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Urban Ecosystem accounts following the SEEA EA standard: A pilot application in Europe

Report on an Integrated System for Natural Capital Accounting in the EU (INCA)

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Contents

Abstract

National and local authorities are promoting the restoration (re-greening) of urban areas to mitigate societal challenges such as urban heat island effect, poor air quality or biodiversity loss. Urban re-greening is among the implementation actions supporting targets of the European Green Deal, EU Biodiversity Strategy 2030, its proposal for a Nature Restoration Law, and the proposal for an amendment of the Regulation on Environmental Accounts. However, to monitor progress towards policy targets and an overall enhancement of urban ecosystems, policy makers require regular, consistent and comparable data. The implementation of United Nation's System of Environmental Economic Accounting – Ecosystem Accounting (SEEA EA) on urban ecosystems could help to track changes in ecosystems' extent, condition, services and derived benefits. Despite SEEA EA became a statistical standard, it has been only tested in pilot ecosystem accounting exercises, of which very few are urban ecosystem accounts. This report presents a pilot SEEA EA urban ecosystem account for EU-27 and EFTA Member States in 2018. It discusses challenges for the development of urban ecosystem accounts and potential solutions. The outputs illustrate where re-greening efforts should be applied and discusses feasibility and potential issues of targets. The report also presents key insights to operationalise SEEA EA for urban ecosystem accounts. It provides an instructive guiding example to national and local authorities starting to draft their own urban ecosystem accounts.

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1 Introduction

1.1 Background and policy context

The role of urban areas is gaining each time more attention from policy makers and researchers due to their role as source and solution of current societal challenges (Wolfram & Frantzeskaki, 2016; European Commission, 2023). Their relevance has also been reflected in the Sustainable Development Goals, with its 11th goal (*making cities inclusive, safe, resilient and sustainable)* focused specifically on urban areas. This increasing attention is justified on the environmental pressures generated by urban areas, which are responsible for more than 70% of world's greenhouse gas emissions and 80% of the world's energy consumption (UNDP, 2016). They also account for more than 53% of the world's population (United Nations, 2023). In the case of EU, urban population accounts for a 75% of the total population, with an increase of 2% per decade (2000-2020) (United Nations, 2023), which is expected to overpass the 80% by 2050 (Eurostat, 2021). This growth in urban population has been accompanied by an extension of urban areas equal to a 3.4% per decade (2000-2020), which is expected to continue, since additional housing and infrastructure will be required for this increasing population (Zulian et al 2022b). Consequently, urbanisation has become the second largest pressure on natural ecosystems (European Environment Agency, 2020), which has triggered the need for innovative actions, research and policies to face existing and emergent societal challenges such as climate change, biodiversity loss and environmental pollution.

Among the set of innovative actions targeting urban areas, many national and local authorities, in Europe and beyond, are promoting the restoration (re-greening) of urban areas through solutions such as nature-based solutions (NBS)[1] (UNEP-WCMC, 2022). It is expected that those re-greening actions serve to support major EU policy priorities, especially those from the European Green Deal, the derived EU Biodiversity Strategy for 2030, and (Climate) Adaptation Strategy (*Forging a climate resilient Europe*). However, policy makers from international to local levels, as well as professionals supporting them, require regular, consistent and comparable data to monitor the state of nature and the real value of current and future restoration actions. The implementation of the **United Nation's System of Environmental Economic Accounting –** Ecosystem Accounting (SEEA EA) on urban ecosystems could be a suitable approach to establish a common baseline and to track changes in ecosystems**' extent, their condition and derived** services.

Recently, SEEA EA has become a standard statistical framework on ecosystem accounting. Specifically, it is a spatially-based integrated statistical framework for compiling stocks and flows concerning all types of ecosystems, including those of anthropogenic character, such as urban ecosystems and agroecosystems (United Nations, 2021). Its development has been strongly supported by the European Commission, being EUROSTAT a chair of the UN Technical Committee. As part of the EU implementation of SEEA EA, in July 2022 the European Commission (EC) proposed an amendment of the EU Regulation on European environmental accounts, introducing among other changes the development of ecosystem accounts (extent, condition, services [biophysical]).

1.2 Purpose of the report

Despite SEEA EA has advanced from an exploratory statistical framework to a standard, it has been only tested in pilot accounting exercises around the world. At the European level, advances on ecosystem accounting have strongly relied on the project Integrated Natural Capital Accounting (INCA), which builds on the Mapping and Assessment of Ecosystem and their Services (MAES) analytical framework and derived works (e.g., Vysna, et al., 2021). INCA has been jointly developed by the Joint Research Centre, Eurostat, DG Environment, European Environment Agency, and DG Research and Innovation. Among current pilot accounting exercises there are very few ecosystem accounts focused on urban ecosystems (Heris et al., 2021). Moreover, in many cases, they are focused on specific components of urban ecosystems, e.g. urban tree accounting systems (Hanssen et al 2019), and not on the overall ecosystem.

[1] Nature-based solutions are solutions inspired and supported by nature, which are cost-effective, and simultaneously provide environmental, social and economic benefits (European Commission, 2015),

Consequently, a pilot EU accounting focused on urban ecosystem and following SEEA EA rules might help to identify remaining issues and draw key lessons. Information provided by the urban accounts may be relevant to support the achievement of EU policy priorities of the urban agenda.

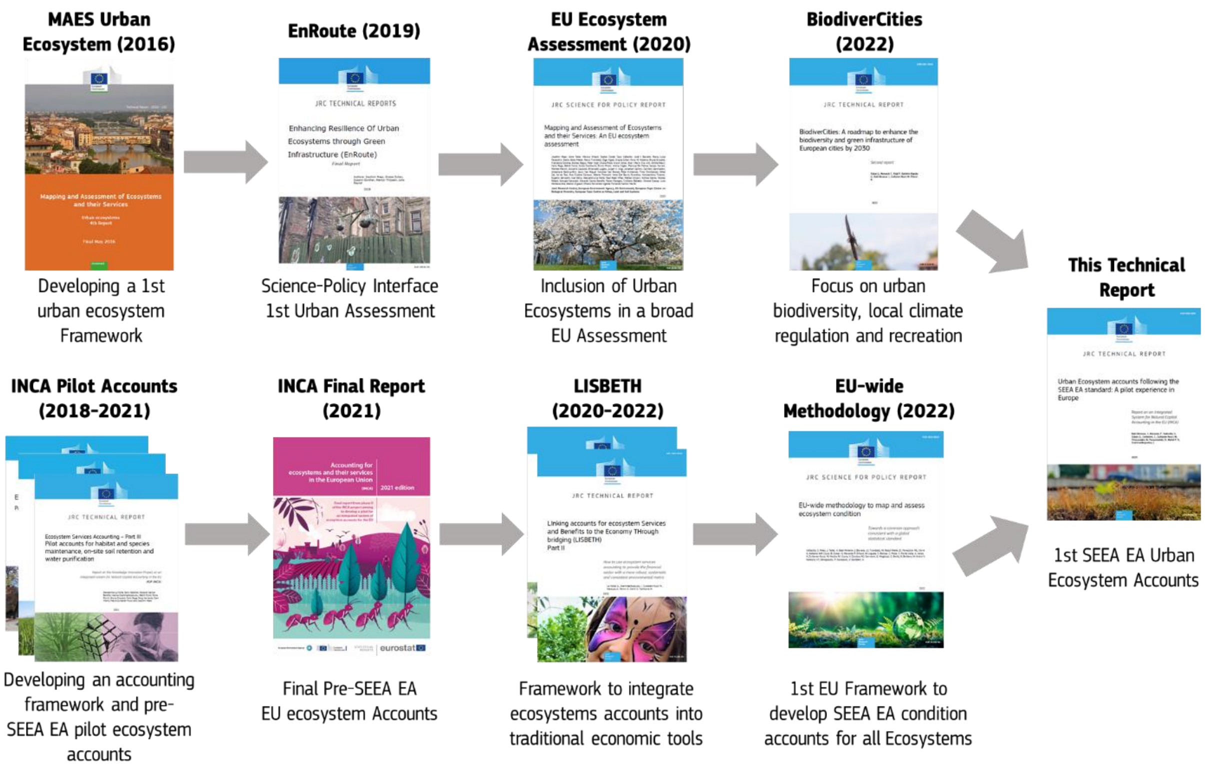
This report presents pilot accounts on urban ecosystems for EU-27 and EFTA (Iceland, Liechtenstein, Norway and Switzerland) Member States (MS) for the year 2018.

