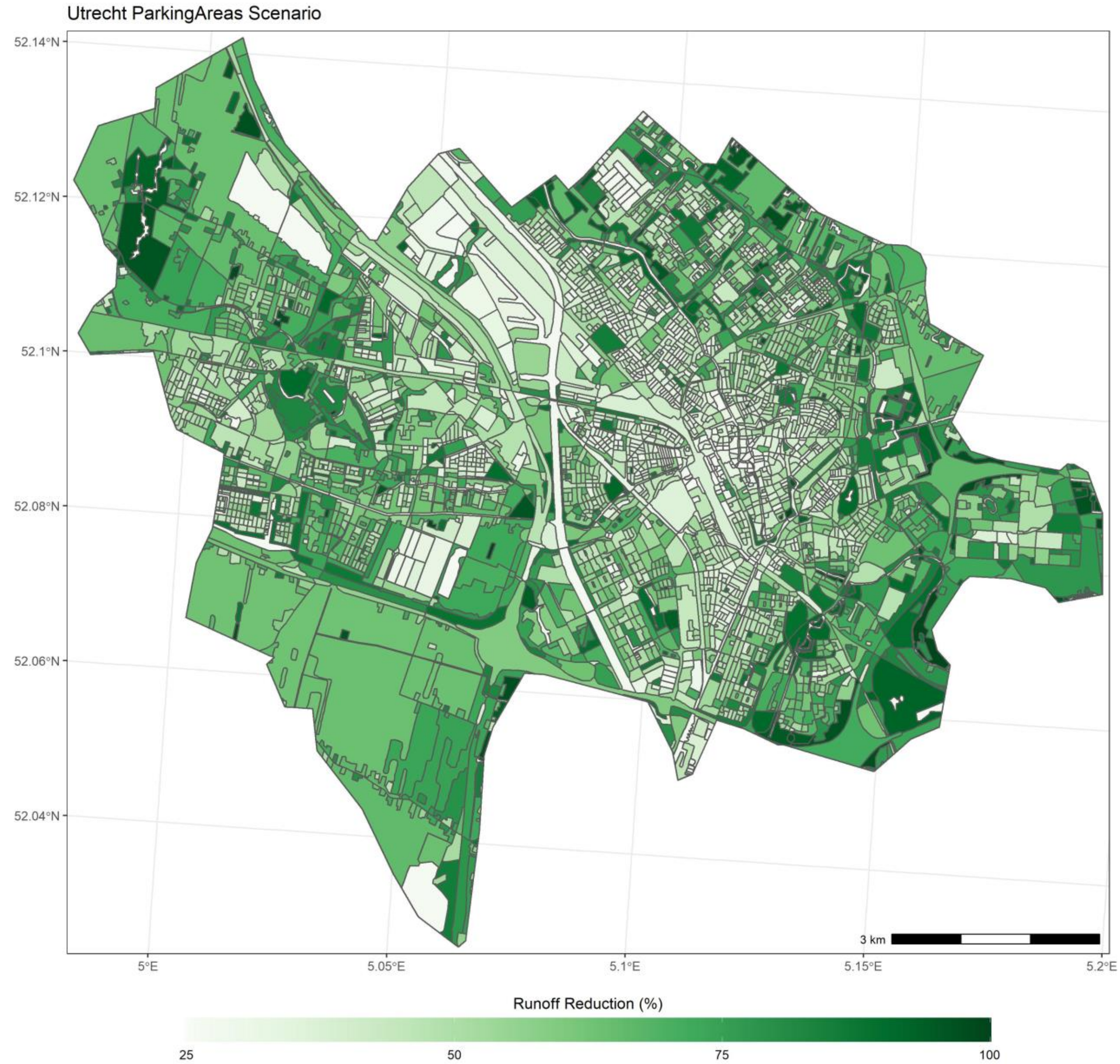

Figure M87. Utrecht ParkingAreas scenario Runoff Reduction (%)

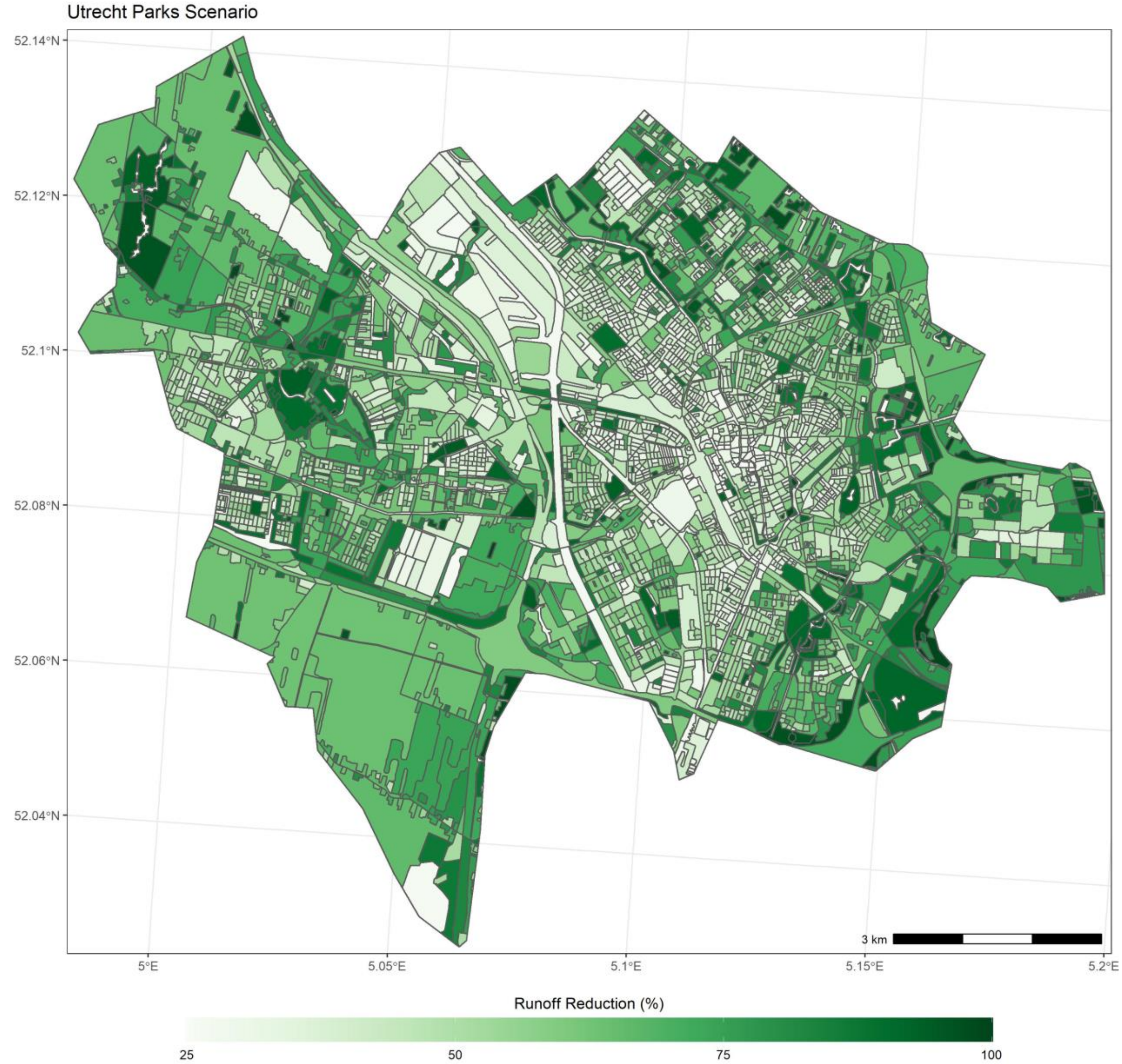

Figure M88. Utrecht Parks scenario Runoff Reduction (%)

