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Prepared by:

Christoph Schröder, Emanuele Mancosu (UMA)

Gerbert Roerink (Alterra)

Date:

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Project Manager:

Marie Cugny-Seguin

European Environment Agency

UNIVERSIDAD DE MÁLAGA

Universidad de Malaga

ETCSIA

PTA - Technological Park of Andalusia

c/ Marie Curie, 22 (Edificio Habitec)

Campanillas

29590 - Malaga

Spain

Telephone: +34 952 02 05 48

Fax: +34 952 02 05 59

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1 INTRODUCTION AND OBJECTIVES

1.1 RATIONALE

Approximately 75% of the population of Europe currently lives in urban areas and urbanization is continuing to increase. As such, urban areas are a hot-spot for greenhouse gas emissions. At the same time, the soil and vegetation of urban green infrastructure provide important carbon sinks that can offset some of these emissions. Thus, urban areas are both drivers of global environmental change and heavily influenced by it, and climate change is one of the major challenges for urban areas in Europe. The report on the European Environment, State and Outlook 2010 (EEA 2010) states that urban designs which, for example, boost urban green infrastructure are fundamental in tackling climate change. Nevertheless, among all benefits Urban Green Infrastructure provide to the human well-being, carbon storage and sequestration is missing in this report. The Urban Adaption Report (EEA 2012) just mentions carbon sequestration of urban green areas as one out of many benefits.

Carbon storage and sequestration is one of the main indicators for measuring ecosystem service provision of urban green infrastructure and the one that has important implications beyond the urban scale as it might have a significant contribution to national carbon accounting. Nevertheless, it is not well investigated and underestimated, so far which is highlighted by the very small number of local case studies, not to speak about the lack of a national wide or even Pan-European estimation.

The EEA responded to this knowledge-gap by asking its European Topic Centre on Spatial Information and Analysis (ETC-SIA) to review existing literature, develop a methodology proposal, do a first spatial analysis for estimating carbon in some selected urban areas across Europe, identify knowledge and data gaps and give some recommendations for future work to do.

1.2 OBJECTIVES

The objective of this document is to provide an overview of the state of the art of carbon storage estimation in urban areas and the presentation of a methodology proposal for a Pan-European estimation. The obtained results are manifold and respond to the task's objectives on different levels. Thus the present document provides:

1) A review of the available scientific literature about the topic
2) Information about the most suitable datasets for calculating carbon storage in urban green areas on a European scale
3) A first methodology for such calculation, focussing on urban trees and forests.
4) The results of the application of this methodology to specific case studies.
5) Recommendations on further improvements and follow-up activities

2 CONTENT OF THE DOCUMENT

The document is structured in the following way:

- **Chapter 3** offers a review on relevant conceptual and methodological literature and on available data sets to be used. The review highlights the deficiencies of existing datasets and explains their potential. Hence, this chapter provides guidance for stakeholders at different scales (local to European) for the application of similar approaches at their specific scale.
- **Chapter 4** specifies some conceptual issues and describes the final methodological approach to calculate carbon storage in urban green areas. The ratio is derived from existing references and implemented for the purpose of the task
- **Chapter 5** provides the results of the first application of the proposed methodology to four selected urban areas in Europe. The results are compared with those of the local reference case studies.
- **Chapter 6** reviews test made with the HANTS dataset for detection and analysis of urban green areas. The results are discussed and a new approach is presented.
- **Chapter 7** provides several recommendations at different levels of application. Particularly, improvements of available data and of the methodology are discussed. Some additional considerations are made aimed at potential users of the methodology. Finally an outlook of possible follow-up activities is given.
- **Chapter 8** lists the used bibliography.

3 LITERATURE AND DATA REVIEW

3.1 LITERATURE REVIEW

The objective of the literature review is to identify the most relevant scientific papers and (on-going) research projects that deal with the complexity of carbon sequestration and storage in urban areas (see discussion and clarification of terminology above). In a first section some conceptual papers are presented that highlight the importance of urban ecosystem services in the current discussions of mitigation and adaptation of urban areas to climate change. In this context, references addressing the role of urban areas in carbon sequestration and storage, particularly urban green areas are elaborated in this document. In the second sub-chapter, the components of green urban areas with respect to carbon sequestration and storage are identified and explained. In the last sub-chapter, a summary on recent studies related to carbon sequestration and storage in urban areas on different scales i.e. local and regional is provided.

3.1.1 Urban green areas and ecosystem services

As will be shown throughout the review, there are few peer-reviewed studies about carbon storage and sequestration in Europe, basically, because of the high uncertainties attached to such an approach. In order to fill this gap, different European research projects have been set up to focus on urban ecosystem services in general and carbon sequestration and storage in particular aiming at advancing in the conceptual and technical development to measure and assess this issue.

Recent research about the role of urban ecosystem services has produced a wide range of theoretical findings, methodological approaches and practical guidelines over the last few years. On the European level, different research projects are currently addressing the issue of ecosystem services in urban areas. Both the BiodivERsA research and dissemination project URBES (Urban Biodiversity and Ecosystems Services[1]) as well as the FP7 project TURAS (Transitioning towards Urban Resilience and Sustainability[2]) focus on the ecosystem services which urban green areas are providing. On a global scale, a global assessment of urbanization, biodiversity and urban ecosystem services which summarizes the most important challenges and opportunities of this topic around the globe, has been recently published (Elmqvist et al. 2013). As part of this assessment, carbon sequestration in urban ecosystems, particularly by trees, is considered as one of the central regulating services (Gómez-Baggenthun et al. 2013, Gómez-Baggenthun & Barton 2013, TEEB 2011) providing human well-being in urban areas. Within this context, urban green areas are the fundamental basis for urban ecosystem service provision (Kabisch & Haase 2013).

Although urban expansion rates in Europe are relatively low in comparison with the global average rate, still an annual growth rate of about 2,5% of urban land can be observed (Seto, Fragkias,

[1] http://www.urbesproject.org

[2] http://www.turas-cities.org/

Güneralp, & Reilly 2011). In this context, urban green areas – broadly defined as any vegetation found in the urban environment, including parks, open spaces, residential gardens, or street trees - are of fundamental importance, but also highly threatened by compaction and urban sprawl. Regarding the distribution of urban green areas within urban zones, a clear difference between Northern and Central European cities (20-40% of green urban spaces respectively) and Southern Europe (10%) has been identified (Fuller and Gaston 2009). In terms of change, Kabisch & Haase (2013) detected an increase in urban green spaces in Western and Southern Europe, whereas urban green spaces declined in most of Eastern European cities. The enhancement and expansion of green urban areas are some out of different complementary strategies to combat climate change in urban areas and part of the strategy to protect, restore and sequester C in the above and below-ground biomass and in the soil C pool (Ral 2012).

3.1.2 Role of urban areas in the carbon cycle

The role of urban areas in the Global Carbon Cycle has long been underestimated and even neglected in global modelling approaches. But, urban areas play a significant role in the Global Carbon Cycle as source of carbon emission due to the effects of urban sprawl against other land use types. In this sense, it is expected that a further 1.2 million square kilometres of land will be converted to urban land use by 2030, resulting in a loss of carbon storage in natural vegetation of about 1,38 PgC (Seto, Güneralpa & Hutyra 2012). Urban areas are responsible for more than 70% of global CO2 emissions and transform the structure of the local carbon flows over considerably larger areas than what they occupy (Svirejeva-Hopkins, Schellnhuber & Pomaz 2004). On the other hand, urban areas have a large variety of pools storing carbon where urban green areas play a specifically important role. This potential of urban areas in storing C is generally underestimated. A study states that US settlements store 10% of the total C stored in all US ecosystems (Churkina 2012). One of the reasons is the relative high share of green areas in comparison to impervious in urban areas. The carbon cycle between sources and sinks in urban areas is intrinsically coupled, thus the climate regulating effects of urban carbon pools have to be taken into account on the Global Carbon Cycle (Churkina 2008).

3.1.3 Case studies for carbon storage in urban green areas

Carbon in urban green areas is stored in the form of above ground and below ground biomass. Above-ground, trees make up the major part of biomass compared to turf grass, lawns and gardens. For below ground, the soil carbon pools has been identified as one of the most relevant carbon pools in urban areas, even below build-up areas (Brown, Miltner & Cogger 2012). Nevertheless, for the present methodology only above ground vegetation will be taken into account, i.e. trees, grass, bushes and gardens. Although urban grassland biomass is small compared to tree-related biomass due to the fact that growth will balance die back and cut back (Strohbach, Arnold & Haase 2012), on a continental level they may sum up an important area. In most studies, the urban soil carbon pool is not considered because of the uncertainties related to the estimations of below-ground biomass (Hutyra, Yoon & Alberti 2011), underestimating the overall carbon storage potential of urban areas.

Generally, there is a major difference between urban green areas and other forests and grasslands in terms of growth rates, species composition and management. Urban green areas are intensively managed and allocated carbon is constantly removed, leading probably to lower stocks and higher fluxes of carbon. These characteristics have to be taken into account when defining the overall methodology and specific conversion factors.

As mentioned in the introduction, it has to be emphasized that only direct carbon storage by biomass will be considered. Factors such as avoided C emissions from energy conservation or associated with tree or park maintenance will be neglected, mainly due to lack of consistent, Pan-European data. . A number of papers have dealt with this kind of lifecycle analysis with promising results, but mainly applicable at the local scale (e.g. Strohbach et al. 2012, Scharenbroch 2012).

3.1.3.1 Carbon storage in urban trees and forests

Trees are the most important pools for carbon storage in urban settings. It has been shown that urban forests, - defined as the sum of all woody and associated vegetation in and around dense human settlements - can sequester and store a large amount of carbon in cities (Strohbach et al. 2012, Strohbach & Haase 2012, Nowak & Crane 2002, Hutyra et al. 2011, Lamlom & Savidge 2003). There are different methodological approaches for estimating tree biomass and carbon content in urban areas. Depending on the scale of the analysis, direct sample measurements serve as date input for local or regional scale models. Alternatively, local sample points or urban forest inventories are extrapolated combined with land-use data and conversion coefficients are applied in order to obtain regional estimates.