1.3 Related JRC research activities and report policy relevance

This study builds on previous JRC research activities (Figure 1) on urban ecosystem assessment and mapping (from MAES), ecosystem accounting (INCA), and on the outputs of BiodiverCities (Zulian et al., 2022b), especially on aspects related to reporting units and analysis of the ecosystem service of local climate regulation provided by urban trees. This study was developed in parallel and in coordination with the EU-wide methodology to map and assess ecosystem condition (Vallecillo et al., 2022) hereafter referred to as “EU-wide methodology”), being aligned with it on aspects related to urban ecosystem extent and condition. It further advances some discussions of the EU-wide methodology on urban ecosystems and presents pilot accounting results.

In terms of policy priorities, this report provides insights and examples for the proposed amendment of the EU Regulation on European environmental accounts (EU Commission 2022a) and the proposal for a Nature Restoration Law (European Commission (2022b), especially regarding urban targets.

Figure 1. Overview of past JRC research activities and their relation to the pilot European urban ecosystem accounting exercise presented in this report.



Source: JRC (own elaboration)

1.4 Aim, specific objectives and structure of the report

The overall aim of this report is to advance the implementation of SEEA EA ecosystem accounts in urban ecosystems. Specifically, this report will illustrate the value of urban accounts to inform on urban ecosystem extent, condition and services. It will also inform on the value of urban accounts to report progress in actions derived from EU policies focused on urban ecosystems. This aim is fulfilled through four specific objectives:

— Identification of current challenges for the implementation of urban ecosystem accounts according to SEEA EA rules (Chapter 2).
— Development of extent accounts for urban ecosystems, which includes providing potential solutions for related challenges such as identification of suitable reporting units and definition of urban ecosystem sub-types (Chapter 3).
— Development of condition accounts for urban ecosystems based on a subset of urban condition variables (imperviousness per inhabitant, share of tree cover, share of urban green, and air pollution) selected in the EU-wide methodology (Chapter 4), and discussion of related challenges.
— Development of ecosystem services accounts for urban ecosystems for air filtration and local climate regulation paving the way to extended urban ecosystem service accounts (Chapter 5).

An overall conclusion is included in Chapter 6, which presents key insights, lessons and further works for technicians and policy makers working on the development of urban ecosystem accounts.

This technical report focuses on SEEA EA ecosystem extent, ecosystem condition, and ecosystem service biophysical flow accounts, which are adopted as part of the international statistical standard. Despite a main purpose of ecosystem accounts is to inform on changes over time, the current pilot is focused on a specific year, since it aims to illustrate the value of urban ecosystem accounts. SEEA EA monetary ecosystem accounts (ecosystem services flow in monetary units, and monetary ecosystem asset) are not included in this report.

2 Towards European urban ecosystem accounts compliant with SEEA-EA: current challenges

Main relevant concepts

Ecosystem accounting area: is the geographical territory for which an ecosystem account is compiled.

Ecosystem assets: are contiguous spaces of a specific ecosystem type characterised by a distinct set of biotic and abiotic components and their interactions.

Ecosystem condition: is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics.

Definitions of other relevant concepts are included in the Glossary at the end of this report.

As briefly introduced in Chapter 1, SEEA EA is a spatially-based integrated statistical framework for compiling ecosystem accounts, per ecosystem type (United Nations, 2021). It is composed of five accounts: ecosystem extent, ecosystem condition, ecosystem services flow in biophysical units, ecosystem services flow in monetary units, and monetary ecosystem asset. SEEA EA also encourages the development of thematic accounts for specific-policy relevant environmental themes such as biodiversity, climate change and urban areas (United Nations, 2021). Thematic accounts benefit from some flexibility regarding SEEA EA rules. Mainstreaming the use of ecosystem accounts is expected to support sectorial and cross-sectorial policy making at national and sub-national levels (Edens et al., 2022; La Notte & Zulian, 2021; Nel & Driver, 2015). For example, informing on the contribution of ecosystems to the economy (Edens et al., 2022; European Commission, 2015); or helping to compare current use of ecosystems services against sustainable references (La Notte & Zulian, 2021). As a result of the methodological advances and policy expectations, countries such as those from the European Union (EU) and the European Free Trade Association (EFTA) are moving from the development of pilot and experimental exercises to the drafting of ecosystem accounting policies explicitly adopting the SEEA EA framework (Bagstad et al., 2021). In fact, compilation of national ecosystem accounts by EU MS might be a requirement in the near future, as planned in the proposed amending EU Regulation on environmental economic accounts (EU Commission 2022a). Therefore, potential issues of SEEA EA need to be solved in advance to ensure an effective legal implementation.

The objective of Chapter 2 is to identify current challenges for the implementation of urban ecosystem accounts in Europe (EU-27 and EFTA countries) according to SEEA EA principles. Insights and lessons collected from previous urban ecosystem accounting exercises, and gathered from experts, are also summarised in this Chapter.

The report distinguishes between conceptual or operational challenges (see Section 2.2). Conceptual challenges refer to the development or adjustment of theoretical definitions needed to operationalize the implementation of urban accounts. For example, ensuring a sound integration of urban ecology concepts and scientifically robust classifications of ecosystem types and sub-types suitable for urban ecosystems. Operational challenges refer to practical developments or refinements needed to set up a clear procedure for the implementation of ecosystem accounts, consistent with the theoretical framework. The identification of challenges and lessons in Chapter 2 acts as a point of reference for the analysis of Chapter 3, 4 and 5, where part of the challenges will be further considered. In a broad sense, the identification of challenges is a first step towards the definition of a common approach to operationalise SEEA EA on urban ecosystem accounts at European level.

2.1 Review of ecosystem accounting studies **and experts' workshop**

The identification of challenges for the implementation of urban ecosystem accounts started from a detailed analysis of the SEEA-EA framework (United Nations, 2021), including the chapter describing the research and development agenda (i.e., list of topics for which further consensus and research is required). Additional challenges were identified via a systematic literature review of grey documents and scientific papers on ecosystem accounting. It was complemented with a synthetic review of studies focused on specific topics relevant for urban ecosystem accounting that were considered in need of in-depth analysis. In both the systematic and the synthetic review, studies focused on other SEEA frameworks (e.g., SEEA-Water) or on challenges related to the interrelation of SEEA-EA with other statistical frameworks were excluded. Studies discussing advances on ecosystem services methods, but with no clear link to challenges of ecosystem accounting were also excluded.

The systematic literature review was split in three steps:

1. An initial set of documents was retrieved from a virtual expert forum[2] and discussion papers of the working groups[3] involved in the development of the current SEEA-EA statistical framework (United Nations, 2021). Several of the retrieved documents were already published as peer-review papers or technical reports, or included references to peer-review papers.

2. The retrieved documents and their relevant references were used as input data to identify other studies on urban ecosystem accounting by making use of the online tool Connected Papers[4]. This tool is based on the concepts of co-citation and bibliographic coupling, and it uses the input paper to build a graph of papers that share references as well as co-citations in other papers. The result identifies relevant (and recent) papers in the area of research. It helps to overcome typical issues of systematic reviews associated with missing keywords in the search strings that could led to missing key references. Once new relevant papers were identified, they were also used as an input in Connected Papers. The process was repeated until no new paper was appearing.

3. Additional scientific papers were searched in Web of Science and Scopus making use of the broad search term "ecosystem account*" and limiting the studies to those written in English language. This last step was used to double-check that relevant references were not missing.

Following the systematic review, which retrieved 79 papers (see Annex I – Table I.1), the synthetic review focused on two topics, in a broad perspective, in order to identify any operational or conceptual challenge:

1. Classification, description and spatial delimitation of urban ecosystems;

2. Ecological condition, integrity and health of urban ecosystems;

These topics relate to multiple conceptual challenges already identified in the systematic review. For each topic, an initial set (group) of known valuable studies identified by the authors by expert opinion was further expanded making use of Connected Papers, following the logic already explained above. The additional studies identified, 26 studies (see Annex I – Table I.2), helped to clarify challenges or provided suitable solutions for them or permitted to derive useful reflections.

Among all the studies collected, a subset were recent pilot urban ecosystem accounting exercises from which lessons were drawn regarding specific challenges. Those lessons do not represent final solutions, but suitable alternatives to be considered.