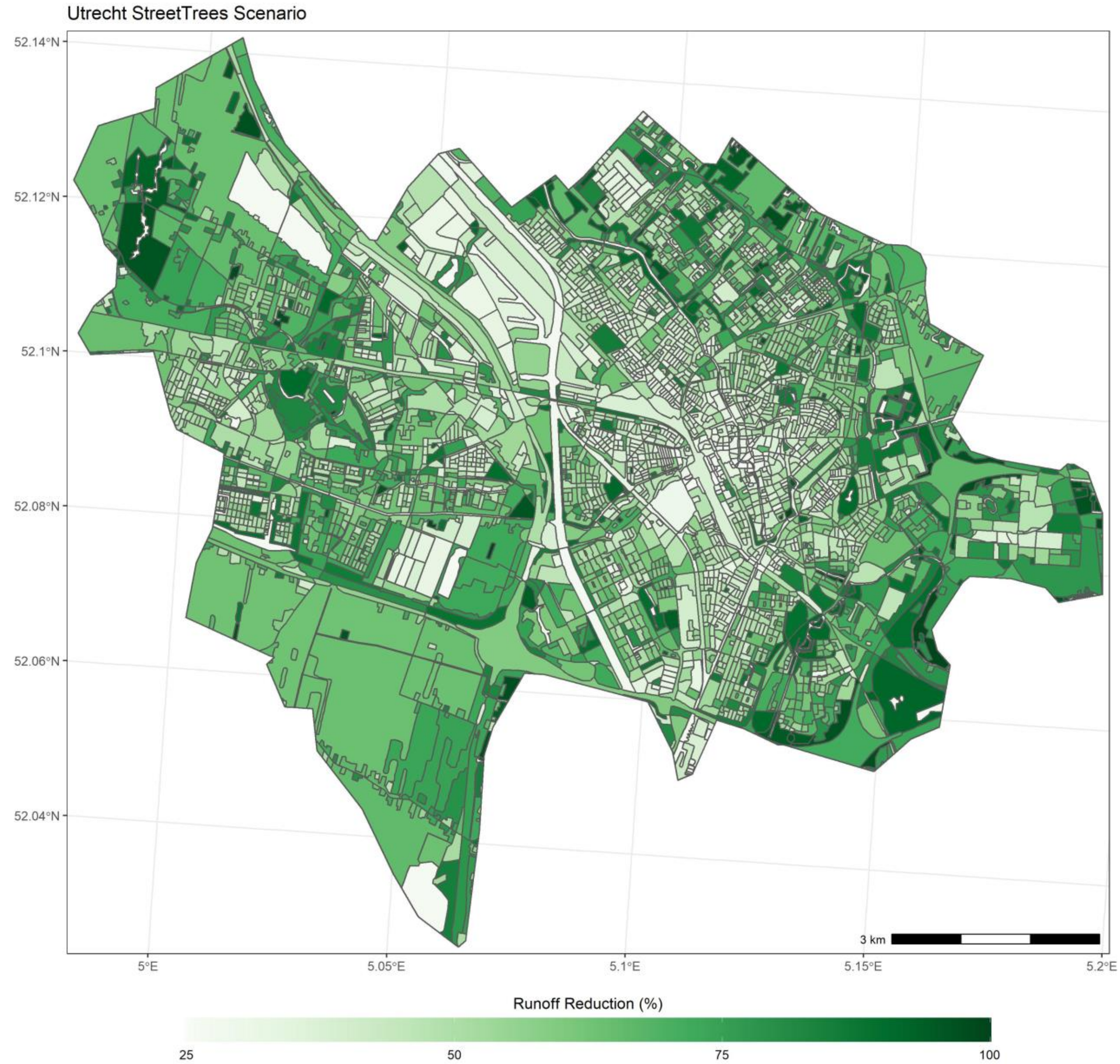

Figure M89. Utrecht StreetTrees scenario Runoff Reduction (%)

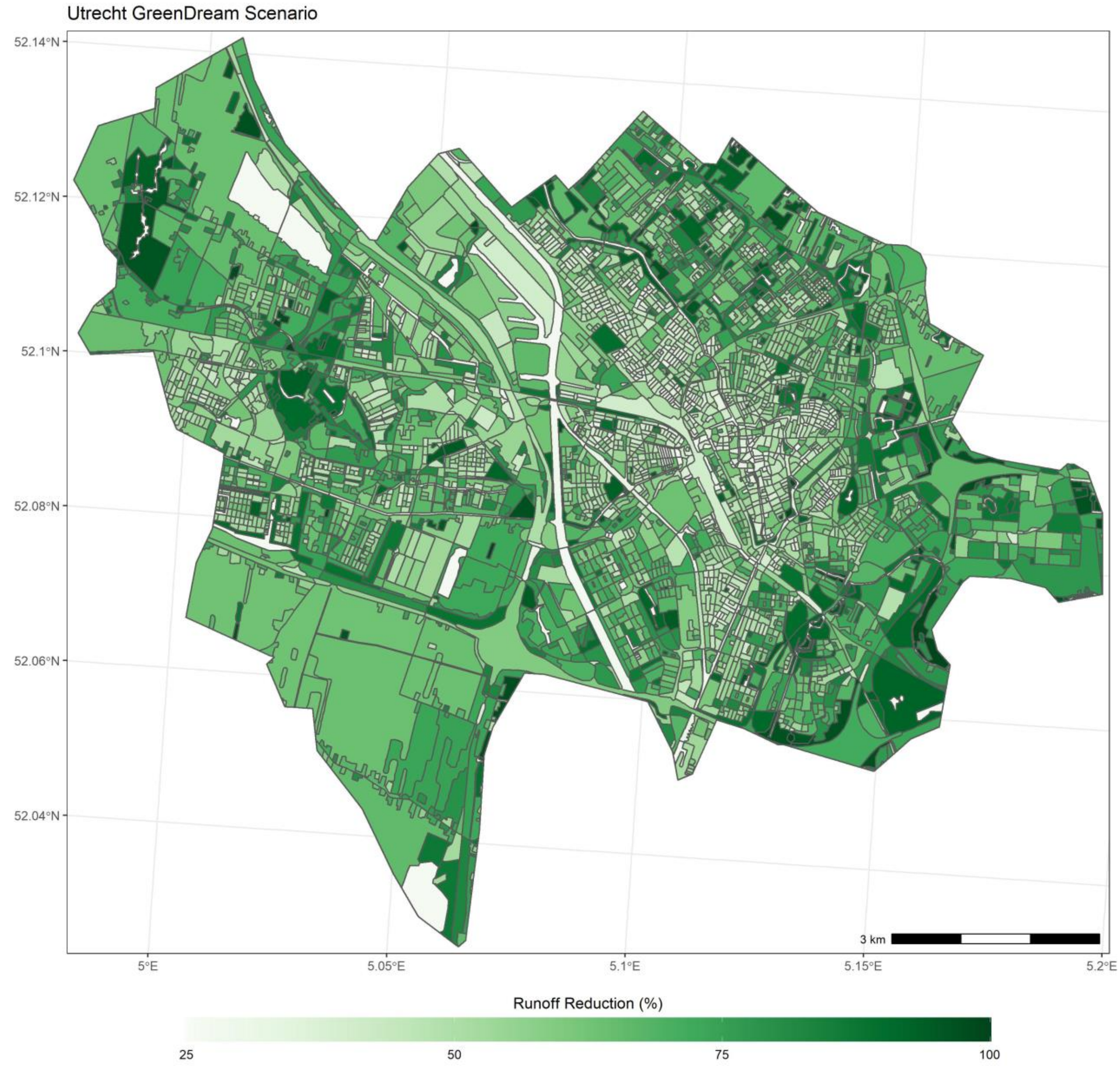

Figure M90. Utrecht GreenDream scenario Runoff Reduction (%)