Local studies rely heavily on field samples, forest inventories and, to a lesser degree, on areal or satellite images. The following parameters of forests are usually taken into account in carbon storage (above-ground) calculation: Tree species, annual increment, biomass (living and dry), deadwood, litter mass, organic soil. Local case studies make use of all these parameters for a comprehensive estimation of carbon storage by urban trees. Regional studies often lack detailed information on tree species and their annual increment which limits the estimation of carbon storage on this scale.

The biomass of trees is commonly estimated with allometric equations. They are based on the physiological relationship between diameter at breast height (DBH) and tree. Allometric equations vary between species and may also vary within species due to site conditions (Nowak & Crane 2002). In urban settings, trees have different growing conditions than those in closed forest stands, but only few urban allometric equations exist so far (Strohbach et al. 2012) which limits its application.

Strohbach & Haase (2012) provide a comprehensive review of existing local studies on carbon storage around the globe. They highlight that there are only 4 published studies in Europe (see Table 1 and section 5.1 for further details), besides a higher number of local estimation of carbon storage and sequestration in the US.

City and reference area	Carbon storage	BGR	Method	Source
Leipzig, Germany (Municipal boundary)	11.8 (average)	Continental	Above-ground carbon in trees, stratified random sampling across land cover	Strohbach & Haase 2012
Karlsruhe, Germany (Municipal boundary)	32.3 (average), 12.8 (urban area without forest)	Continental	Above-ground carbon in trees, inventory data of forests and linking field data to remote sensing material	Kändler et al. 2011
Leicester, UK (Municipal boundary)	31.6 (average)	Atlantic	Above-ground carbon in vegetation, stratified random sampling across land cover and land ownership	Davies et al. 2011
Barcelona, Spain (Municipal boundary)	11.2 (average)	Mediterranean	Above- and below-ground carbon in trees, UFORE model and field data	Chaparros & Terradas 2009
				adapted and simplified from Strohbach & Haase (2012)

Table 1: Comparison of local studies on urban carbon storage in vegetation in Europe

These local studies follow similar approaches: Stratified random sampling across land cover types, using different dimensions (diameter at breast height, height, diameter at ground level) as well as aerial photo information are used to calculate the biomass content of a tree, applying species specific biomass equations or average ratios. These plot information is then extrapolated to similar land cover types (Strohbach & Haase 2012, Kändler et al. 2011). Other studies use sample data as input for modelling approaches at local scale (e.g. Brack 2002 for Canberra, Chaparro & Terradas for Barcelona) that additionally may predict sequestration scenarios for different development options.

In other cases a combination of these data sources is used. Davies et al. (2011) use both vegetation surveys and GIS based land cover maps for quantifying the above-ground carbon storage in Leicester (UK). Based on the tree-by-tree calculation of above-ground dry-weight biomass and the tree density in the survey plots, the above-ground carbon store associated with trees in each of the nine vegetation categories were estimated and, subsequently, for the city as a whole. Similarly, Liu & Li (2012) use a combination of satellite images to detect the forest patches and a field survey in order to determine tree species and characteristics (mainly diameter at breast height and health conditions). For each species a specific biomass equation is applied which gives us the carbon content in biomass that is then extrapolated to the whole city area based on the satellite images. Furthermore, if two years are available the Carbon sequestration can be estimated as the difference of C stored between year *y* and year *y + 1*, based on the annual growth rates of tree DBH.

These local level approaches can hardly be applied to **regional scale analysis** due to the lack of suitable datasets (e.g. tree inventories, comparable urban forest maps). Nevertheless, the local studies provide the necessary parameters to be explored and methodological approaches on how to relate land cover information and survey data that allows for such extrapolation.

Nowak and Crane (2002) and Nowak et al. (2013) show how to estimate the carbon storage of urban trees in the conterminous USA based on local field data and applying a bottom-up approach: Based on C storage data for individual trees in each city the total carbon storage and sequestration for the city is determined. To estimate the carbon values of urban trees nationally, the total carbon storage and sequestration value of each city is divided by the total city tree cover (m^2) to determine the average carbon density value per unit tree cover ($kg \cdot C \cdot m^{-2}$ cover). The median standardized carbon value ($kg \cdot C \cdot m^{-2}$ cover) was then multiplied by total urban tree cover in the conterminous USA to estimate the national carbon totals for urban trees. Total urban tree cover estimates were based on very high resolution satellite imagery. Due to the lack of available local reference studies and comparable C storage data for individual trees for Europe, this bottom-up approach cannot be considered for the task.

Zheng, Ducey & Heath (2013) follow a top-down approach, using land-cover maps and HRL forest layers to estimate forest carbon sequestration in a regional setting (Northern New England, USA). Through the combination of these data with a tree canopy dataset, treed areas in non-forest land cover classes could be detected. Based on forest inventories, carbon storage ratios were calculated.

3.1.3.2 Turf grass and lawns

Methodological approaches to estimate turf grass, garden and lawn biomass and their carbon content are rare. Apart from other services turf grass provides (e.g. urban heat dissipation, erosion control, aesthetic benefits), significant carbon sequestration (Qian & Follett 2012). Nevertheless, the high biomass productivity of turf grasses is strongly related to management impacts such as mowing, irrigation and fertilizing and depends on the grass species used. Hence, the biomass productivity and related soil organic content in turf grass use to be higher in these managed grasslands than in its native counterparts or agricultural ecosystems.

Their overall area and its role on carbon sequestration are seen as small compared to urban trees (Strohbach et al. 2012), but on a continental scale they account for an important amount of carbon storage. Turf grass lawns capture carbon dioxide from the atmosphere through photosynthesis and store it as organic carbon in soil, making them important “carbon sinks”. But despite this fact, the greenhouse gas emissions from fertilizer production, mowing, leaf blowing and other lawn management practices are similar to or greater than the amount of carbon stored by ornamental grass in parks (Townsend-Small & Czimczik 2010). Due to this complexity and the lack of suitable, Pan-European data about these emission effects, carbon storage in urban grassland was not considered in this task.

As will be shown in section 4, the development of the estimation methodology of carbon storage depends fundamentally on (a) the existing local reference studies and (b) on available datasets on the European scale.

3.2 REVIEW OF AVAILABLE AND RELEVANT DATASETS

As mentioned earlier, different types of land cover and inventory maps are used on regional and continental scales, in combination with thematic layer with high resolution on forest and/or grassland, and local to regional statistical data on forest stands. Table 2 provides the available and relevant datasets at the European scale.

Dataset	Scale / Resolution	Content	Usability
Urban Atlas	1:10000 (MMU 0,5 ha)	Land use and land cover data for Large Urban Zones	Identification of green urban areas and other related land cover classes
JRC Forest Layer	25 m	Forest cover map with classes. • Broadleaved Forest • Coniferous Forest • Non-forest, Water • Clouds/snow and no data	Detection of forest types in green urban areas
HRL Imperviousness	20 m	Degree of Imperviousness 0 – 100%	Definition of low imperviousness patches in urban areas to identify grasslands/gardens
HRL Grassland	20 m	Permanent grasslands	Under development, could be used for grassland detection in urban areas
Urban Morphological Zones (UMZ)	1:100000	Urban morphological zones (UMZ) are defined by Corine land cover classes considered to contribute to the urban tissue and function	Delimitation of urban areas
Local Administrative Units (LAU)	1:100000	LAU level (LAU level 2, formerly NUTS level 5) consists of municipalities or equivalent units in the 27 EU Member States.	Municipal boundary

Table 2: Available datasets for urban green areas

3.2.1 Land cover data sets

Although CORINE Land Cover, the most prominent Pan-European dataset on land cover has a separate land cover class for "Urban green areas", its spatial resolution is not high enough to evaluate urban green spaces at smaller scale.

Instead, the European Urban Atlas has been developed for this purpose. Urban Atlas is part of the local component of the GMES/Copernicus land monitoring services. It provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings (more than 100.000 inhabitants as defined by the Urban Audit) for the reference year 2006 at a scale of 1:10.000, with a minimum mapping unit of 0.25 ha for urban uses and 1ha for non-urban uses. The relevant Urban Atlas classes for the analysis of green urban areas are:

- 1.4.1 Green urban areas
- 1.4.2 Sports and leisure facilities

- 2 Agricultural areas, semi-natural areas and wetlands
- 3 Forests

According to the Urban Atlas mapping guide, urban green areas are defined as public green areas for predominantly recreational use such as gardens, zoos, parks, castle parks, as well as suburban natural areas that have become and are managed as urban parks. Forests or green areas extending from the surroundings into urban areas are mapped as green urban areas when at least two sides are bordered by urban areas and structures, and traces of recreational use are visible. This is the major distinction to the Forest class (3) that extends in suburban areas with no topological relation to urban structures.

Green urban areas do not include class 142 “sports and leisure facilities” as they cover a number of sealed areas, such as race courses and areas of sport compounds. The same holds true for other uses with high percentage of impervious areas like cemeteries, included in class 1.2.1 “Industrial, commercial, public, military and private units” or even airports (class 1.2.4). Nevertheless, these areas definitely contain biomass pools that have to be estimated by using other information sources.

In any of these urban classes, a distinction is made between land cover, i.e. grassland, bushes, trees, etc.. For the purpose of the estimation of carbon storage it is crucial to know the land cover characteristics of the areas. So, high resolution information has to be added in order to identify the actual land cover of these areas.

3.2.2 Thematic layers with high resolution

The JRC Forest Layer (Kempeneers et al. 2011) is a Pan-European Forest / Non Forest Map with target year 2006, with 25m spatial resolution, derived from LISS III, SPOT4/5 and MODIS satellite imagery and Corine Land Cover 2006 data. It therefore coincides with the Urban Atlas reference year. It includes the classes: Broadleaved Forest, Coniferous Forest, Non-forest, Water, Clouds/snow and no data.

Those areas are defined as “forest” which are occupied by forest and woodland with a vegetation pattern composed of native or exotic trees. The threshold for forest detection is 30% of crown cover in the 25m pixel. Woodlands with trees smaller than 5 m height are expressively excluded.

The JRC Forest Layer enhances the information about tree cover within the city, providing detailed distinction of tree patches within the Urban Atlas class “Green Urban Areas” and other types of land uses included in other classes (such as cemeteries, sport and leisure facilities).