To complement the identification of challenges, and the lessons from pilot studies and the synthetic review, insights from experts were also gathered via a short workshop. First, JRC experts on other ecosystem types were consulted and the list of urban ecosystem accounting challenges was shared with them. This initial consultation confirmed that in most cases challenges are also relevant for accounts of other ecosystem types. The consultation was extended to additional experts via a workshop organised during the European Ecosystem Services Partnership Conference of 2022 (12th October 2022, Crete [Greece]). The experts involved were asked to share in advance challenges that they had already identified or experienced. They were also informed about the challenges retrieved in the previous steps, which were described before the beginning of the workshop. The panel was not restricted to urban ecosystem experts. It was considered that insights and solutions applied in other ecosystems sharing similar challenges could be valuable independently on whether they were originally framed for urban ecosystem accounting.

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[2] Source: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020
[3] Source: https://seea.un.org/content/seea-eea-revision-research-areas
[4] Accessible at: https://www.connectedpapers.com

2.2 Key challenges, lessons learned and insights from experts

2.2.1 Identification of key conceptual and operational challenges

The challenges identified in the literature review have been summarized in Table 1. Experts participating to the workshop did not inform on new challenges, since those shared in advance by them overlap with the ones from the literature. The challenges have been organized in four broad categories related to specific issues or specific types of accounts (e.g., extent, condition). Each category includes conceptual and operational challenges, except for the category practical bottlenecks that refer specifically to operational issues related to technical knowledge, data limitations and data infrastructure. Only some key references are provided per challenge together with a short description. For an exhaustive list of the literature retrieved, please see Annex I (Table I.1 and I.2).

In this studt, it was not possible to test suitable solutions for all the challenges identified. Table 1 indicates the chapter in which each challenge is discussed. Chapter 3 discusses challenges related to urban ecosystem extent accounts. Chapter 4 and Chapter 5 discuss challenges related to accounts on ecosystem condition and ecosystem services respectively. Those challenges that were not considered during the development of the EU-27 and EFTA pilot urban ecosystem accounts, are further described in Chapter 6 in relation to future research.

Table 1. Summary of conceptual (C) and operational (O) challenges identified for urban ecosystem accounts

Category	Conceptual (C) and operational (O) challenges	Description	Further details	Key references
Ecosystem extent accounts	Distinction between urban ecosystems and artificial surfaces (C)	Urban ecosystems correspond to more than the strict artificial surfaces that form an urban area (Vallecillo et al., 2022). At the same time, artificial surfaces exist also outside urban areas. SEEA EA recognises the special character of urban areas by allowing the development of thematic accounts. Despite this recognition there is still no clear differentiation in terms of spatial delineation of what corresponds to an urban ecosystem for ecosystem accounting purposes. It is also still necessary to differentiate for which ecosystem accounting purposes delineation of urban ecosystems or (only) urban artificial surfaces are required.	Discussed in Chapter 3	Virtual Expert Forum SEEA EEA. 2020a, 2000b,
	Delineation of urban ecosystems as landscape mosaics (C)	Urban ecosystems represent landscape mosaics not only made of artificial surfaces but that include other multiple “natural” ecosystem types (e.g. forests, grasslands) and therefore ecosystem assets. This contradicts the spatial perspective of SEEA EA, which define ecosystem assets as mutually exclusive spatial occurrences. A reconciliation between SEEA EA rules and the urban ecology perspective of urban ecosystem as a mosaic landscape is possible via thematic accounts, but this aspect is not clarified yet.	Discussed in Chapter 3	Virtual Expert Forum SEEA EEA. 2020c, 2020l, 2020m
	Minimum size and other criteria to form an urban ecosystem accounting area (C)	SEEA EA does not indicate a common set of criteria to define what an urban ecosystem is and what is not. As a result, the concept remains vague for accounting purposes and different countries, might apply different criteria leading to a non-harmonic delineation of urban ecosystem accounting areas. As a consequence, comparability or exchange of data, even for policy purposes would not be possible.	Discussed in Chapter 3	Wang et al.,2019
	Clustering of urban ecosystems in sub-functional groups (C)	As for any other ecosystem type, urban ecosystems need to be clustered/split in sub-functional groups (referred to as homogeneous ecosystem areas in the EU-wide Methodology). This is recognised for other ecosystems in the IUCN Global Ecosystem Typology (SEEA EA reference) such as forests which are clustered by temperature and water deficit gradient. However, it is not anticipated in the case of urban ecosystems. A lack of clustering might lead to unfair comparisons among urban ecosystems belonging to different sub-functional groups as well as	Remaining gap discussed in Chapter 6	Wang et al.,2019

Category	Conceptual (C) and operational (O) challenges	Description	Further details	Key references
		an inadequate definition of ecosystem condition reference levels. Those issues might have consequences when ecosystem accounts should inform policy priorities or targets or their monitoring.		
	Internal differentiation of single urban ecosystems in more detailed ecosystem types (C)	It should be possible to decompose single urban ecosystem accounting areas representing an urban ecosystem mosaic into more detailed ecosystem types. As it occurs with the general definition of urban ecosystems, and their clustering in sub-functional groups, their internal differentiation in detailed ecosystem types need to be done in coordination among different stakeholders to permit future comparisons, exchange of data and lessons.	Exploratory analysis developed in Chapter 3	Wang et al.,2019
	Coherence between delineation of urban ecosystem assets and reporting units and national vs. local policy making (O)	SEEA EA ecosystem accounts have been originally developed for national and international policy scopes. However, there is a great recognised potential of urban ecosystem accounting to also serve local policy needs. Therefore, definition of urban ecosystem assets and reporting units should be adequate for both, national and local policy scopes.	Discussed in Chapter 3	Virtual Expert Forum SEEA EEA. 2020e; Wang et al.,2019
Ecosystem condition accounts	Differentiation of ecosystem condition and ecosystem extent accounts (O)	The separation of ecosystem extent and condition accounts could become blurred when delineating ecosystem sub-types. The latter might be defined by gradients of characteristics that correspond to condition variables at higher levels of aggregation. To avoid problems, such as accounting artefacts, further rules might be required before full ecosystem accounting implementation.	Briefly discussed in Chapter 2 and 4	Virtual Expert Forum SEEA EEA. 2020a, 2020e, 2020f
	Selection of a common minimum set of ecosystem condition variables and reference conditions (O)	In the case of urban ecosystems, the relationship between ecosystem condition variables and ecosystem services flows needs to be further clarified. A balance between the aims of ecosystem condition and services accounts is needed to avoid excessive constraints in the selection of condition variables. Selection of a suitable set of variables is constrained to the feasibility of identifying reference levels for them. For anthropogenic ecosystems, optimal supply of ecosystem services (as a consequence of optimal condition) might be a suitable approach to define reference levels.	Discussed in Chapter 4 and 6	United Nations, 2021
	Condition variables to describe anthropogenic ecosystems as socio-ecological-technological systems (C)	Urban ecosystems, as any other anthropogenic ecosystem, are socio-ecological-technological systems, where humans and their technology are a fundamental component. SEEA EA ecosystem condition accounts need to be expanded in the case of urban ecosystems, and the selection of condition variables should go beyond ecological variables strictly related	Briefly discussed in Chapter 2, 4	Virtual Expert Forum SEEA EEA. 2020l, 2020m; Vallecillo et al., 2022