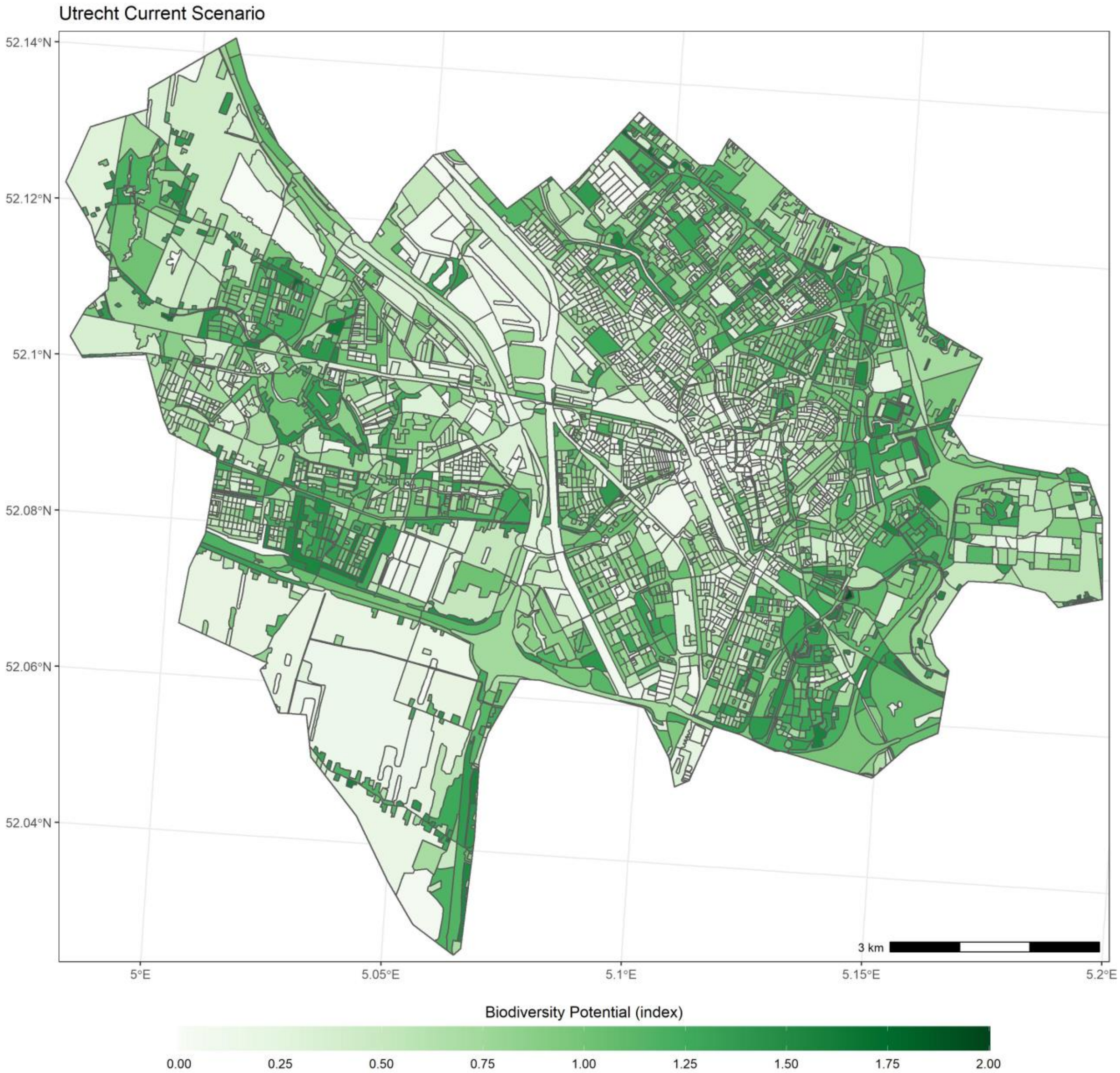

Figure M91. Utrecht Current scenario Biodiversity Potential (index)

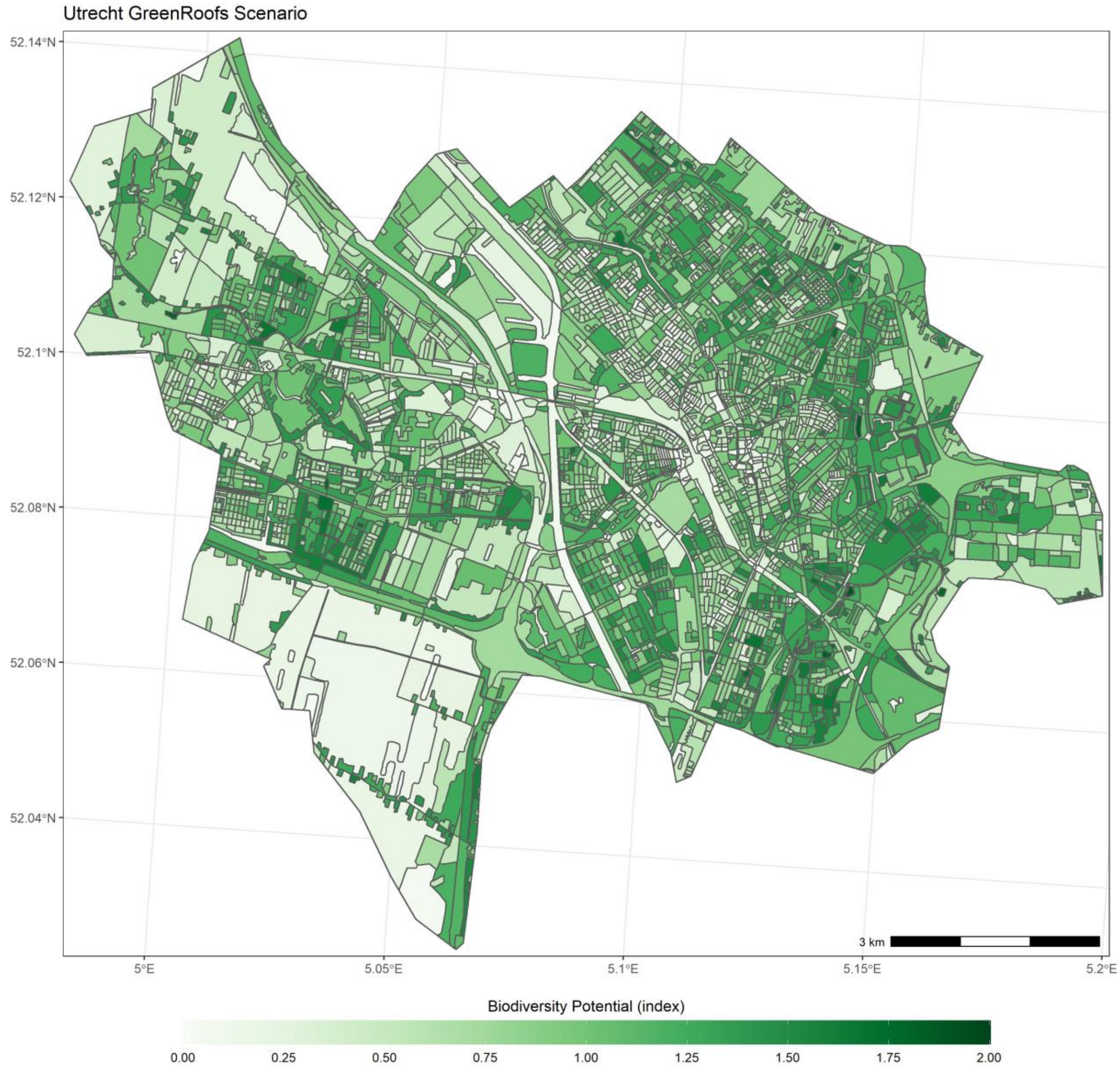

Figure M92. Utrecht GreenRoofs scenario Biodiversity Potential (index)