Nevertheless, there are some problems with the use of JRC Forest Layer in urban areas. To begin with, forest patches with canopy closure less than 30% are not classified as forest in the map. Very open stands in urban settings or single street trees are therefore not recognised. As could be detected by comparing the Forest layer with available aerial images (Bing maps), only some bigger tree patches in squares, parks and along streets urban areas are detected, underestimating the total urban tree cover (see examples in Figure 1).

Figure 1: Forest layer deficiencies – underestimation of tree cover

Due to similarities of spectral signature, the JRC Forest Layer even detects forest patches where no trees are present, as this example of Barcelona's port shows (see Figure 2)

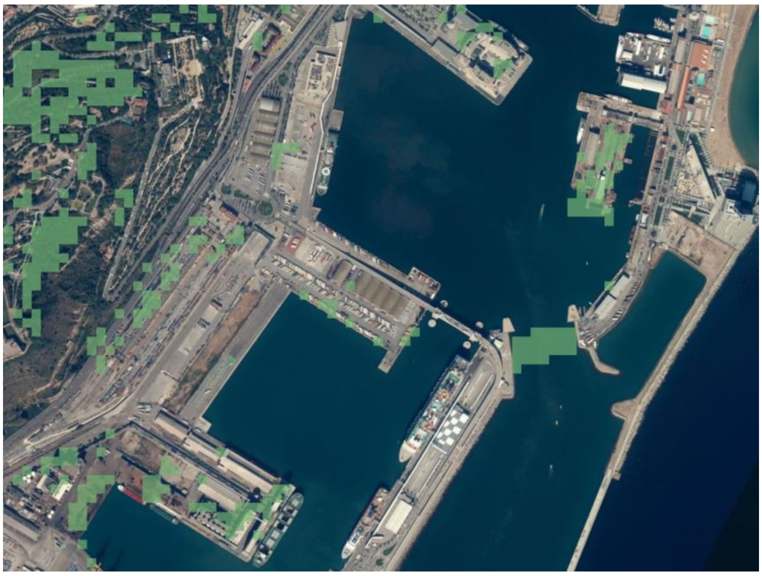


Figure 2: Forest layer deficiencies – tree detection in different land use class

This deficiencies are partially solved by combining the JRC Forest layer and the forest class of the Urban Atlas dataset (both with reference year 2006), providing the whole picture of urban forests. This way both the canopy cover of urban tree patches from JRC Forest Layer, mainly contained within the Urban Atlas class "Green Urban Areas", and surrounding urban forests from Urban Atlas (class "Forests") are accounted for. This has led us to identify two classes of tree cover in urban areas: On the one hand "urban trees", i.e. the inner city tree patches identified by the JRC Forest Layer, and urban forest, more extensive forest patches in the suburban areas of urban zones. Figure 3 exemplifies the urban trees along inner-city streets as green linear features and larger areas of urban forest for the cases of Barcelona and Karlsruhe.

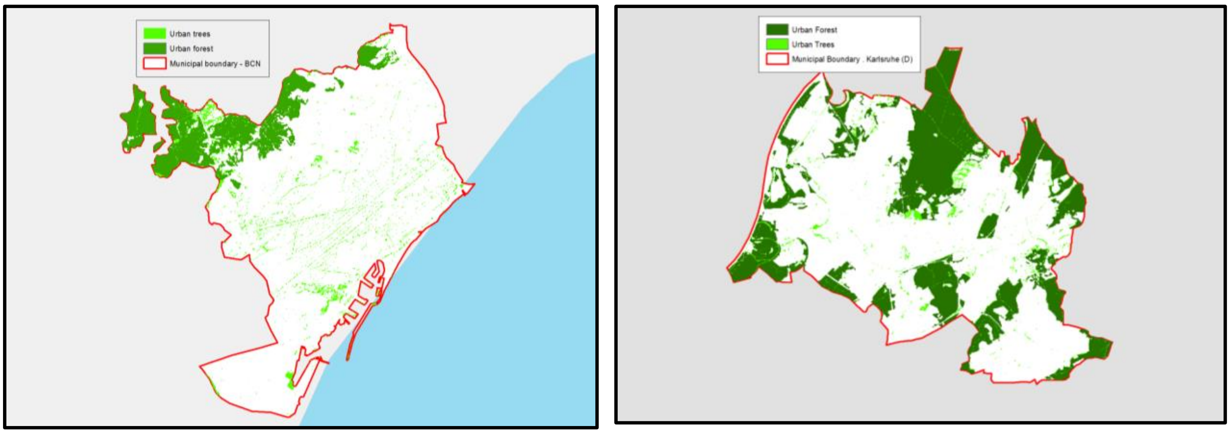


Figure 3: Urban tree and forest layer for Barcelona (left) and Karlsruhe(right)

The Urban Atlas class “Forest” complements the information of JRC Forest layer by providing a more continuous cover than the forest layer as shown in Figure 4. The light green layer is the Urban Atlas class “Forest”, the dark orange pixel are from the JRC Forest Layer.

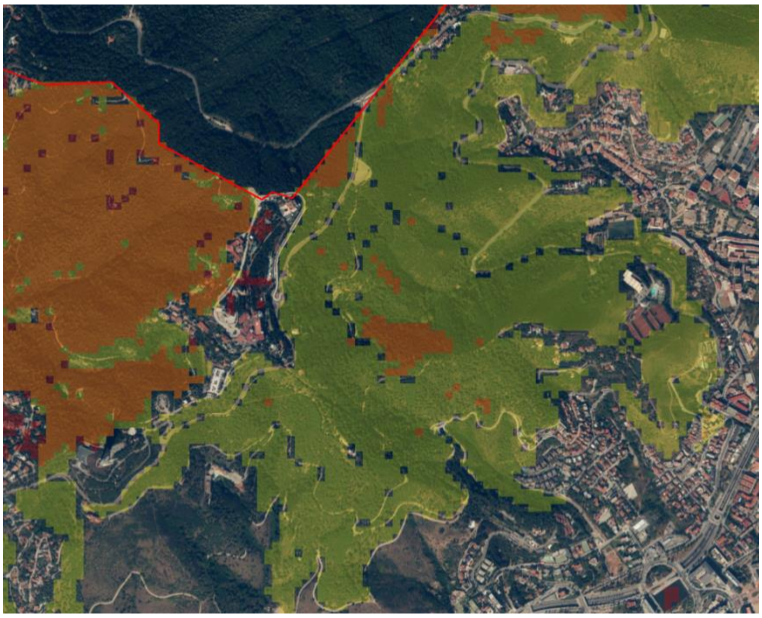


Figure 4: Complementarity of Urban Atlas class “Forest” and JRC forest layer (see description in the text)

The high-resolution (HR) Imperviousness Layer can be used for urban grassland (gardens and parks) detection. The imperviousness product is mapped by applying processing chains to multi-temporal earth observation data. Information is represented in a HR Imperviousness Layer with consistent 1 ha Minimum Mapping Unit. The Imperviousness Layer provides a data range from 0 to 100, indicating the degree of soil sealing. Urban green areas can be assumed to have a degree of soil sealing less than 30. Although, finally, the Imperviousness Layer is not used in the current estimation, this working definition could be applied to later test.

Several Pan-European high-resolution layer (20 m resolution) will be available mid 2014, including:

- an update of the imperviousness layer and Urban Atlas

- Tree cover density layer
- Forest type map,
- Grassland layer.

All of them might provide additional information for urban areas and enhance the quality of the results (see recommendations below).

3.2.3 Ancillary Data

The delimitation of urban areas has always hindered and still does the analysis of urban indicators in Europe. From a data point of view, different approaches have been used: administrative (LAU), morphological (UMZ) or functional (Urban Audit). Recently, Dijkstra & Poelman (2012) have proposed a new definition combining these approaches.

For our purposes, Local Administrative Units (LAU) and Urban Morphological Zone (UMZ) are considered to be useful. UMZ can be defined as "a set of urban areas laying less than 200m apart". Those urban areas are defined from land cover classes contributing to the urban tissue and function. They reflect the compactness of an urban zone. LAU instead represents the administrative boundaries, including urban tissue and suburban land uses. The extension depends on historical and administrative reasons instead of geographical conditions.

From a spatial analysis point of view the morphological delineation are better suited as relations between compactness and urban green areas can better be interpreted. But regarding urban green areas, management in terms of local policy that often have implications for areas lying few kilometres apart is of crucial importance. So administrative boundaries (i.e. LAU) might also be a reasonable delimitation. [3]

For a better understanding of the differences in geospatial representation, Figure 5 provides a comparison of LAU and UMZ for two of the test cities.

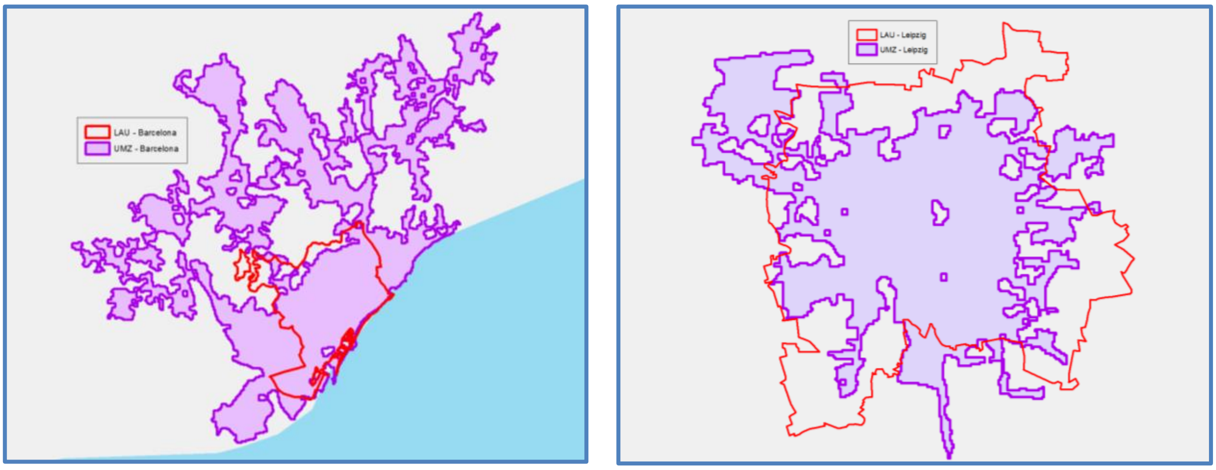


Figure 5: Comparison of LAU and UMZ for Leipzig and Barcelona

[3] See the documents "A framework for Integrated Monitoring in Europe" and "Update to IUME concept and datamodel proposal" for more detailed discussions.