Category	Conceptual (C) and operational (O) challenges	Description	Further details	Key references
		to natural features.		
	Reference conditions for anthropogenic ecosystems not grounded on a classic rational of ecological integrity (C)	Underpinning reference ecosystem condition to a classical conceptualisation of ecological integrity is not fully applicable to anthropogenic ecosystems. The same holds true for the concept of restoration, not commonly attached and applicable to those ecosystems. An adaptation of concepts is needed in the case of urban ecosystems.	Briefly discussed in Chapter 2, 4 and 6	Vallecillo et al., 2022; Keith et al 2019
	Aggregation of ecosystem condition indicators into synthetic indices (O)	Aggregation into a condition index is an optional step in the statistical standard. SEEA EA is open in terms of the most suitable approach for the aggregation of ecosystem condition indicators into indices. Before full implementation common approaches should be agreed among national and/or local authorities.	Briefly discussed in Chapter 2 and Chapter 6	Virtual Expert Forum SEEA EEA. 2020l, 2020m; United Nations, 2021
	Full consideration of ecosystem degradation via ecosystem condition accounts (C)	Urban ecosystems already place a great pressure (and direct and indirect impact) on other ecosystems at regional and global level. This pressure should be also captured in urban ecosystem condition accounts, to better inform on how urban ecosystems influence ecosystem degradation elsewhere	Remaining gap discussed in Chapter 6	Markandya et al., 2019, Wang et al., 2019
Ecosystem services accounts	Consensus in the definition of ecosystem capacity and its links with accounts of ecosystem extent and condition (C)	The links between the concept of ecosystem capacity and ecosystem extent and condition should be further considered. Specific aspects to be further analysed are the implications of a systemic definition of ecosystem capacity, especially regarding definition and measurement of ecosystem degradation and the definition of optimal (reference) conditions.	Briefly discussed in Chapter 5 and 6	United Nations, 2021
	Complementary valuation of ecosystem services and assets, (C)	Besides exchange values, other complementary valuation approaches that might also help decision making are not yet developed. This includes the assessment of disservices and negative externalities. It might also include consideration of disparity in the access to services. The last information might also help to inform reference condition in an urban ecosystem asset, which should be representative of reference (optimal) condition for all the humans inhabiting the asset.	Remaining gap discussed in Chapter 6	Markandya et al., 2019, Wang et al., 2019; United Nations, 2021
	Clear principles and practices for the accounting of intermediate ecosystem services (O)	Recognising flows of ecosystem services between ecosystem assets, even if they are not final services (i.e., received by an economic unit) might help to track exchanges among assets and their dependencies. By tracking them, the accounting system will support the development of ecological production functions that describe linkages among ecosystem assets in the supply of services. Therefore, establishment of clear	Remaining gap discussed in Chapter 6	Hein et al., 2019

Category	Conceptual (C) and operational (O) challenges	Description	Further details	Key references
		principles and practices for these intermediate accounts, even when they are not final services, is also necessary.		
Uncertainty in ecosystem accounts	Assessing and reporting uncertainty in ecosystem accounts (C)	There is a lack of reflection on the need or not of reporting uncertainty There is also a lack of uncertainty estimation guidance and what is an acceptable level of uncertainty for the different ecosystem accounts.	Remaining gap discussed in Chapter 6	Virtual Expert Forum SEEA EEA. 2020i,j,k
Practical bottlenecks for national and local implementation and data exchange	Few illustrative pilot ecosystem accounts, especially for some account types (e.g., ecosystem condition), and lack of practical guidance (O)	Many existing accounting pilot experiences do not fulfil rules of SEEA EA, especially for some accounts such as ecosystem condition. Due to the novelty of the standard there is a lack of practical guidance and pilot accounts. This is especially true also for urban ecosystem accounts.	Pilot accounts presented in Chapter 3,4 and 5	United Nations, 2021
	Conceptual and technical complexity of ecosystem accounts, which makes them knowledge, time and resource demanding (O)	The conceptual and technical complexity requires training associated with the framework, data collection protocols and compilation of accounts. Accounts would need to be regularly updated, therefore their development will not be a one-time effort and would require a strong protocol in place (including quality controls) for which a specific budget allocation is needed.	Remaining gap introduced in Chapter 6	Virtual Expert Forum SEEA EEA. 2020n, 2020o; United Nations, 2021
	Lack of consensus on input data, data quality standards, principles and practices, and agreed generalizable models for accounts (O)	Input data will need to be collated and integrated from multiple sources, which will require consensus in terms of data quality standards. There is still lack of common principles and protocols in terms of accessibility of input and output ecosystem accounting data as well as on agreed generalizable models (e.g. ecosystem services models). Lack of coherence in input data, standards, models and principles might jeopardise comparability and exchange of information between ecosystem accounts developed by different stakeholders.	Remaining gap introduced in Chapter 6	United Nations, 2021
	Lack of principles and practices for the development of spatial data infrastructures for ecosystem accounting that support interoperability and data sharing among stakeholders (O)	A common framework for the development of spatial data infrastructures that can easily communicate and exchange data or be shared by multiple stakeholders will be necessary before a full implementation. It might be especially important if as part of the scope of ecosystem accounts, data will need to be exchange between public authorities and private organisations such as businesses.	Remaining gap introduced in Chapter 6	United Nations, 2021

Source: JRC Analysis

2.2.2 Key examples from recent urban ecosystem accounting experiences and the synthetic review

Recent urban ecosystem accounting applications and the synthetic review provided key lessons learned on five challenges that are summarised in the following lines. Further details can be found in Annex I – Table I.3.

Purpose of urban ecosystem accounts

Regarding the purpose of urban ecosystem accounts, Cryle et al., (2021) informed on their value beyond their roles as satellite national ecosystem accounts. They emphasized that urban ecosystem accounts, especially thematic, should be used as an opportunity to inform public policy related to:

- urban planning,
- urban management, and
- investment decisions.

These potential uses should therefore influence how urban ecosystem accounts are draft. In terms of investment decisions, it was emphasized the potential roles of accounts on deciding about future interventions such as those related to nature-based solutions. To better support the potential uses in decision making, it was recommended to include in urban ecosystem accounts auxiliary data such as expenditure on management and restoration of ecosystem assets, disservices derived from urban ecosystem assets and socio-economic distribution of benefits derived from ecosystem services (i.e., local environmental justice considerations).

Differentiation of urban ecosystem accounts, spatial delineation of accounting areas and reporting units

It is highlighted by several sources that urban ecosystem should be more than accounts referring strictly to artificial surfaces as an ecosystem type (EFTEC 2017; ONS 2019; Grenier et al., 2020). They should include green and blue open spaces embedded in between patches of artificial surfaces, but also surrounding them (i.e., periurban green and blue open spaces). To capture urban ecosystems as accurately as possible in terms of spatial delineation, and reporting units, several options have been already applied:

- buffers around built-up areas (EFTEC, 2017 and ONS 2019);
- municipal boundaries with a constraint on population number to differentiate between urban and rural municipalities (Heris et al., 2021)
- OECD functional urban areas, city statistical areas, metropolitan region (Cryle et al., 2021);

Clustering of urban ecosystems in sub-functional groups

For the clustering of urban ecosystems in sub-functional groups, two main alternatives have been proposed:

- Clustering based on physical composition and configuration metrics representing properties such as compactness, centrality, complexity, porosity (Lemoine-Rodriguez et al., 2020)
- Clustering based on the above metrics plus socio-economic factors such as population density, population, and density of infrastructure features or artefacts per person (e.g. vehicles per inhabitant) (Schwarz 2010; Huang et al 2007).

Additionally, the EU-wide Methodology (Vallecillo et al., 2022) composition and configuration metrics and socio-economic factors also recommends the use of geophysical characteristics (e.g. climate zones) for the definition of clusters.

Internal differentiation of single urban ecosystems in more detailed ecosystems types

For the internal differentiation of single urban ecosystems in more detailed ecosystem types, four main alternatives have been suggested:

— The use of local climate zone classification (Stewart and Oke, 2009);
— The use of aggregated land cover classifications such as CORINE (Heris et al., 2021; Petersen et al., 2022);
— The development of specific urban land cover classifications based on the combination of different types of biophysical characteristics such as buildings, surface materials, water, vegetation, and vegetation height (Zhou et al., 2014; Hamstead et al., 2016);
— The differentiation of urban ecosystems along an urban gradient (e.g. core area, inner area, suburban) based on built up area density and/or population density (Dong et al., 2019).

Reference conditions for anthropogenic ecosystems not grounded on a classic rational of ecological integrity

For the identification of reference condition in urban ecosystems, urban ecosystem health was identified as a valuable underpinning concept in the synthetic review. Ecosystem health should always include the human dimension, and therefore, how urban ecosystem condition influences human health (Guo et al., 2002; Guo 2003). It was also highlighted the need to consider also the social and technological dimension, when evaluating urban ecosystem processes that might influence urban ecosystem health, and therefore condition (Alberti et al., 2003, 2010; Meerow et al., 2016). To identify reference conditions for urban ecosystems, it was suggested to rely on comparative assessments based on the current conditions of existing urban ecosystem assets or future scenarios for them (Guo et al., 2002). The approach suggested is similar to the definition of best-attainable conditions by the use of statistical approaches based on ambient distributions, as suggested in the Annex 5.2, Table 5.9 of SEEA EA (United Nations, 2021).