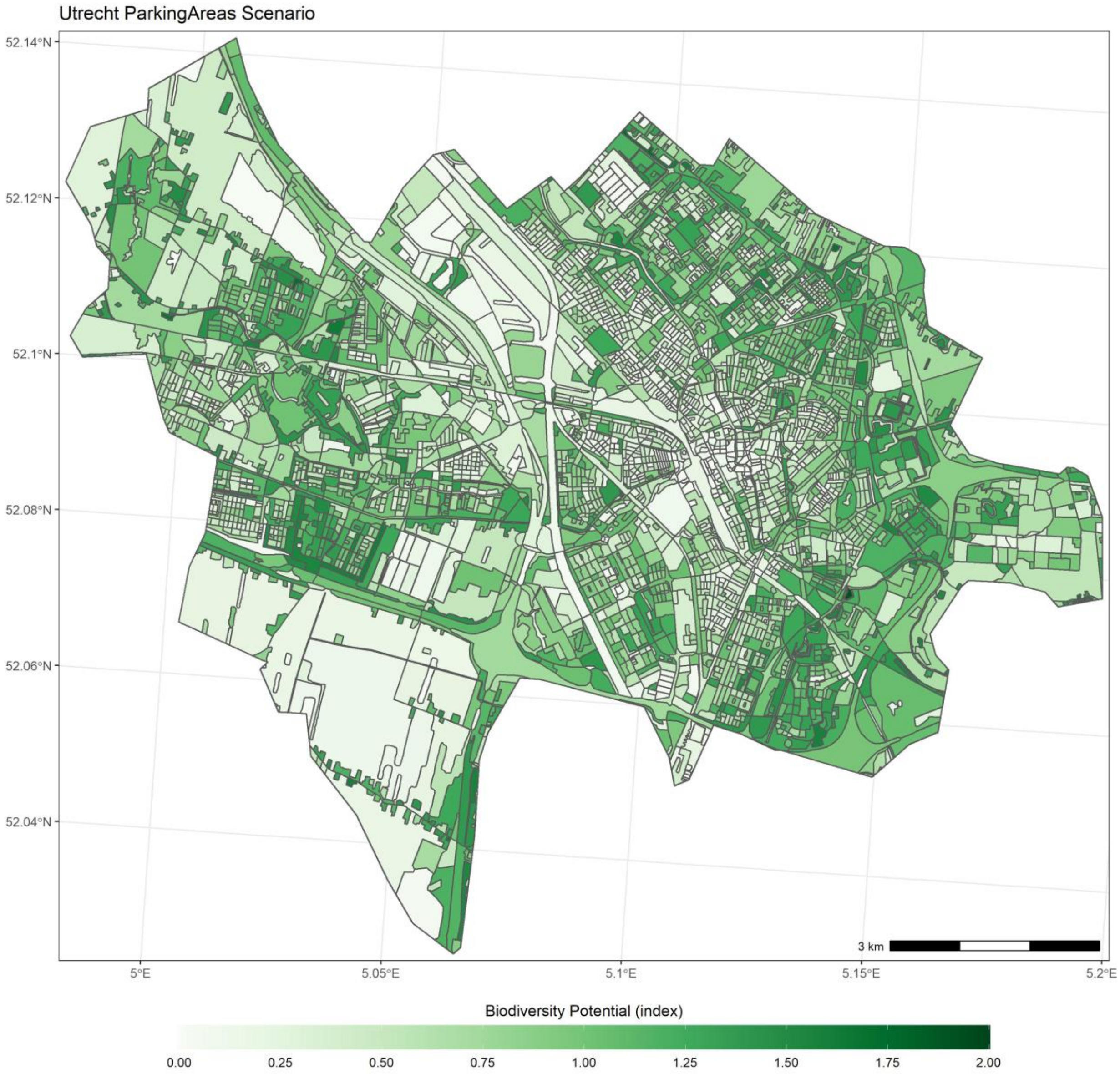

Figure M93. Utrecht ParkingAreas scenario Biodiversity Potential (index)

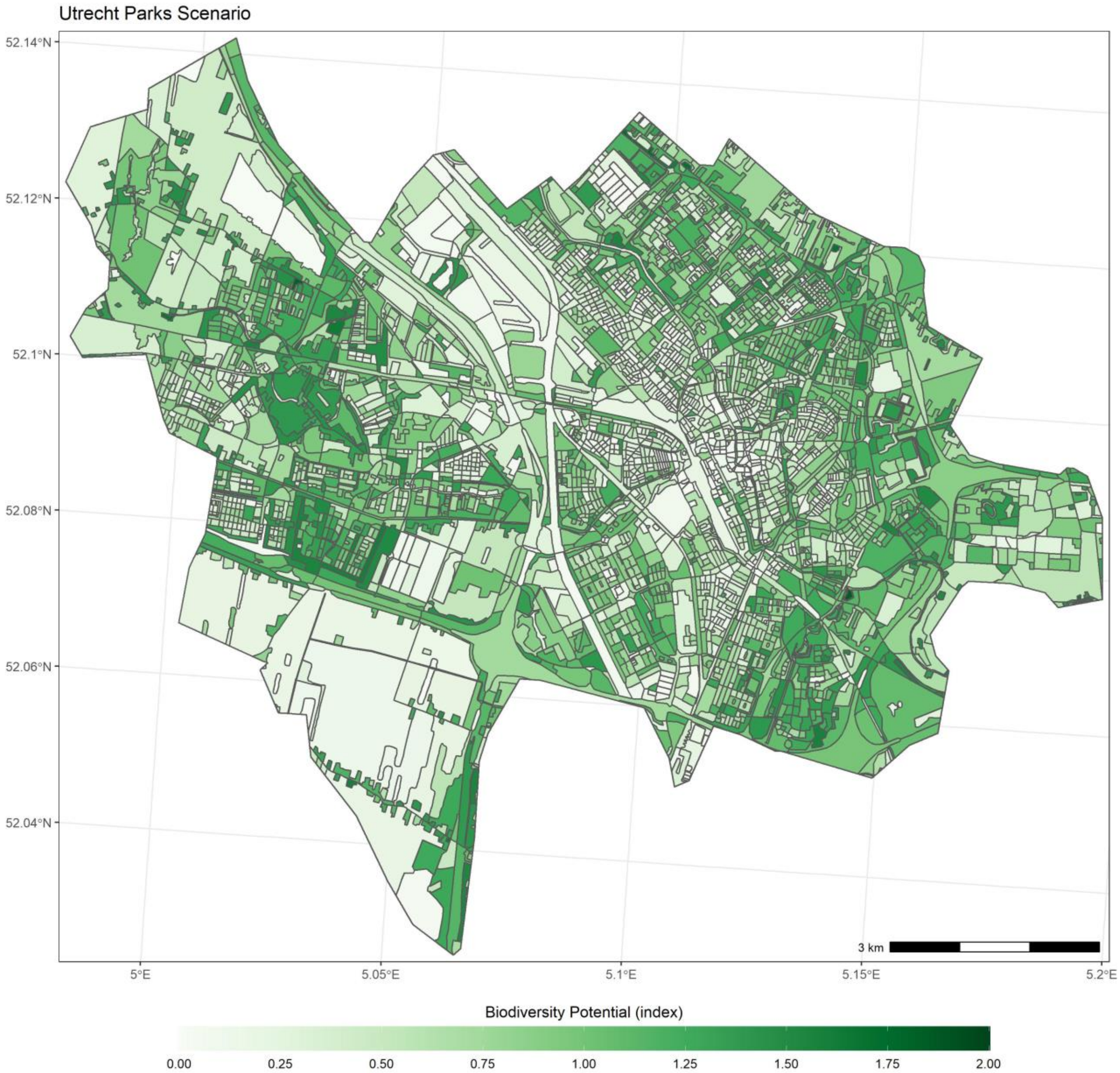

Figure M94. Utrecht Parks scenario Biodiversity Potential (index)