4 METHODOLOGY PROPOSAL

4.1 CONCEPTUAL CLARIFICATION

The literature and data review modified some of the task's objectives and, at the same time, clarified different conceptual issues as well as terminology.

4.1.1 Carbon storage versus sequestration

Carbon sequestration includes the storage and capture of organic carbon in biomass. For the estimation of carbon storage information about biomass distribution, amount and characteristics have to be available for, at least, one point in time. Carbon capture additionally requires information about biological dynamics (i.e. respiration, growth) and land cover changes that affects carbon capture (e.g. urbanization or creation of urban green areas). Taken into account the available datasets, it has become clear that only carbon storage could be addressed. All datasets date from one reference year (2006)[4] and, hence, provide the image of forest and urban green area distribution at one point in time. As soon as the new HRL are available (particularly Urban Atlas), a change analysis could be undertaken to move a step forward and address carbon sequestration. Apart from the land cover information, differentiated data on growth rates etc. are not available yet.

4.1.2 Urban forest versus urban green areas

In order to be able to validate the envisaged results, it is necessary to count with local case studies on carbon storage. As has been shown, only for studies are available for Europe. Three out of four only account for carbon stored urban trees, disregarding due to different reasons other sinks of carbon like soil and grassland. [5] Hence, the task also focussed on urban trees and forests in order to be able to estimate the validity of the expected outcomes.

4.1.3 Case studies versus Pan-European estimation

Due to resource constraints, the Pan-European estimation of carbon storage in urban green areas was disregarded. The project and task manager came to the conclusion that a detailed description of available literatures and data as well as of the methodology proposal would be more important at this state than a rough estimation of carbon storage for all European urban areas. Therefore, the task concentrates on the case study cities, investigating as well the innovative use of HANTS data in urban areas.

[4] For the Imperviousness Layer an update for 2009 is available.

[5] See discussion above.

4.2 RATIO DEFINITION

The fundamental part of the methodology was to develop the right ratio to transfer the information of tree cover to biomass and carbon content. The step by step approach is presented in the following subsections.

4.3 FOREST BIOMASS AND CARBON CONTENT

Overall average ratios are proposed by Nowak et al. (2013) and Nabuurs et al. (1997) for the US and Europe respectively. Besides these averages and given the Forest Type Map 2006, produced by the Joint Research Centre (JRC) which provides the distinction between coniferous and broadleaved forest, a more differentiated ratio description will be elaborated here in different steps:

1) Above ground biomass stock in plantation forests expressed as tonnes dry matter ha-1 is provided for broad forest types and different biogeographical zones by IPCC 2003 based on the statistics of FAO 2000. The ratios for plantation forests were selected assuming that urban trees may have more similarities with plantation forest than with natural forests.

Temperate Forests				
	Age class	**Pine**	**Other coniferous**	**Broadleaf**
Eurasia				
Maritime	≤20 years	40	40	30
	>20 years	150	250	200
Continental	≤20 years	25	30	15
	>20 years	150	200	200
Mediterranean & steppe	≤20 years	17	20	10
	>20 years	100	120	80

Boreal Forests				
	Age class	**Pine**	**Other coniferous**	**Broadleaf**
Eurasia	≤20 years	5	5	5
	>20 years	40	40	25

Figure 6: Aboveground biomass stock in plantation forests by broad category (tonnes dry matter/ha) (Source IPCC 2003)

These biomass stock equivalents have to be multiplied by 0,8 based on Nowak's et al. (2013) assumption that open-grown, maintained trees tend to have less above-ground biomass than predicted by forest-derived biomass equations for trees of the same Diameter at Breast Height (DBH)[6].

2) Biomass to Carbon

Based on Magnussen & Reed (2004)[7], carbon content of dry biomass is calculated by the factor of 0.475.

[6] 1.30 for Europe and 1.37m for US

[7] http://www.fao.org/forestry/8758/en/

In many applications, the carbon content of vegetation may be estimated by simply taking a fraction of the biomass, say

$C = 0.475 * B$ where C is carbon content by mass, and B is oven-dry biomass.

Figure 7: Carbon fraction of biomass (Source Magnussen & Reed 2004)

Hence, different values for each biogeographical region are presented to be tested and compared to available estimates of the reference case studies. In the following table the different steps of calculation are represented and the final ratio is highlighted.

Temperate Forests	**Area to biomass (seeFigure 6)**	**Biomass equivalent factor (* 0,8)**	**Ratio (kg/m2) (*0.475)**
Atlantic BGR			
Maximum	200	160	**76,0**
Minimum	30	24	**11,4**
Continental BGR			
Maximum	200	160	**76,0**
Minimum	15	12	**5,7**
Mediterranean BGR			
Maximum	80	64	**30,4**
Minimum	10	8	**3,8**
Atlantic BGR			
Maximum	200	160	**76,0**
Minimum	40	32	**15,2**
Continental BGR			
Maximum	200	160	**76,0**
Minimum	25	20	**9,5**
Mediterranean BGR			
Maximum	120	96	**45,6**
Minimum	17	13,6	**6,46**
Boreal			
Average (Coniferous and Broadleaf)			
Maximum	40	32	15,2
Minimum	5	4	1,9

Table 3: Detailed ratio calculation for different Biogeographical Regions (BGR)

4.4 URBAN GRASSLAND BIOMASS AND CARBON CONTENT

For the sake of completeness, also the ratios for urban grasslands are presented although urban grasslands are no longer object of the final estimation.

As mentioned before, urban agriculture, private gardens and public parks will all be treated as "urban grassland". Urban grassland will be defined in the context of this task from a data-driven point of view. Hence, all urban green areas detected in Urban Atlas that are not urban forest and/or have a value below 30% in the HRL Imperviousness are considered urban grassland. Table 4 indicates the maximum and minimum ratio for the estimation of carbon content of grassland biomass per unit area.

Methodologically, total carbon in urban grasslands can be determined by multiplying the total grassland area with the average carbon stock per m^2 associated with herbaceous vegetation (Davies et al. 2011). There is no a Pan-European ratio. Hence, a biogeographical differentiation should be applied.

Urban land cover	Ratio C/area unit (kg/m^2)	Methodological source	Data source
Grassland			HRL Imperviousness[8], Urban Atlas
Maximum	1,4	Davies et al. (2011), Townsend-Small & Czimczik (2010)	
Minimum	0,6	Davies et al. (2011)	

Table 4: Proposed ratio for urban grassland

[8] Values <30% are defined as grasslands, urban gardens and urban agriculture areas, based on the definition of build-up areas = >30% of soil sealing.

5 ESTIMATION OF CARBON STORAGE IN SELECTED URBAN AREAS

5.1 SELECTED URBAN AREAS

Four local case studies that address carbon storage in urban green areas in Europe were identified (Strohbach and Haase, 2012). The four are comparable and recent local studies in Europe that cover different biogeographical regions (BGR) (Figure 8 and Table 1 above).

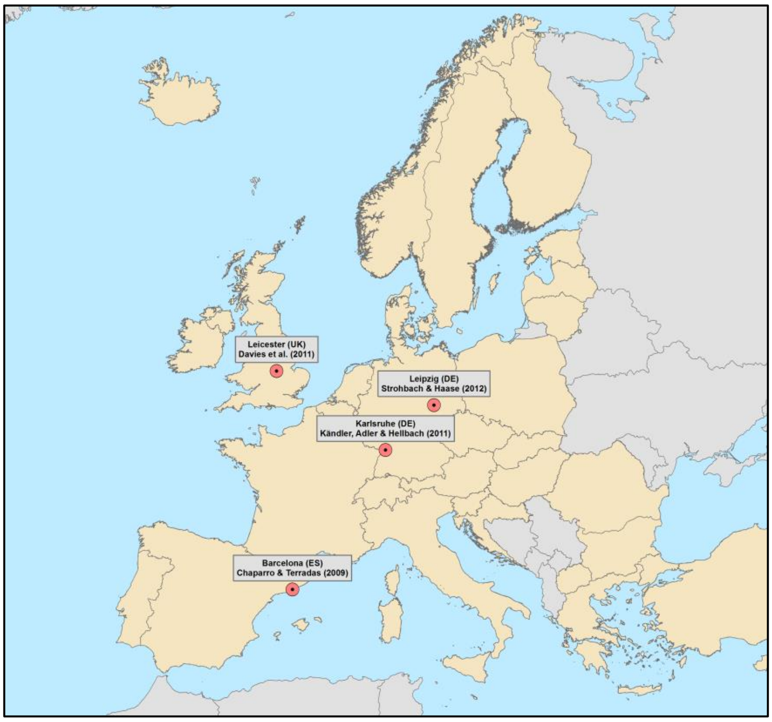


Figure 8: Overview of selected local case studies

All studies, but the Leicester study, calculate carbon storage only in trees. They use different methodologies and reference data to estimate carbon storage and come up with a carbon storage indicator $Mg{\cdot}C{\cdot}ha^{-1}$. As already discussed by Strohbach & Haase (2012), the Leicester study raises important questions of its representativeness for the UK, while the other studies provide meaningful results. Leipzig and Barcelona show similar results although they belong to different climates and BGR. Karlsruhe with large areas urban forests has much higher carbon storage per area unit.

5.2 DATASETS AND DATA QUALITY

For the comparison between the elaborated methodology in this task and the results from the local studies, the following datasets were used:

Dataset	Scale / Resolution	Content	Use
Local Administrative Units (LAU)	1:100000	LAU level (LAU level 2, formerly NUTS level 5) consists of municipalities or equivalent units in the 27 EU Member States.	Municipal boundary
Urban Atlas (2006)	1:10000 (MMU 0,5 ha)	Land use and land cover data for Large Urban Zones	Identification of urban forests
JRC Forest Layer (2006)	25 m	Forest cover map with classes. • Broadleaved Forest • Coniferous Forest	Detection of forest cells in urban areas

Table 5: Datasets used in the first carbon storage estimations.