2.2.3 Key insights from the expert workshop

Relevant insights gathered for eight challenges are described below. In some cases, alternatives were proposed, illustrated with short examples. In other cases, the feedback only emphasized the relevance of some challenges for specific accounts or methodological decisions to be considered for developing them.

Clustering of ecosystem in sub-functional groups

Experts strongly suggested to cluster ecosystem types in sub-functional groups based on agreed-upon criteria for differentiating sub-ecosystems at national and international level (e.g., among EU and EFTA countries). Despite works might be done independently by each responsible authority, ensuring some level of coordination will permit the development of crosswalks at European level. They will ensure that exchange of data is possible for ecosystem sub-types.

This clustering was considered important also in the case of anthropogenic ecosystems such as urban ecosystems. It was stressed the relevance of comparing only urban ecosystems among those of the same sub-functional group to avoid misleading comparisons. The clustering was also considered relevant for an appropriate definition of reference levels.

Differentiation of ecosystem condition and ecosystem extent accounts

Two main alternatives were proposed:

— For the differentiation of ecosystem sub-types, it should be avoided the use of characteristics (and gradients of variables representing them) that might be suitable condition variables.
— When the above option is not possible, especially at detailed levels of ecosystem differentiation, the use of a variable should be prioritized for the most suitable type of account (extent or condition).

In the case of urban ecosystems, the first alternative can be applied by prioritizing the use of auxiliary data such as population density, which will not be suitable condition variables, for the differentiation of urban ecosystem sub-types. The second alternative applies to the case of features such as hedgerows, tree lines and small forested areas (sometimes referred as "landscape features"). When the spatial resolution of available data allows it, they should be treated as sub-ecosystem types instead of using them in relation to a condition variable (e.g. linear density of hedgerows). This rationale considers that for the accounts of some services, such as soil retention, might be necessary to know the location of features such as hedgerows. Therefore, mapping them as ecosystem assets (prioritizing the use in ecosystem extent accounts), when working at detailed levels of ecosystem type differentiation, might be more helpful than accounting them in ecosystem condition accounts. This decision does not prevent to use the same variables as condition variables at higher levels of ecosystem type aggregation.

For the same challenge, experts also pointed out that morphological attributes, such as size and shape of single ecosystem assets, especially at high level of ecosystem sub-type differentiation, could be valuable condition variables. Those attributes should not be seen strictly associated to ecosystem extent accounts. For example, size of specific ecosystem assets is considered in the index of condition (IBECO) developed by the Norwegian Institute of Nature Research for forests (Framstad et al., 2022). In fact, size and shape of ecosystem assets might represent condition variables for which reference levels might be identified by using a best-attainable condition approach.

Condition variables beyond pure ecological characteristics to describe anthropogenic ecosystems

Whenever possible, it was strongly suggested to not include variables beyond the ecological dimension in ecosystem condition accounts. However, it was also recommended to monitor and report key auxiliary variables used in those accounts, which might not relate to the condition dimension. For example, for urban ecosystems, variables such as ownership of green space or their accessibility, which might inform on the equitable distribution of some services, should be monitored and reported despite they might be considered auxiliary.

It was also recognised that there has been little reflection on the need to integrate condition variables related to the social and technological dimensions, in the case of anthropogenic ecosystems such as urban ecosystems and agroecosystems. It was acknowledged the potential value of investigating this topic for anthropogenic ecosystems, which would allow a more informed discussion and future recommendations.

Reference conditions for anthropogenic ecosystems not grounded on a classic rational of ecological integrity

It was acknowledged that in some cases underpinning concepts of ecosystem condition, such as ecological integrity, might generate issues when applying them, since they do not fit all ecosystem types. As a result, they are not being useful in guiding works on steps such as defining reference conditions for some ecosystem types such as urban ecosystems. In those cases, it was suggested to use and interpret underpinning ecosystem condition concepts in a flexible way. It was also acknowledged that future updates of SEEA EA or their implementation in specific contexts should be more careful with the use of general concepts that might not suit all ecosystem types.

As a general remark, for reference levels in anthropogenic ecosystems such as urban ecosystems, the use of a best attainable approach was suggested as a default suitable approach for defining reference levels. Best attainable conditions can be defined by sampling the values in similar ecosystem sub-types, being an appropriate clustering of ecosystem sub-types highly relevant. It was also emphasized that values should pass a validation assessment to ensure statistical significance of the results and to avoid setting ecologically meaningless reference values.

Aggregation of ecosystem condition indicators into synthetic indices

There were doubts raised about the real ecological meaning of aggregating ecosystem condition indicators into indices, especially regarding the development of a final single ecosystem condition index. The development of that single index, especially the weighting of components appeared subjective. In some cases those weights cannot be defined based on empirical analysis and would rely on expert opinion. It was also considered relevant to investigate the propagation of potential errors associated with the aggregation, which somehow related to the consideration of uncertainty in ecosystem accounting.

Experts also stressed that the aggregation should be done in a different way depending on its final purpose, including policy purposes. For example, optimal condition might (or not) need to consider how condition influences optimal supply of ecosystem services. Including this kind of constraint will influence the weighting of single condition indicators. Implicitly this issue is associated with how anthropocentric or non-anthropocentric is the value perspective applied when developing the accounts. In the case of some anthropogenic ecosystem types, such as urban ecosystems, a highly anthropogenic perspective might be appropriate, but this might not be the case for the condition accounts of other ecosystem types. Additionally, whether the aggregated indexes should inform single policy topics (e.g. biodiversity) or multiple topics (e.g. biodiversity and ecosystem condition for human health) will influence what is considered optimal condition and therefore the weighting applied to develop indices.

In terms of credibility, experts suggested that the aggregation should be considered credible and legitimate by scientists, policy makers and when possible society (or groups representing them). This is especially relevant in those cases, where aggregation will be based on expert opinion and not on empirical analysis.

<u>Assessing and reporting uncertainty in ecosystem accounts</u>

Experts agreed on the need of considering and reporting uncertainty as part of ecosystem accounts. It was suggested the option of exploring the applicability of the standardized uncertainty scales used in IPCC and IPBES reports. It was also suggested to investigate more than one methodological approach for reporting uncertainty, before agreeing and implementing a specific one.

<u>Few illustrative pilot ecosystem accounts and lack of practical guidance</u>

Experts emphasized the need of having a general guidance with some specific details at ecosystem level to support the implementation of these accounts by national and local authorities. It was also stressed that different guidance should be designed for public and private organizations. They stressed the value that ecosystem accounting data could have as part of the reporting (e.g. sustainability reporting) of private organizations and the importance of considering their needs also at early stages of the ecosystem accounting implementation. Among other reasons because a common language and shared frameworks will ensure communication and exchange of data and knowledge.

<u>Conceptual and technical complexity of ecosystem accounts, which makes them knowledge, time and resource demanding</u>

Experts agreed that excessive knowledge, time and resource demand should be (and can be) minimized by using a minimum common set of core indicators among different national authorities and among private organisations. The minimum set can be combined with indicators that are not shared, since are specific of the interest of few parties. Moreover, it was suggested that specific training should be organized for private practitioners and public officers. As part of this training it would be relevant to clearly explain to them why these accounts are relevant and the derived benefit that could derive from them in terms of informing public and private policies.

2.3 Key messages

Considerations when implementing urban ecosystem accounts

— For accounting purposes, urban ecosystems should be differentiated from artificial surfaces, since urban ecosystems are also formed by green and blue open spaces, including those of periurban contexts;

- Policy purposes for urban accounts influence the delineation of ecosystem accounting areas and the selection of reporting units;
- Urban ecosystems, similarly to other ecosystem types like natural ecosystems, should be clustered in upon agreed sub-functional groups for which reference conditions should be defined specifically;
- Urban ecosystems are landscape mosaics that can be internally differentiated in further disaggregated ecosystem sub-types;
- Future research should investigate the potential added value of considering the social and technological dimensions in urban ecosystem accounts, as auxiliary or core variables accounted.

3 Urban Extent Ecosystem Accounts

As described in Chapter 2, some of the current SEEA EA challenges are related to ecosystem extent accounts (see Table 1). Chapter 3 briefly discusses solutions considered for those challenges (Section 3.1 and 3.2) considered during the development of the pilot accounts for urban ecosystems at European level (Section 3.3). As indicated in Chapter 1 (Section 1.3), this technical report is strongly related to the research activities developed in BiodiverCities (Zulian et al., 2022b) and EU-wide Methodology (Vallecillo et al., 2022). As a result, some challenges have been partially considered in previous reports and some analysis have been already developed. For those cases, this report will provide brief descriptions and will refer to specific sections in the EU-wide Methodology and BiodiverCities for further details.