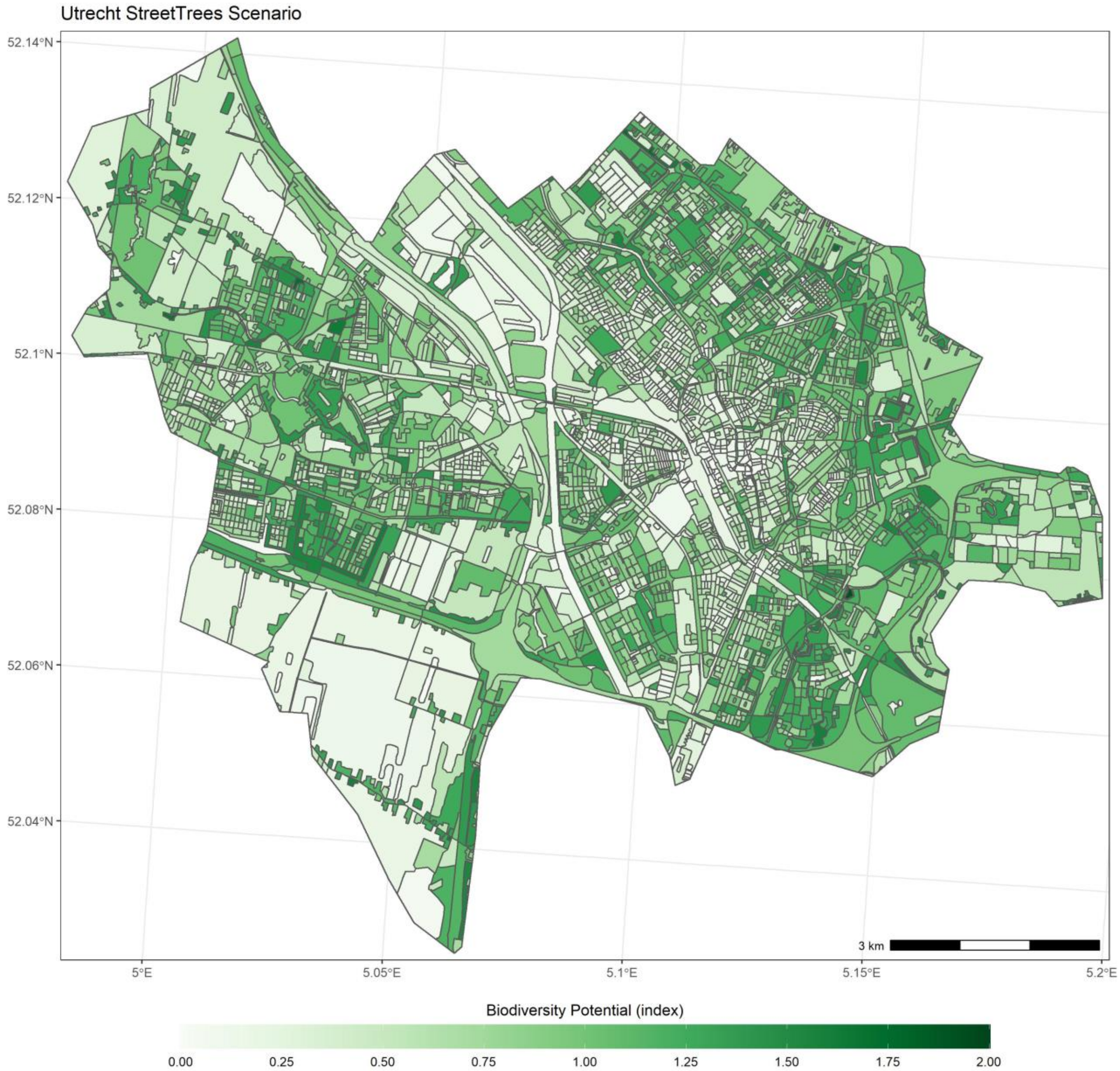

Figure M95. Utrecht StreetTrees scenario Biodiversity Potential (index)

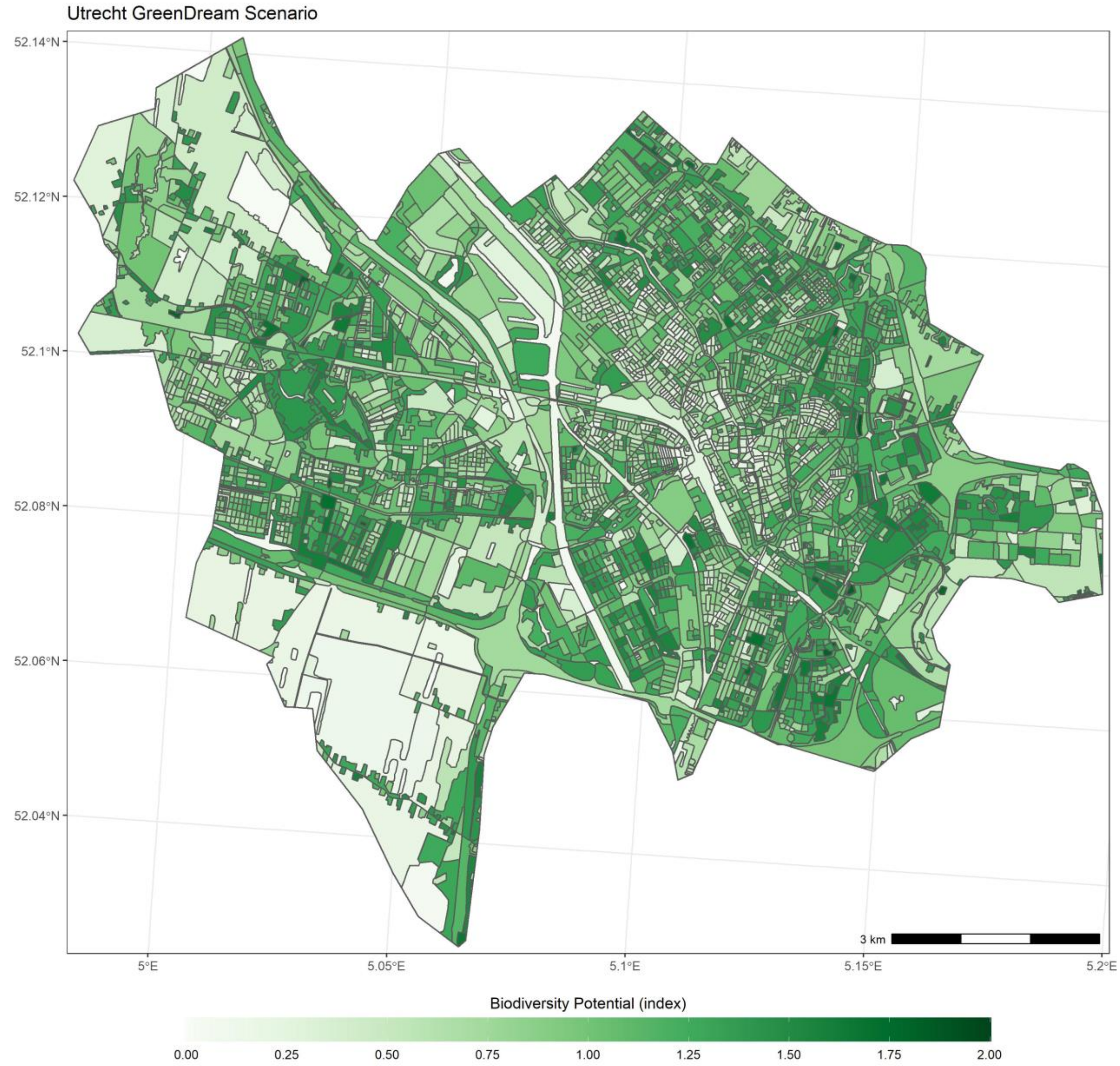

Figure M96. Utrecht GreenDream scenario Biodiversity Potential (index)