Compared to the proposed datasets in section 3.2.1 (see also Table 2) , there are two major differences. First, instead of the Urban Morphological Zones (UMZ) the Local Administrative Units (LAU2) are used due to the fact that the local reference studies refer to municipal boundaries. Second, only forest was analysed in this first estimation because the reference studies also concentrate on above-ground carbon storage in trees. Hence, the HRL Imperviousness is not considered in the tree-centred approach as it does not provide additional information. The same holds true for Urban Atlas classes different to "Forest" that are not used in the context of this approach.

5.3 PROCESSING AND DATAFLOW

Figure 9 shows the overall dataflow to generate carbon storage data in the selected urban areas. All input data are masked for the extent of the municipal boundary and, if necessary, converted to 25 m raster.

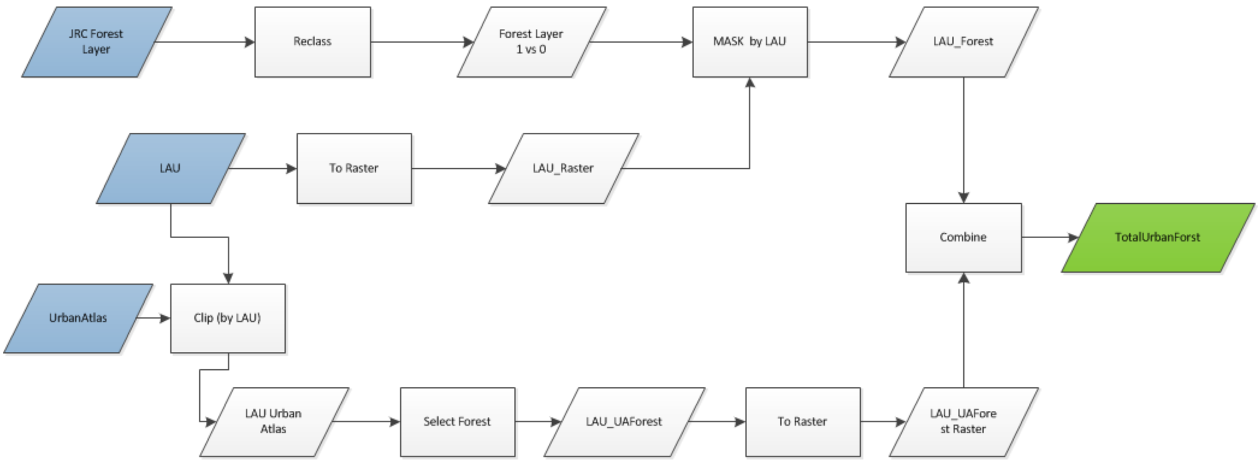


Figure 9: Dataflow for carbon storage calculation

The central idea is to obtain a geospatial layer with the full coverage of urban forest for a given urban area (TotalUrbanForest).The ratios discussed earlier are then applied to the spatial information derived from this layer to calculate biomass and carbon content. Different ratios (minimum and maximum) are applied to the layer in order to evaluate the suitability of these conversion factors.

5.4 RESULTS

In a first step four maps with the total forest coverage were produced (see Figure 10). A brief look at the maps highlights some interesting differentiating features between the test cities. For instance, the major forest area of Barcelona is concentrated on the hilly hinterland, while the inner city is structured by a dense network of small green infrastructure (small parks, street trees). In the case of Leipzig, the hotspot of forest cover is along the Elster river. Some bigger urban tree patches can be found as well in the eastern part of the city. Forest patches in Karlsruhe are concentrated around the compact city, leaving little urban tree patches in city centre. Finally, Leicester is the most densely populated LAU with just a few urban tree patches all over the municipal area.

The obtained results regarding carbon storage in urban trees and forests are summarized in Table 6. The comparison with the results of the local reference studies shows the validity for the maximum ratios of the proposed methodology. It is obvious that apart from the Leicester case, the order of magnitude of total forest carbon storage between the studies is the similar. Nevertheless, there are still important differences that also are reflected in the different amount of carbon storage per hectare, being slightly underestimated in the Barcelona case, but moderately underestimated in the Leipzig and Karlsruhe case. Regarding the Leicester case, Strohbach & Haase (2012) already mentioned that this study provides “a surprising amount that raises questions about how representative the study is for British cities”. In this line, our results confirm the doubts about the representativeness of the study.

In section 3.2.2, already some deficiencies of the JRC forest layer regarding the full coverage of inner city tree patches were highlighted. These data gaps may explain part of the underestimation. In the final chapter some recommendation will be provided which includes the estimation of error of the JRC Forest Layer in order to have an idea how much tree cover is not recognised and, hence, not accounted for in terms of carbon storage.

The results with the minimum ratio can be regarded as not valid. As far as the minimum ratio has been derived from the biomass content of young trees (< 20 years), questions about suitability of this minimum scenario arises, particular taking into account that many urban forest stands may enter in this age class.

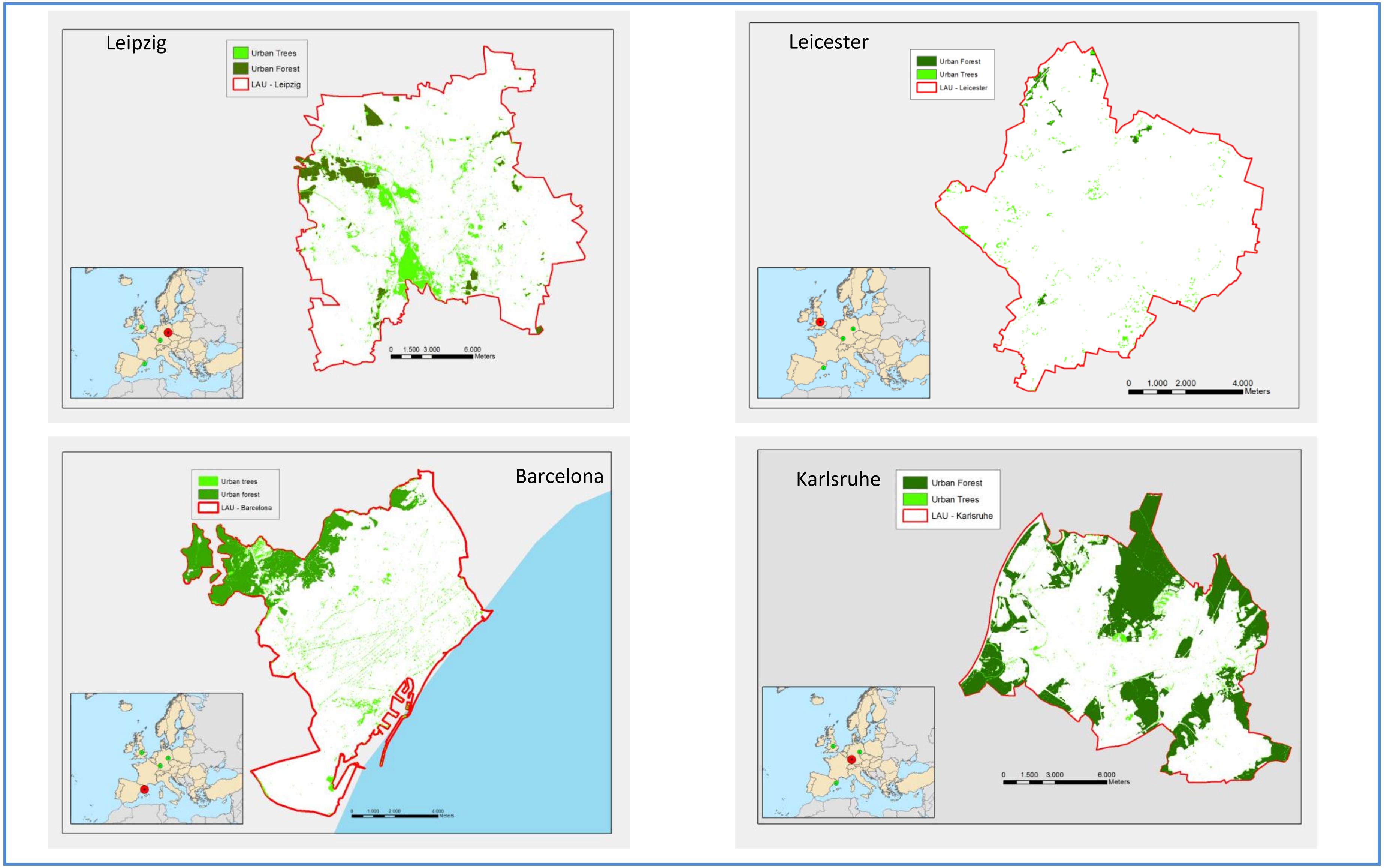


Figure 10: Total forest coverage of test cities

	Land cover based carbon storage of trees								Local reference studies	
	Area (ha)	Forest area (ha)	Forest area %	Coniferous (% of total forest)	Broadleaf (% of total forest)	Applicable ratio (max/min)	**Total forest Carbon storage (Mg·C)**	**Mg·C·ha^{-1} (of total urban area)**	Total Carbon storage (Mg·C)	Mg·C·ha^{-1}
Leipzig	29.872,8	3.094,0	10,4	11,5	88,5	**76,0** **6,1**	**235.120** **18.981**	**7,9** **0,6**	316.000	11,8
Leicester	7.339,7	150,3	2,0	8,7	91,3	**76,0** **11,7**	**11.418** **1.762**	**1,6** **0,2**	231.521	31,6
Barcelona	9.817,3	1.656,6	16,9	96,8	3,2	**45,1** **6,4**	**74.733** **10.560**	**7,6** **1,1**	113.437	11,2
Karlsruhe	17.407,7	5.598,6	32,2	41,1	58,9	**76,0** **7,3**	**425.453** **40.659**	**24,4** **2,3**	560.000	32,3

Table 6: Results of carbon storage estimation and comparison to local reference studies

In terms of indicator for carbon storage, carbon storage per area unit has been identified as the best indicator to describe and compare urban regions on European and other scales. Despite the fact that the per unit indicator invites to compare different urban areas, these urban areas (i.e. municipal boundaries) are not comparable in many cases as they are of administrative nature. The use of the Urban Morphological Zones (UMZ) is therefore recommended. Additionally, population data could provide an even more integrated way to compare this data. For the accessibility of urban green areas may be complementary indicator to consider.