3.1 Distinction and delineation of accounts for urban ecosystems and settlements and other artificial surfaces

In terms of ecosystem type classification, this report follows the SEEA EA recommendation and uses the IUCN Ecosystem Typology as a reference. Specifically, it follows the current recommendations of a Task force on Ecosystem Accounting formed by EUROSTAT and statistical offices of several Member States (MS) of EU-27 and EFTA. Among other activities, the Task force is developing a guidance note on ecosystem extent accounts, which includes an EU ecosystem typology for accounting purposes. This report makes uses of the EU ecosystem typology of Eurostat at Level 1 (Table 2).

Table 2. EU ecosystem typology Level 1

Category	Name of ecosystem type
1	Settlements and other artificial areas
2	Cropland
3	Grassland (pastures, semi-natural and natural grasslands)
4	Forest and woodland
5	Heathland and shrub
6	Sparsely vegetated ecosystems
7	Inland wetlands
8	Rivers and canals
9	Lakes and reservoirs
10	Marine inlets and transitional waters
11	Coastal beaches, dunes and wetlands
12	Marine ecosystems (coastal waters, shelf and open ocean)

Source: Task Force Ecosystem Accounting

Each ecosystem type corresponds to an aggregation of specific CORINE land cover classes Level 3. There are only two land cover classes (“beaches, dunes and sand” and “bare rocks”) that can belong to more than one ecosystem type Level 1 (categories 6 and 11 in Table 1), for which the allocation to specific ecosystem types is done making use of additional rules. The correspondence table between specific CORINE land cover classes and ecosystem types is included in Annex II – Table II. 1. In Annex II, there is also a brief description of the additional steps applied to allocate “beaches, dunes and sand” and “bare rocks”[5] land cover classes to Sparsely vegetated ecosystems or to Coastal beaches, dunes and wetlands depending on their geographical position.

The ecosystem type “settlements and other artificial areas” refers to any artificial land cover, including mineral extraction sites, roads or railways or landfills of any kind, independently of their relation or not to urban areas. It also refers to any kind of built feature, independently of their urban or rural character. This

[5] The procedure to allocate both land cover classes to a specific ecosystem type are still being discussed in the Task force by the time this Technical Report is published. Therefore, the allocation rules used in this report might not represent the final set of allocation rules proposed in the Task force.

means that individual buildings embedded in natural ecosystems will also belong to this ecosystem type. However, this kind of ecosystem definition does not represent urban ecosystems because:

- it includes human artefacts of any kind;
- it accepts single artificial objects independently of the context in which they are embedded; and
- it does not include periurban green and blue open spaces that despite their non-artificial nature are urban in character.

Similar concerns were already raised during the last SEEA EEA expert forum (Virtual Expert Forum SEEA EEA. 2020a, 2000b,) and the development of the EU-wide Methodology (Vallecillo et al., 2022). As a result, for ecosystem accounting purposes, it cannot be assumed that the ecosystem type "settlements and other artificial areas" represents urban ecosystems due to conceptual differences. In a broad sense, the concept of urban ecosystem refers to the densely built and populated artificial zones that form urban areas and the surrounding green and blue open spaces strongly related to them. According to this conceptualisation, in an urban ecosystem built-up areas are only one of the components of a complex mosaic formed by ecosystem types such as agroecosystems, forests and freshwater ecosystems (Maes et al., 2020a). This differentiation between urban ecosystems and "settlements and other artificial areas" is also consistent with the lessons and insights presented in Chapter 2.

As a consequence of the above rationale, the definition of ecosystem accounting areas for **"settlements and other artificial areas" and "urban ecosystems" should follow two** different approaches, as described in detail in the EU-wide Methodology (Vallecillo et al., 2022). In the first case, a general approach should be applied. This approach omits overlaps with other ecosystem types for what concerns delineation of ecosystem types and their assets. It should be the preferred approach when the aim is to develop spatially exhaustive accounts for all the ecosystems of an entire territory, such as the entire territory of EU-27 and EFTA MS (Figure 2A). Instead, when the focus should remain specifically on urban ecosystems, a thematic approach (i.e., urban ecosystem accounts), should be used. In this second case, the scope of analysis is narrowed down to highly urbanised zones and their surroundings, whose extent defines the ecosystem accounting area.

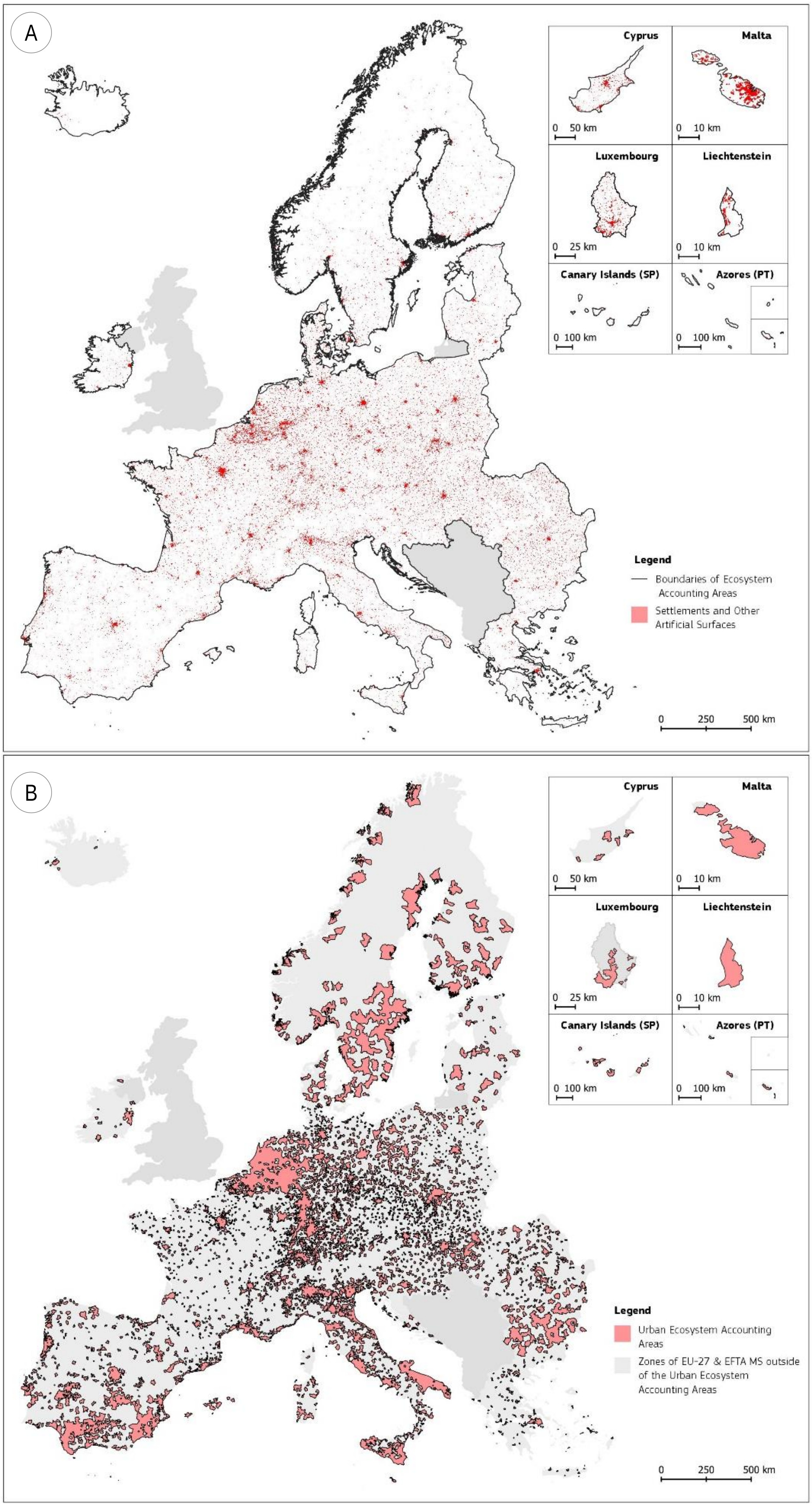
As anticipated in Chapter 2 – Section 2.2.2, recent pilots of urban ecosystem accounts have already proposed several alternatives to define ecosystem accounting areas. Two of the alternatives proposed use population constraints and local political boundaries to differentiate areas of rural and urban character (Heris et al., 2021; Cryle et al., 2021). By considering local political boundaries, both alternatives are suitable for developing thematic ecosystem accounts that among their policy uses include informing local urban policies. For the case of EU-27 and EFTA MS, both alternatives can be translated in the definition of ecosystem accounting areas by making use of the extent of two EU regulated territorial units:

- Local Administrative Units (LAU) classified as "cities", "towns and suburbs" according to the Degree of Urbanisation (Regulation (EU) 2017/2391; EUROSTAT, 2018);
- Functional Urban Areas[6] (FUA) (Regulation (EU) 2017/2391; EUROSTAT, 2018).