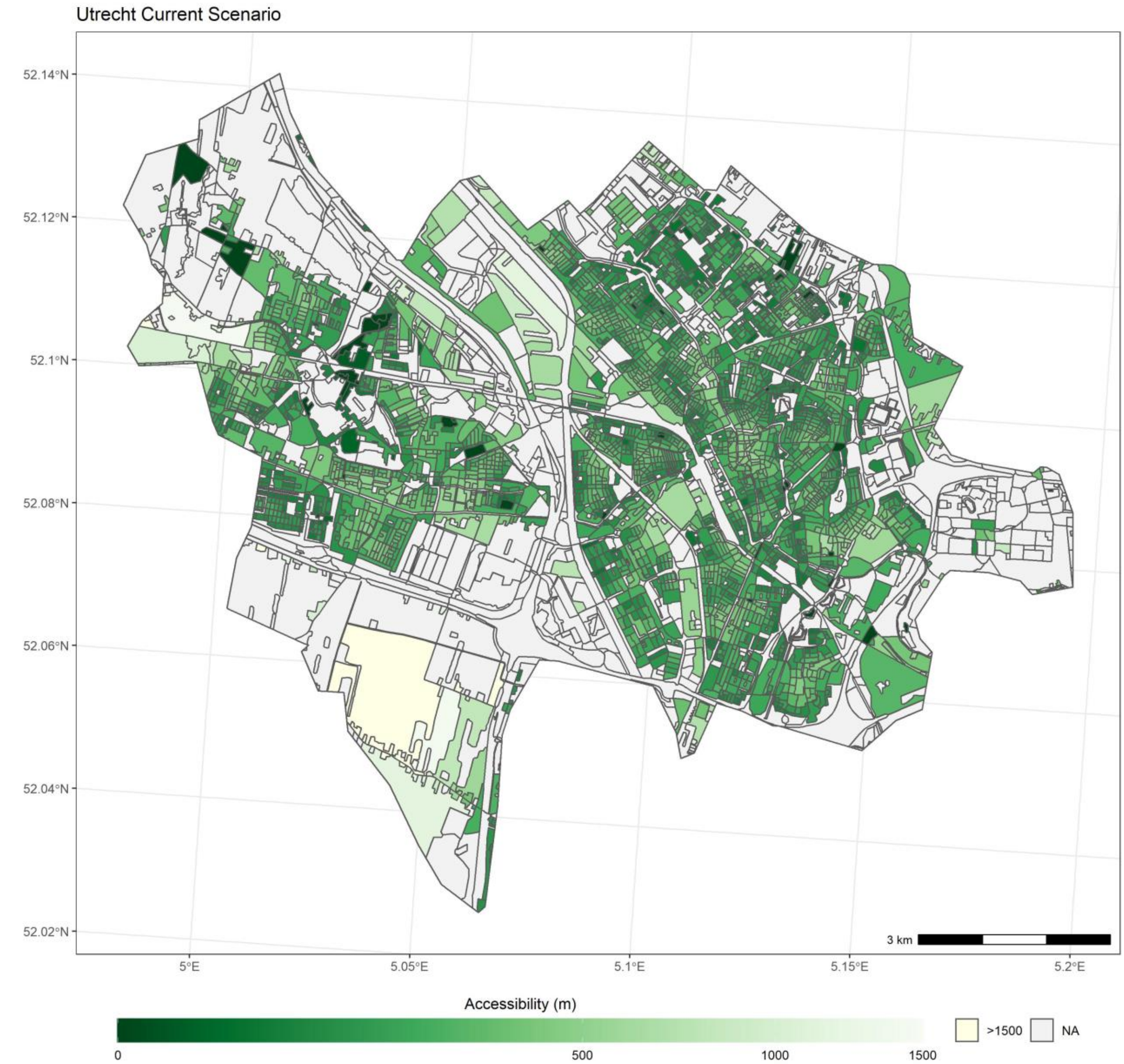

Figure M97. Utrecht Current scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

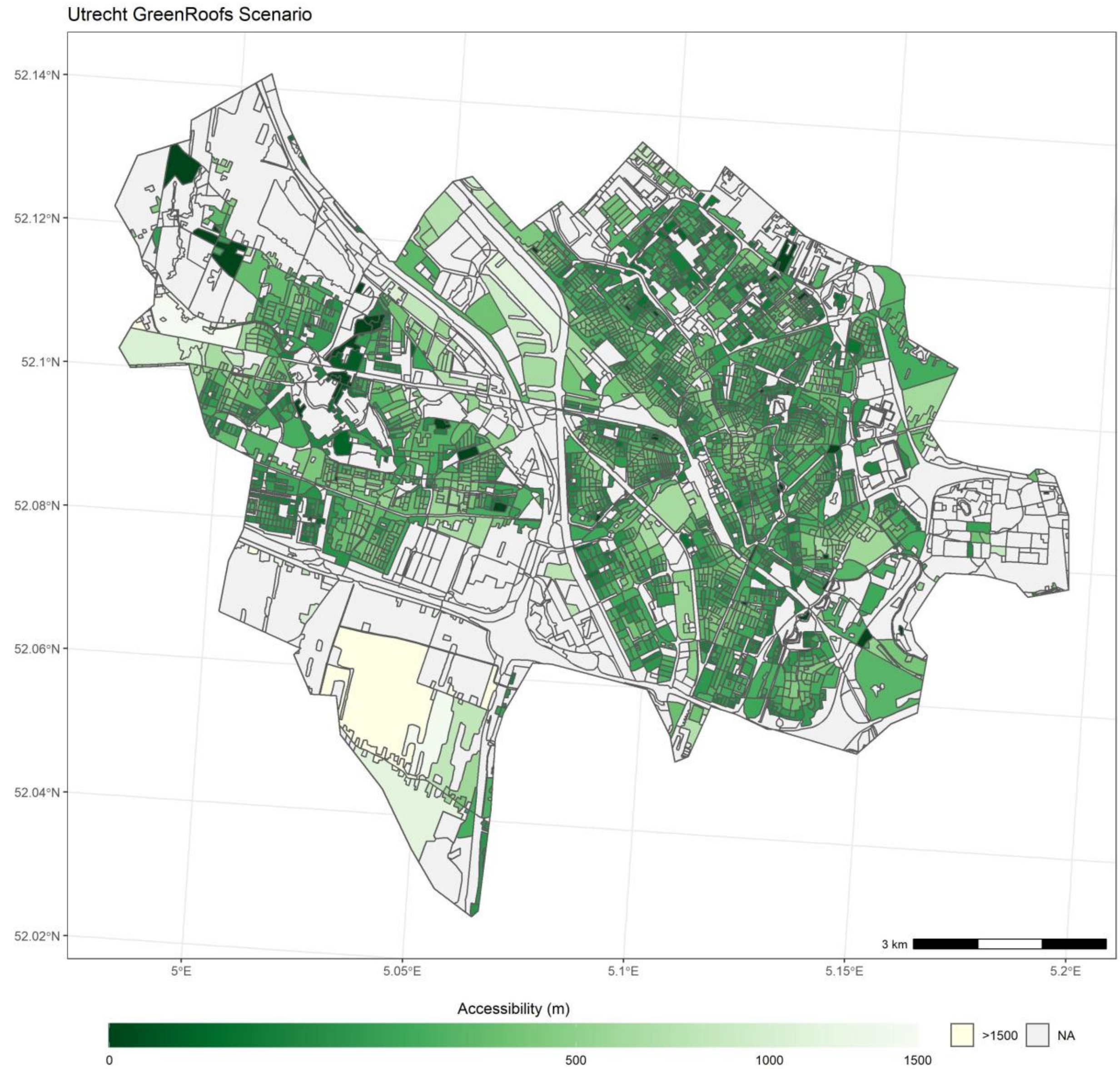

Figure M98. Utrecht GreenRoofs scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