6 USE OF HANTS DATA FOR CARBON STORAGE ESTIMATION

6.1 BACKGROUND

For the ETC-SIA task “Carbon sequestration in urban green infrastructure” the objective is to get more knowledge about the urban green areas, in terms of area and carbon stock. More specifically the following objectives have been formulated:

- identifying urban green areas;
- classify/differentiate different cities depending on its phenological profile;
- elaborate meaningful time series for urban green areas.

One of the possible solutions to these objectives might be the use of satellite images, more specifically to use the HANTS phenology dataset of Europe with 250 m resolution and covering the period 2000-2012. It contains the following layers:

- Mean NDVI (NDVI value)
- Peak NDVI (NDVI value)
- Low NDVI (NDVI value)
- SOS - Start of Season (Day of the Year)
- EOS - End of Season (Day of the Year)
- POS - Peak of Season (Day of the Year)
- LOS - Low of Season (Day of the Year)

The NDVI is an indicator of green biomass. It is a ratio between 0 and 1, where values below 0.2 indicate bare soil and water and values over 0.8 indicate multiple layers of leaves and other green biomass. However, the objective of this ETC-SIA task is also to quantify the carbon stocks in the cities. Therefore the following sub-question should be solved as well:

- What is the relationship between NDVI and biomass/carbon?

After a first analysis of identifying urban green areas and the temporal behaviour of it by using the HANTS phenology dataset, this section will first evaluate these results in relation to the first three objectives, then explain the relationship between NDVI and Biomass/carbon and finally propose a (new) approach to map the green urban areas for the next phase of a follow-up task.

6.2 EVALUATION OF PILOT STUDY

Since it was decided to work on the green urban areas (only urban trees and forest), this layer was used as mask to extract the areas of study for each of the selected cities.

Due to the resolution of HANTS dataset, the green urban area layers were resampled at the same resolution, 250 m. This procedure causes some disadvantages

- A loose of data especially in the areas where the green area has a linear shape or if the surface is much less than 250 m^2.

- When linear feature were rasterized at 250 m, the obtained surface would not accurately represented the green area, which means low precision in the NDVI value. Barcelona is well reflecting this limitation, while the city of Karlsruhe, which presents a more compact green urban area, is better represented by the raster map. (Fig. 1)

Once data were ready, the average, the maximum and the minimum values were extracted per each year and then plotted to be compared.

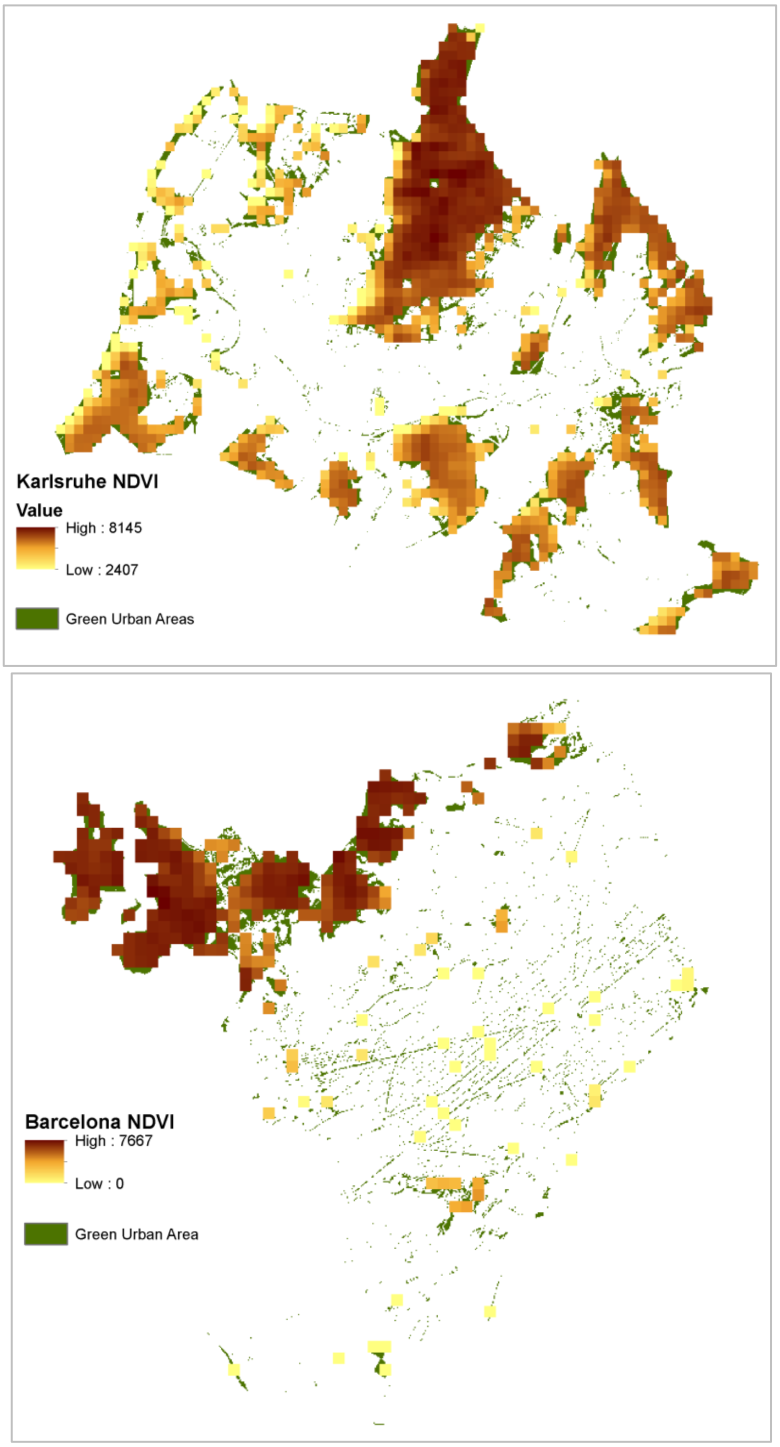


Figure 11: Different results after rasterizing and resampling process at 250m.

The above mentioned approach, extracted the green urban area from the JRC Forest map and the Urban Atlas. To do so these maps were resampled to 250 m and masked the non-forested areas. As indicated the 250 m resolution resulted in a loss of information due to the fact that trees in the city are individual trees or standing in lines. Almost all green line elements from the high resolution (25 m) JRC forest map and Urban Atlas are lost during resampling. A first conclusion can be drawn:

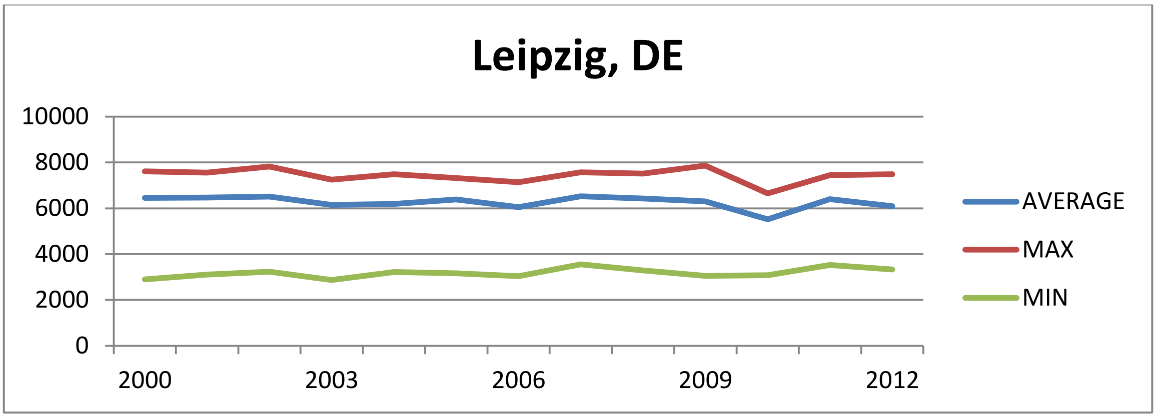
- It is impossible to classify "pure" urban green area from 250 m resolution data, like the HANTS phenology dataset and give a realistic estimate of green urban area

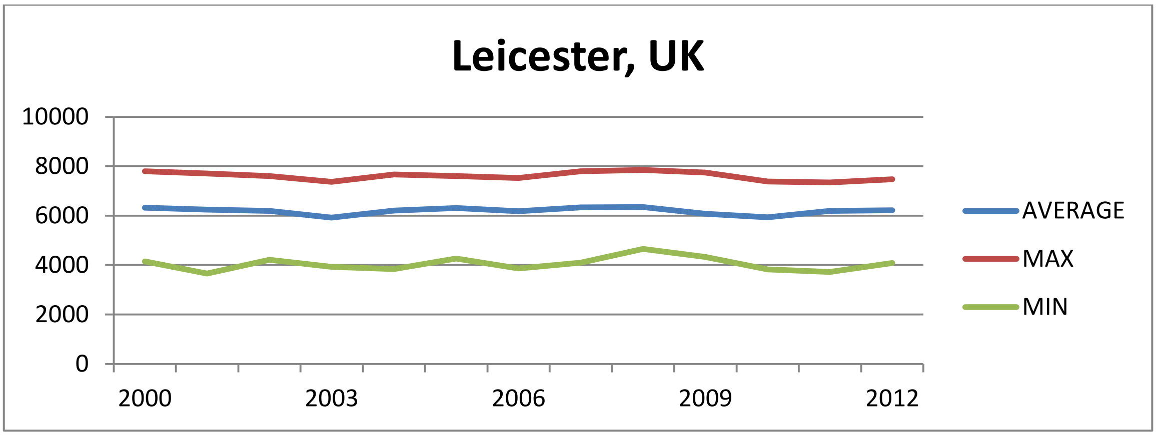
Only larger green urban area, like parks, can be identified and monitored properly with 250 m resolution data. One could question if these larger parks represent the "greenness" of a city. If apart from the large parks or other large green urban areas only 100% urbanised areas exist one could argue if this is a green city. While a city with a lot of individual trees and other green patches in all streets, might result in a low green urban area on 250 m resolution scale, it might be a lot "greener" than the previous example. The second conclusion can be drawn as:

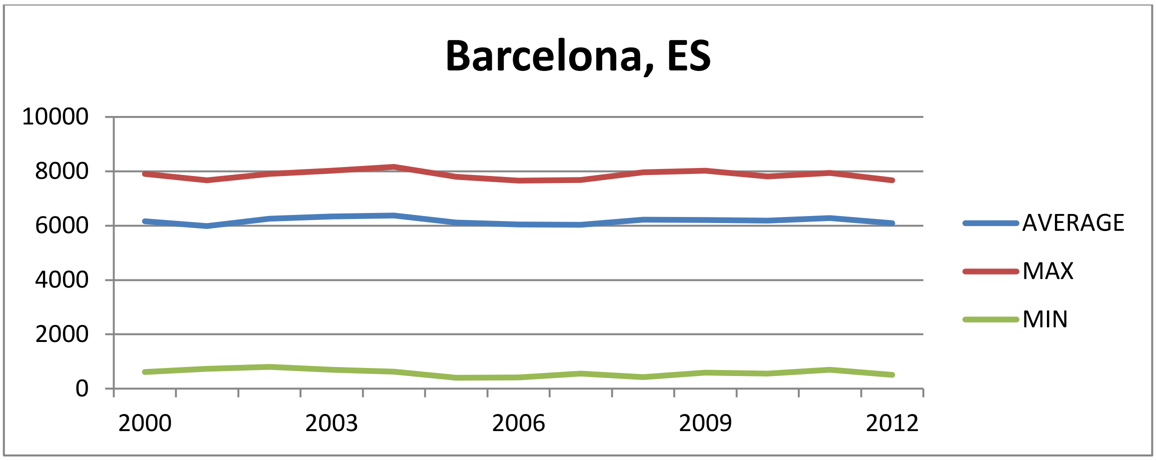
- Large green urban areas, like parks, do not present the "greenness" of a city.

So it is impossible to differentiate cities on the basis of the large green urban areas (urban forests) only. Figure 12 shows for all cities (Leipzig, Karlsruhe, Barcelona, Leicester) more or less the same average NDVI value (around 0.6) and the same maximum NDVI value (around 0.8). Only the minimum NDVI value is different between the cities. This is caused by the problem of mixed pixels combined with effect of the different climatic zones. The dry Mediterranean Barcelona has the lowest values, and the wet Leicester the highest. Although this is useful information and might help differentiate the greenness of the city, it is not enough to come to a full classification of greenness.

Regarding the urban carbon stock, it makes sense to focus on the larger urban areas, like parks and urban forests, as these probably store the largest amount of carbon within the city. However, with the focus on pure green urban area pixels one loses a lot of information from smaller patches of green urban areas. Proposed is to come to another approach by switching from the focus on identification of green urban pixels to quantification of the greenness of each pixel (= NDVI vegetation index) and analyse this on city or neighbourhood level. Then a city is classified on the basis of its NDVI value, instead of its green area value. This is worked out in the "New approach" section below.







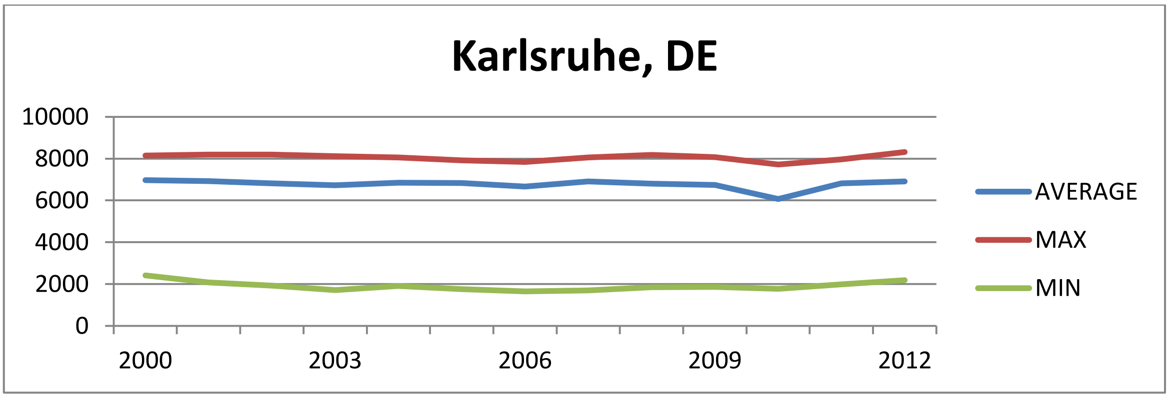


Figure 12: Average, Max and Min values derived from mean NDVI (HANTS datasets), for the selected cities.

In this section some examples are shown about the NDVI profile for a city derived by the change along the time series considered.

Figure 13: NDVI values represented in a RGB image: red year 2006, green year 2000 and blue year 2012.

The map of Karlsruhe in Figure 13 shows the variance of NDVI values between three years: 2000, 2006 and 2012. In the pixels where the green colour prevails, means that the NDVI value was higher in 2000 respect other years, while where prevail the blue, means that in the 2012 was recorded the highest value.

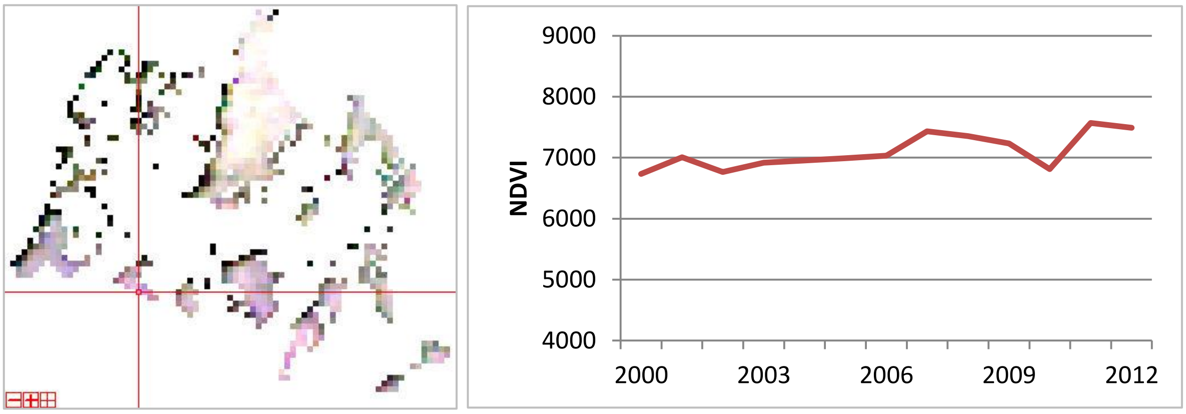


Figure 14Example of increasing NDVI value respect the 2000.

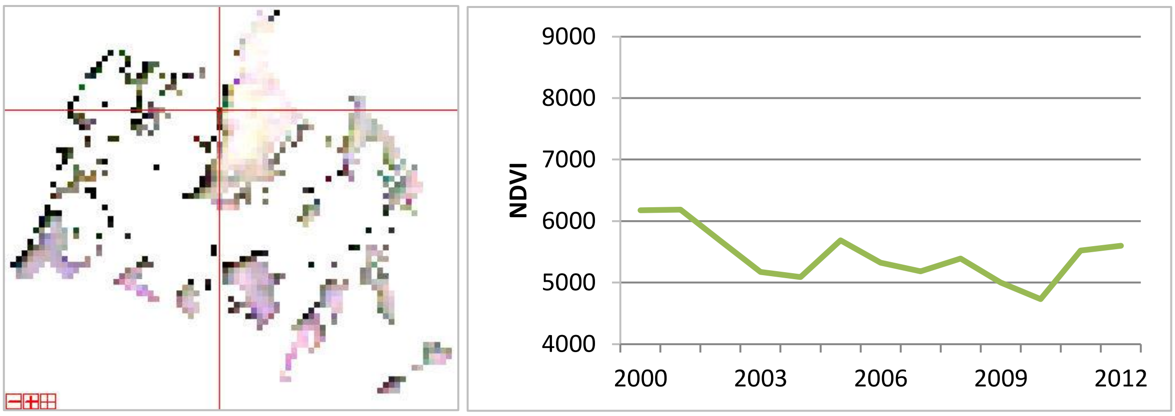


Figure 15: Exampleof decreasing in NDVI value. Resume table – Carbon and NDVI

Table 7, finally shows the carbon storage results from our land cover based approach (left side of the table) and the Max., Min. and Mean NDVI for the period 2000-2012.

	Land cover based carbon storage of trees					HANTS mean NDVI		
	Total Area (ha)	Forest area (ha)	% of forest within municipal boundary	Total forest carbon storage (T)	**T/ha (of total urban area)**	**MAX NDVI**	**MIN NDVI**	**AVERAGE NDVI**
Leipzig	29.872,8	3.094,0	10,4	235.120	**7,9**	7437	3181	6267
Leicester	7.339,7	150,3	2,0	11.418	**1,6**	7603	4048	6192
Barcelona	9.817,3	1.656,6	16,9	74.733	**7,6**	7860	587	6174
Karlsruhe	17.407,7	5.598,6	32,2	425.453	**24,4**	8057	1907	6771

Table 7: Mean values of NDVI time series (2000-2012) compared to Carbon storage data.

6.3 Relationship between NDVI and biomass/carbon

6.3.1 Spectral signatures of water, soil and vegetation

When radiation hits an object, it can be transmitted, absorbed or reflected. The mutual magnitude of these processes is determined by the properties of the object. With remote sensing the amount of reflected solar radiation can be measured as a function of wavelength, called spectral reflectance. Figure 16 illustrates the spectral reflectance of some typical objects.

Water absorbs most of the incoming radiation and only reflects a small amount (particularly in the visible part of the spectrum; at longer wavelengths water does not reflect any significant radiation).

Soils exhibit quite a smooth spectral reflectance curve. Distinct features are found in narrow spectral bands due to absorption by minerals and iron oxide. Broader features occur near 1,4 µm and around 1,9 µm, due to absorption by the moisture content. The absorption by moist also causes the gradually decreasing reflectance with increasing wavelength in the MIR region. The soil moisture causes the spectral reflectance of a wet soil to be lower than that of a dry soil.