An exploratory analysis comparing both territorial units for the definition of urban ecosystem areas have already been developed in BiodiverCities – Section 2.1 (Zulian et al., 2022b). This study shows that making use of FUA leaves out a 20.7% of the urban population and a significant part of settlements classified as towns and suburbs. Therefore, the use of all LAU classified as "cities", "towns and suburbs" (hereafter urban LAU) was considered more suitable for the definition of urban ecosystem accounting areas in Europe (Figure 2B). Annex II – Figure II.1 differentiate types of urban LAU in the urban ecosystem accounting area for EU-27 and EFTA MS.

[6] Functional urban areas are formed by cities and their commuting zone, which might encapsulate rural areas. Both, cities and the commuting zones are formed by single local administrative units, and therefore also defined according local political boundaries.

Figure 2. Ecosystem accounting areas in EU-27 and EFTA MS. A) according to the general approach, including only Settlements and Other Artificial Areas; B) according to the thematic approach (urban ecosystem accounting areas)



Source: JRC (own elaboration)

For this report, the urban ecosystem accounting area for EU-27 and EFTA MS was defined making use of the most updated LAU dataset classified according to the Degree of Urbanisation (LAU 2020[7]). Like in BiodiverCities, the dataset was corrected to remove LAU misclassified as "cities" or "towns and suburbs". The rules applied to correct misclassified urban LAU are included in Annex II. Figure 2b represents the refined ecosystem accounting area and simple clustering of urban LAU according to population and population density factors (i.e., cities above 50,000 inhabitants, cities below 50,000 inhabitants, towns and suburbs). Section 3.3, presents the pilot urban ecosystem extent accounts using this clustering of urban LAU.

3.2 Definition of reporting units, urban ecosystem sub-types and assets suitable for national and local policy purposes

As introduced in Chapter 2, the policy purposes of the ecosystem accounts will influence the definition of reporting units, and in some cases the definition of ecosystem types and their assets. In EU, it is expected that ecosystem accounts, including thematic urban ecosystem accounts, would be developed to fulfil obligations of the proposed amendment of the EU Regulation on environmental accounts (European Commission, 2022a). It is also expected that these accounts would be valuable to monitor the progress of MS on targets of the proposed Nature Restoration Law (European Commission, 2022b). However, as emphasized in few references (e.g., Cryle et al., 2021), urban ecosystem accounts could be also a valuable tool to inform local urban policy purposes. Hence, to maximise the value of urban ecosystem accounts for EU-27 and EFTA MS they should be developed to be suitable for local and national policy purposes.

By making use of ecosystem accounting areas that correspond to the extent of all the urban LAU in EU-27 and EFTA MS, the use of individual LAU as a minimum reporting unit are a convenient solution. LAU usually correspond to the lowest administrative divisions within a country (EUROSTAT, 2018). In most EU and EFTA MS, LAU correspond to municipalities or communes. Local urban policies are usually defined at the level of municipalities or an aggregation of municipalities (e.g., metropolitan areas), making LAU a suitable reporting unit for local policy purposes. Concurrently, outputs of ecosystem accounts at LAU level can be further aggregated at different NUTS Level (1, 2, 3) or at national level (NUTS Level 0) in case they should serve regional or national policy purposes. Therefore, the use of LAU as minimum reporting units permits the development of urban ecosystem accounts suitable for national and local policy purposes.

For the subdivision of urban ecosystems in single ecosystem types or sub-types[8], it becomes relevant to ensure the interoperability between thematic urban ecosystem accounts and general national ecosystem accounts. This will help to avoid double counting issues as well as to permit the exchange of data between accounting systems. For example, it would permit to transfer data collected by local authorities for their urban ecosystem accounts to spatially exhaustive national ecosystem accounts without interoperability issues. Consequently, as one of the alternatives suggested in Cryle et al. (2021) urban ecosystems should be subdivided in single ecosystem types by making use of the same ecosystem typology of general national ecosystem accounts. In the case of EU-27 and EFTA MS accounts, by making use of the EU ecosystem typology Level 1, as presented in Table 1.

The use of the EU ecosystem typology does not impede their further subdivision in sub-types that are only relevant for thematic urban ecosystem accounts. For example, making use of specific urban land cover classifications such as STURLA or HERCULES (Zhou et al., 2014; Hamstead et al., 2016) or sub-ecosystem types defined through an urban gradient approach (Dong et al., 2019). In the pilot urban ecosystem extent accounts presented in Section 3.3, CLC+ Backbone raster land cover classes[9][10] were tested as potential ecosystem sub-types.

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[7] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba

[8] For clarity, hereafter when referring to EUROSTAT EU ecosystem types at Level 1 the term "ecosystem type" is used. Instead, the term "ecosystem sub-type" is used when referring to a further disaggregation of ecosystems in more detailed types.

[9] https://land.copernicus.eu/pan-european/clc-plus/clc-backbone

[10] CLC+ Backbone was internally validated, but external validations is still pending. For the purposes of this report, The Environment Agency provided early access to the dataset, which is publicly accessible since January 2023

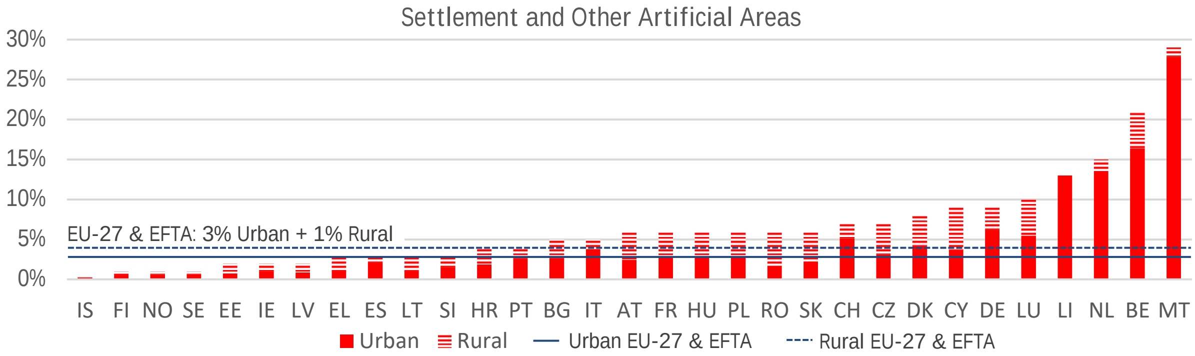
3.3 Pilot European ecosystem extent accounts for urban ecosystems

This section presents a brief comparison between extent accounts for urban ecosystems, i.e., thematic approach, and settlements and other artificial surfaces, i.e., general approach (Section 3.3.1). It further describes extent accounts for urban ecosystems regarding their distribution in different types of urban LAU (i.e., cities above 50,000 inhabitants (CC), cities below 50,000 inhabitants (C), and towns and suburbs (T)) and internal differentiation in ecosystem types (EU Ecosystem Typology Level 1) and sub-types (CLC+Backbone land cover classes). This further description together with the results of condition accounts (Section 4) would help to understand the results of services accounts (Chapter 5), and therefore, the interrelation between accounts.

3.3.1 Comparison between extent accounts for settlements and other artificial areas and urban ecosystem accounts

Ecosystem extent accounts for "Settlements and other artificial areas" and urban ecosystems aggregated at country level (NUTS Level 0) are presented in Table 3 and 4, respectively. Figure 3 summarises the share of Settlements and other artificial areas in MS, and the amount of it present in urban ecosystems.