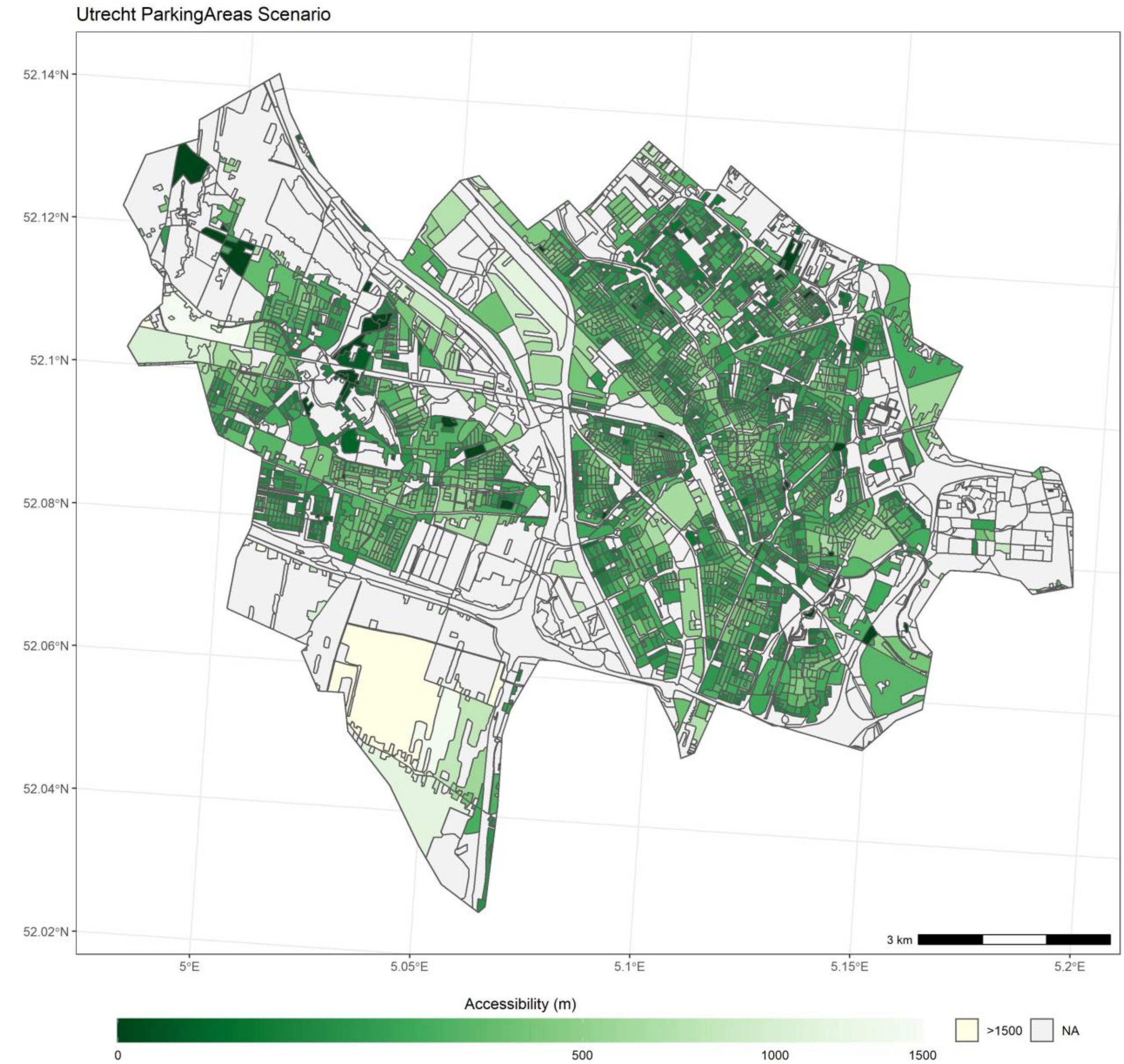

Figure M99. Utrecht ParkingAreas scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

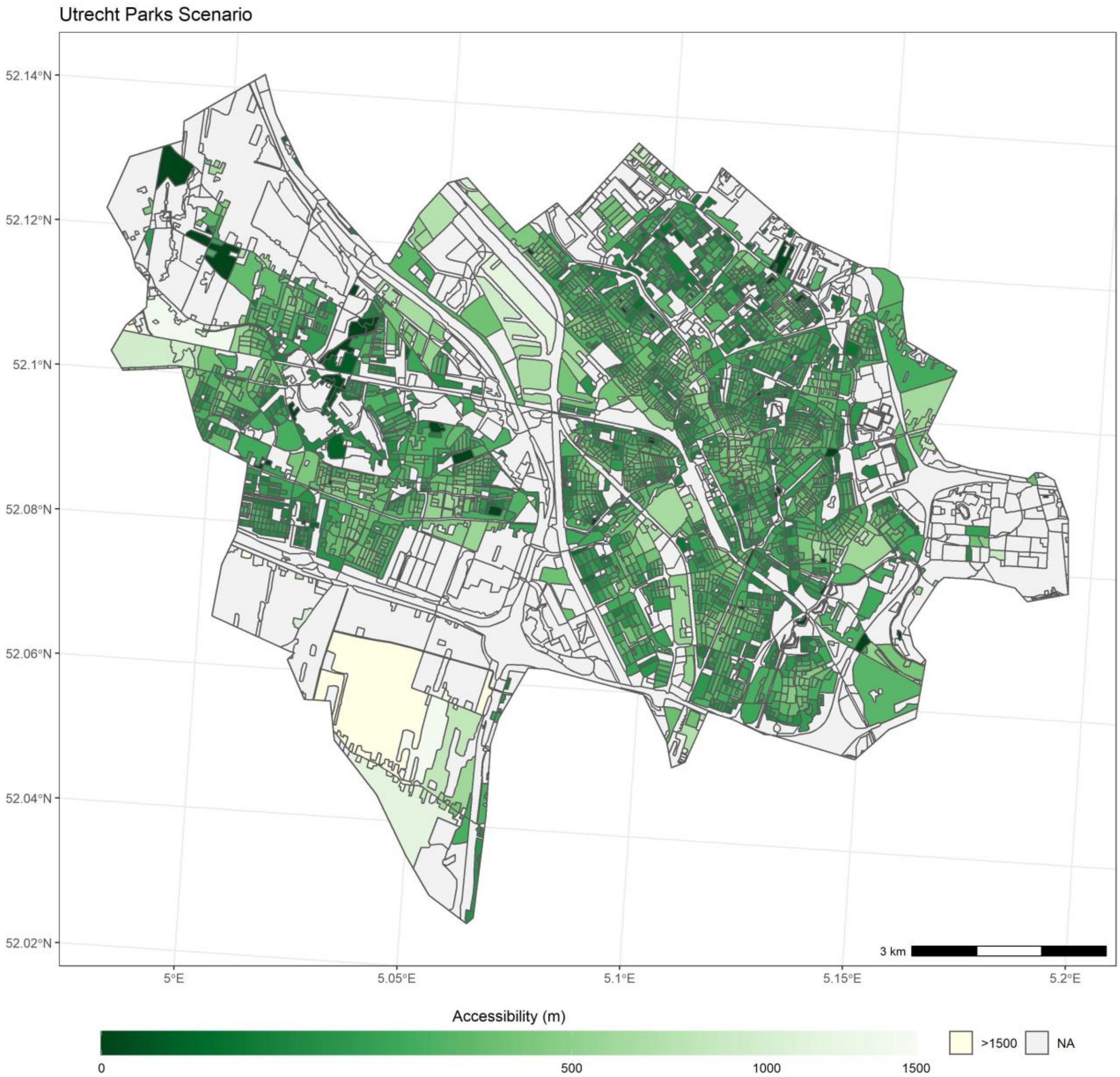

Figure M100. Utrecht Parks scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