Vegetation, on the other hand, shows a very characteristic reflectance curve. The reflectance in the visible part of the spectrum is low due to absorption of this radiation by chlorophyll in the green parts of a plant. In the NIR region hardly any absorption occurs, and reflectance is determined by the amount of transitions between cell walls and air vacuoles in the leaf tissue. As a result, NIR reflectance of green vegetation is high, and a steep slope occurs in the reflectance curve at about 0,7 µm (the so-called red-edge region). In the MIR region we observe a similar influence of moist, as observed for soils.

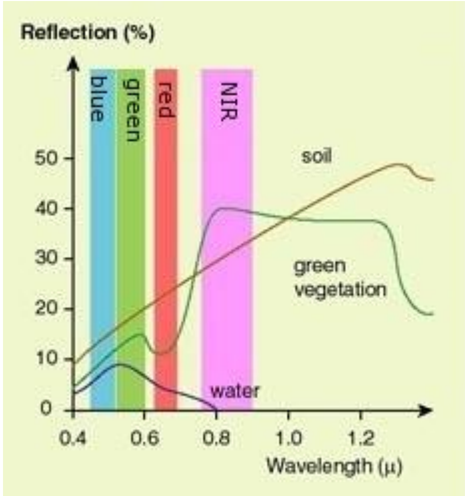


Figure 16: Typical spectral reflectance curves for water, soil and vegetation

Several vegetation indices have been developed over the years. The most well-known index is the Normalised Difference Vegetation Index (NDVI). The NDVI is a ratio between reflected red and NIR radiation and is defined as:

$$NDVI = \frac{NIR - red}{NIR + red}$$

The NDVI index ranges between 0 and 1 and has no physical meaning like the other indicators described in this paragraph. However, it is easy to measure and is very sensitive to temporal and spatial changes of the vegetation cover. Another advantage is also that it is not sensitive to weather conditions as for example temperature. Calculating the NDVI of water will result in negative values, bare soil has an NDVI that is approximately between 0,10 and 0,20 and green vegetation can score up to 0,80.

6.3.2 Relationship between NDVI and biomass

To calculate biomass and/or carbon stocks from NDVI, first the Leaf Area Index (LAI) has to be determined. The Leaf Area Index (LAI) is a ratio of the total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is a dimensionless value, typically ranging from 0 for bare ground to 8 for a dense tropical rainforest.

The LAI can be measured by remote sensing as an empirical relationship of the NDVI (see Figure 17) or can be modelled in a more sophisticated way, using more input variables as well.

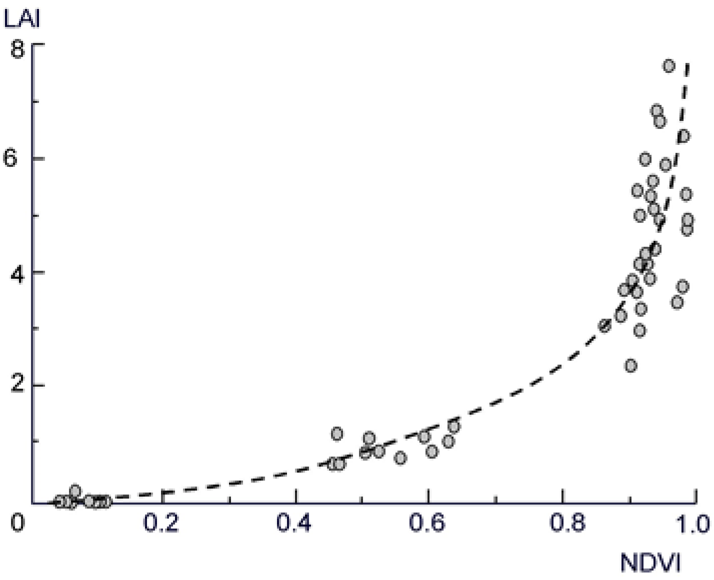


Figure 17: Relationship between NDVI en LAI (Buiten & Clevers, 1990)

The NDVI-LAI relationship is specific for each plant species. From Figure 2 it becomes clear that the NDVI saturates at LAI values that becomes higher than 3; so the relationship is non-linear. An additional layer of leaves hardly has any effect anymore on the NDVI.

The green biomass can be calculated from LAI, the incoming solar radiation and some additional meteo parameters. However, the critical parameter for determination is the crop specific LAI.

In terms of carbon stocks only the green biomass can be determined from the NDVI. However, carbon stocks involve much more than only green biomass. Also tree stems and dead organic matter are part of the carbon stock. So additionally, a method should be developed to include these parameters.

6.4 NEW APPROACH

As explained before it is difficult to map and/or monitor green urban areas with 250 m resolution data. Only the larger green urban areas will be identified. Instead of the focus on area, it is proposed to identify the greenness of a (part of the) city on the basis of the amount of green biomass present in that (part of the) city. So mixed pixels are not a problem anymore but are the solution, i.e. a low value indicated that the city is very urbanised without any green areas and a high value indicated a green city. Apart from the average NDVI value, also the seasonal difference might serve as useful indicator. And the standard deviation of all NDVI values within a city might serve as indicator of the way the green areas are distributed over the city (high values indicate large green areas and large urbanised areas; low values indicate a more equal distribution of the green over the city). This approach could be worked out in the following steps:

1. Input data are the HANTS phenology dataset and a map indicating the urban areas. The urban areas have to be large enough to match the 250 m resolution pixels of the phenology data, so at least 3x3 pixels or a square km in vector format. In practice these are whole cities or city neighbourhoods for the larger cities.

2. Calculate the statistics (mean, standard deviation, max, min, median) of the HANTS phenology parameters per urban element for each available year (HANTS phenology dataset: 2000-present).
3. Analyse the spatial patterns (over Europe, per city, per nation, per climate zone, etc.)
4. Map the greenness of the urban areas, taking into account other parameters, like climate, population density, etc.
5. Analyse the temporal trends over the years. Make a distinction between gradual (climatic) trends and abrupt changes (hotspots).
6. Map the greenness dynamics of the urban areas.

Regarding the biomass and carbon stock calculation for green urban areas, my advice is to leave it as it is for the moment, as it is rather complex and should be done plant/crop specific. For the non-urban areas the method is still under development. It might be reasonable to wait for a more robust method for carbon stock and biomass calculation for non-urban areas and once it is there, the proposed method could be applied also to the urban areas.

7 RECOMMENDATIONS AND OUTLOOK

This final chapter provides several recommendations at different levels of application. Particularly, improvements of available data and of the methodology are discussed. Some additional considerations are made aimed at potential users of the methodology. Finally an outlook of possible follow-up activities is given.

7.1 DATA GAPS AND OUTLOOK

In terms of datasets, there is little room for enhancement as currently no other datasets are available. The envisaged High Resolution Layers for forest and grassland at 20 m resolution as well as the update of the Urban Atlas database instead might bring some enhancement. They will all be referenced to the year 2012 and, hence, will provide additionally the possibility of change detection.

The current underestimation of forest cover, already discussed in chapter 3.2.2 and **Error! Reference ource not found.** needs to be quantified and analysed with more detail in order to provide a quantitative measure of error. This might help to fine tune the results and enhance the overall methodology.

Collaboration with other task that already deal and will deal with urban green infrastructure and other data-centred approaches, is mandatory for forthcoming activities. A common call for better and harmonized data for urban areas across Europe might trigger movements for specific Pan European datasets on urban land cover and biodiversity. The same holds true for specific conversion factors and ratios for urban ecosystem characteristics, relevant for analysis of urban ecosystem services.

Looking at the urban-rural interface, both the data issue and the methodological approach have to be flexible enough to take into consideration the continuum between urban and surrounding. Together with related activities, a common data model needs to be implemented in order to integrate a common approach for mapping and assessing urban and rural ecosystem services.

7.2 METHODOLOGY

As mentioned before, the ratios used in the present task still have to improve in order to obtain more regionally explicit and ecosystem type specific results. This adaptation requires a more detailed review, involving surveys among local and thematic experts. Consultations with the on-going projects URBES and TURAS may trigger significantly the discussion about ratios and conversion factors.

The proposed approach to integrate HANTS datasets in urban spatial analysis should be followed up. Though there are still several gaps and uncertainties to overcome, the first results are promising. Particularly, the time series analysis of the dynamic of urban green areas is of interest, given the lack of multi-temporal land cover information. In this sense, the methodology could integrate the required input to extent the analysis from carbon storage to carbon sequestration.

Other urban land cover like urban grassland, gardens and parks have not integrated in the methodology so far. Nevertheless, a first review of ratios was conducted and possible data were explored. As proposed in previous milestones, the HRL Imperviousness could be used to determine open areas that could be defined as urban grassland, gardens or parks. A test with this dataset should be undertaken in order to evaluate its potential.

7.3 OUTLOOK FOR UPCOMING ACTIVITIES

This document may be the first step to provide a multi-scale methodology for the mapping and assessment of urban ecosystems. The growing global interest in urban biodiversity and ecosystem services calls for addressing other urban ecosystem services as well, following the URBES approach. Within this particular project, Haase et al. (2013) apply a multi-scale approach to estimate the level of provision of urban ecosystem services across Europe. In this sense, similar to the activities related to the Mapping and Assessment of Ecosystems and their Services (MAES), an assessment of urban ecosystem services and its implication on the data side should be discussed. Such an assessment should provide stakeholders at different scales, from local urban planners and manager, regional planners to European policy makers with the sufficient tools to undertake mapping and assessments of ecosystem services such as carbon storage and sequestration.

For this purpose, the local methodologies have to be documented in a structured way, highlighting the best practice cases. On the regional and European scale, the approach proposed in this document has to be further revised and enhanced.

As has been already discussed in the literature review, the integration of grasslands and other carbon pools into estimations of carbon storage is sensitive as carbon emissions related to management of grasslands are not accounted for. Consequently, the whole methodology should, in the long term, consider different factors of input and output of carbon fluxes in order to achieve the full carbon balance of urban areas. This objective is very ambitious, but in the conceptual context of urban metabolism and the thematic perspective of climate change adaptation and mitigation, the complete balance may be of political and scientific interest. In this direction, respiration and human inputs and outputs, imports and exports would need to be modelled as well. Potential data gaps and related needs definitely will serve to enhance the creation and harmonization of urban environmental data which is a crucial aim for better knowledge and management of urban areas.

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