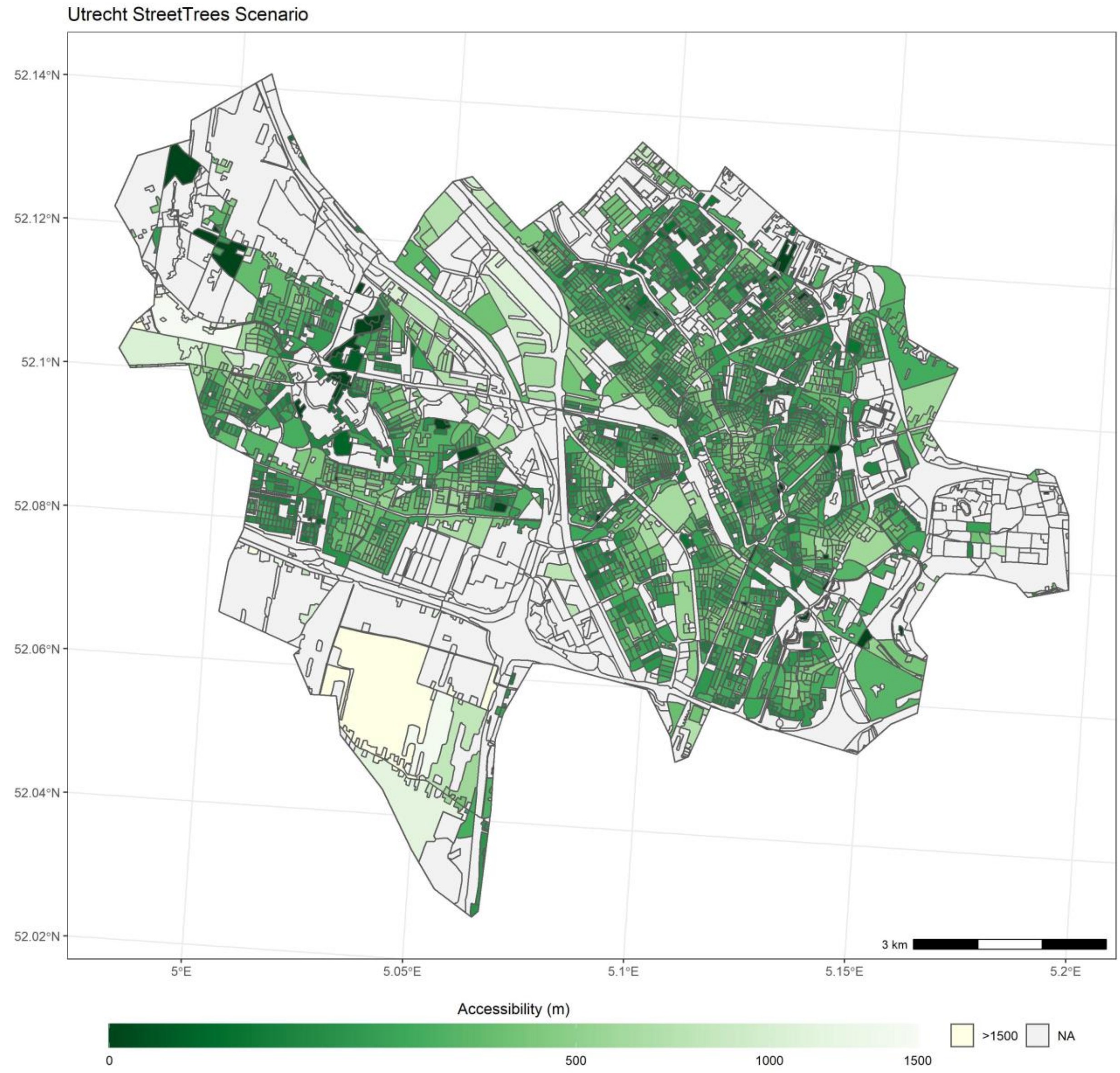

Figure M101. Utrecht StreetTrees scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

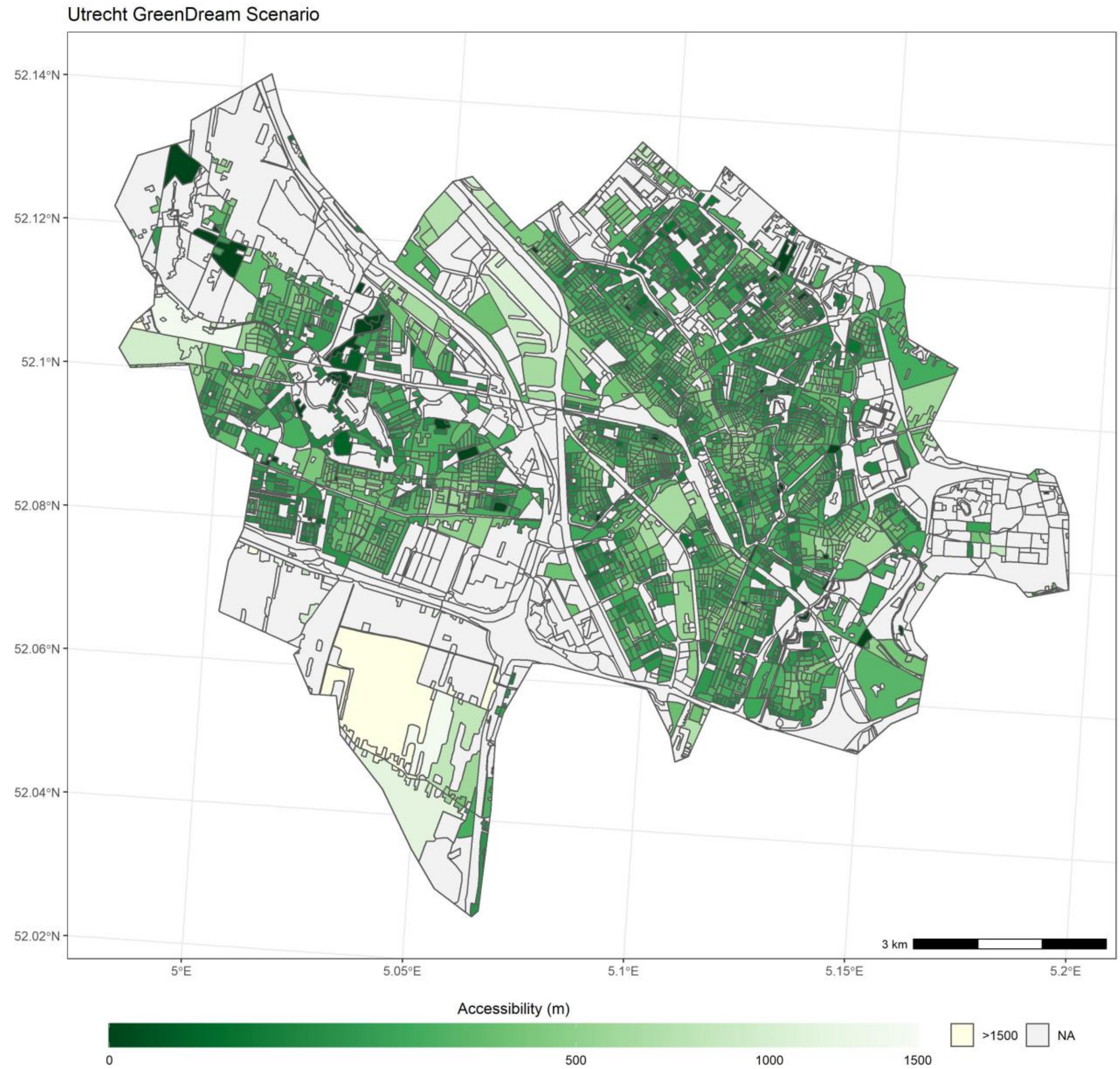

Figure M102. Utrecht GreenDream scenario Accessibility (m). Note the sqrt transformation of the color scale. Grey color indicates missing data because no population in that area

Figure M103. Utrecht Current scenario Greenness (%)

Figure M104. Utrecht GreenRoofs scenario Greenness (%)

Figure M105. Utrecht ParkingAreas scenario Greenness (%)

Figure M106. Utrecht Parks scenario Greenness (%)

Figure M107. Utrecht StreetTrees scenario Greenness (%)

Figure M108. Utrecht GreenDream scenario Greenness (%)