Figure 3. Percentage of the ecosystem type *Settlement and Other Artificial Areas* with respect to the overall land of each MS in 2018. Per each MS, it is indicated the amount of area of this ecosystem type that belong to urban LAU, i.e., inside urban ecosystem accounting areas. Values are sorted from smallest to largest percentage.



Source: JRC analysis

As visualised in Figure 3, and further detailed in Table 3 (*Overall* column) and Table 4 (*Settlements* column), the overall share of Settlement and other artificial areas, as well as its urban share, varies greatly among MS. In most MS, except Liechtenstein (LI), Netherlands (NL), Belgium (BE) and Malta (MT), Settlement and other artificial areas represent less than the 10% of the entire territory. When considering only urban Settlement and other artificial areas, the value goes below 7%. Regarding the share of urban Settlement and other artificial areas, in cases such as Romania (RO), Greece (EL) or Estonia (EE) it represents less than a 40% of the total extent of this ecosystem type. In other cases, such as Malta (MT), Netherlands (NL), Italy (IT) or Spain (ES), it corresponds to more than a 60% of the total extent of this ecosystem type. These results clearly illustrate that urban ecosystems do not represent well the entire extent of Settlement and other artificial areas in many MS, since a great part of it occurs beyond urban LAU. Moreover, urban Settlement and other artificial areas usually represent a tiny fraction of their entire territory of MS, which does not justify a detailed attention to urban dynamics as part of general ecosystem accounts including all ecosystem types. Therefore, a good understanding of urban ecosystem extent and their changes, but also of Settlement and other artificial areas, including those of rural character, would require the use of thematic and general accounting approaches respectively.

Table 3. Ecosystem extent of the ecosystem type *Settlement and Other Artificial Areas* (general approach) in each MS for the year 2018. Values are provided by type of local administrative unit (cities above 50,000 inhabitants, cities below 50,000 inhabitants, towns and suburbs, rural) and as overall values. Values are rounded to the first decimal digit and provided in km[2] and percentage. Values in percentage refer to how much land inside cities, towns and suburbs and rural LAU corresponds to *Settlement and Other Artificial Areas.* MS are sorted in alphabetical order.

	Settlement and Other Artificial Areas									
	Cities ≥ 50,000 inhabitants		Cities < 50,000 inhabitants		Towns and Suburbs		Rural		Overall	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
AT	500.9	54%	-	-	1507.0	15%	2952.4	4%	4960.3	6%
BE	821.7	60%	308.4	58%	3870.4	27%	1407.9	10%	6408.4	21%
BG	1150.7	10%	-	-	1675.8	5%	2495.9	4%	5322.4	5%
CH	226.4	49%	280.5	26%	1567.4	14%	737.0	3%	2811.4	7%
CY	96.9	67%	125.1	39%	126.8	25%	502.7	6%	851.5	9%
CZ	831.0	41%	34.6	33%	1492.8	15%	2895.6	4%	5254.0	7%
DE	8312.0	44%	447.0	32%	14506.8	13%	10350.1	5%	33615.8	9%
DK	486.7	24%	204.2	61%	1189.9	10%	1678.1	6%	3558.8	8%
EE	170.1	45%	-	-	194.6	6%	632.1	2%	996.8	2%
EL	447.1	45%	204.3	59%	903.8	13%	2691.7	2%	4246.9	3%
ES	3565.8	15%	302.0	27%	5078.3	5%	3937.3	1%	12883.4	3%
FI	972.5	9%	6.0	98%	1562.2	4%	2138.3	1%	4679.0	1%
FR	2518.7	66%	3167.0	57%	9980.9	21%	17147.1	3%	32816.7	6%
HR	335.4	27%	-	-	652.3	8%	1123.2	2%	2110.9	4%
HU	1025.4	27%	20.6	39%	1865.7	9%	3069.9	4%	5981.7	6%
IE	115.1	80%	409.4	30%	297.7	9%	855.6	1%	1677.9	2%
IS	54.2	22%	23.8	15%	80.6	10%	228.4	0.2%	387.0	0.4%
IT	3267.8	19%	606.6	42%	8564.5	9%	4048.6	2%	16487.5	5%
LI	-	-	-	-	21.2	13%	-	-	21.2	13%
LT	422.3	52%	-	-	350.9	4%	1434.5	3%	2207.6	3%
LU	29.4	56%	-	-	119.7	23%	123.4	6%	272.5	10%
LV	286.6	58%	-	-	283.8	5%	753.9	1%	1324.3	2%
MT	-	-	36.1	72%	52.3	23%	3.7	9%	92.1	29%
NL	2171.5	35%	242.1	33%	2448.0	12%	561.3	6%	5423.0	15%
NO	336.9	14%	20.0	14%	1336.1	3%	1135.0	0.4%	2828.0	1%
PL	3618.4	47%	10.1	77%	5316.0	11%	10343.3	4%	19287.8	6%
PT	89.6	61%	952.3	31%	1320.7	12%	1285.0	2%	3647.6	4%
RO	1189.1	32%	-	-	2522.8	9%	9504.1	5%	13216.0	6%
SE	1366.9	8%	67.1	40%	2746.2	3%	2549.9	1%	6730.1	1%
SI	102.7	24%	-	-	254.6	6%	350.8	2%	708.1	3%
SK	188.9	33%	136.7	31%	783.7	12%	1862.8	5%	2972.1	6%
EU	34083.2	25%	7279.6	43%	69668.2	9%	86699.2	3%	197733.2	4%
EU & EFTA	34700.7	25%	7603.9	41%	72673.5	9%	88799.6	2%	203780.8	4%

Source: JRC analysis

Table 4. Thematic urban ecosystem extent in each MS for the year 2018. Values are provided in km². Values are rounded to whole numbers and MS are sorted in alphabetical order.

	Ecosystem Type *											
	1	2	3	4	5	6	7	8	9	10	11	12
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT	2007	2714	1059	4257	197	336	23	75	153	0	0	0
BE	5000	7702	1377	1781	125	3	28	52	87	46	15	6
BG	2826	21825	3267	15862	150	259	66	179	314	0	13	6
CH	2074	3276	1548	4010	229	1050	27	29	889	0	0	0
CY	348	461	16	18	104	5	0.4	0	4	0	10	4
CZ	2358	5257	898	3230	0	0	8	21	99	0	0	0
DE	23266	45032	20895	36386	336	134	280	450	1123	91	41	10
DK	1881	9600	269	1618	96	2	182	0	161	22	77	70
EE	365	814	306	1909	1	1	207	5	37	0	3	8
EL	1555	3683	459	1115	914	169	15	27	35	15	57	71
ES	8946	68576	10140	22856	10752	2830	96	219	490	144	773	174
FI	2541	6636	7	33292	0	4	851	95	5342	0	34	296
FR	15670	19543	4923	11772	1558	649	231	393	343	309	417	50
HR	988	3751	684	3609	157	66	27	62	53	0	4	51
HU	2912	14139	2553	4216	0	7	227	175	389	0	0	0
IE	822	819	2471	292	130	15	255	9	9	33	19	7
IS	159	1	142	48	544	200	82	4	7	14	4	6
IT	12439	73413	2651	18363	3261	2158	115	221	736	300	291	226
LI	21	27	28	70	2	9	2	2	0	0	0	0
LT	773	5053	849	3724	3	3	74	21	161	1	4	1
LU	149	152	85	190	0	0	0	1	0	0	0	0
LV	570	1752	747	2999	0	34	259	57	158	0	5	3
MT	88	135	0	2	37	5	0	0	0	0	0	5
NL	4862	9189	7480	2514	304	21	321	409	2168	12	48	5
NO	1693	4508	150	20493	6043	15369	2316	95	1913	22	26	550
PL	8945	23104	4581	19050	27	30	141	225	1009	2	5	9
PT	2363	6353	423	4474	529	22	9	58	43	78	223	26
RO	3712	14199	3564	10135	118	69	113	376	274	0	3	7
SE	4180	19415	1121	65741	9	173	2269	172	11030	67	48	392
SI	357	1254	316	2927	24	30	2	13	11	0	7	1
SK	1109	3505	339	2582	6	4	5	37	74	0	0	0
EU	111034	368074	71480	274912	18837	7027	5805	3350	24302	1120	2096	1426
EU & EFTA	114981	375885	73347	299532	25655	23655	8232	3480	27112	1156	2125	1983

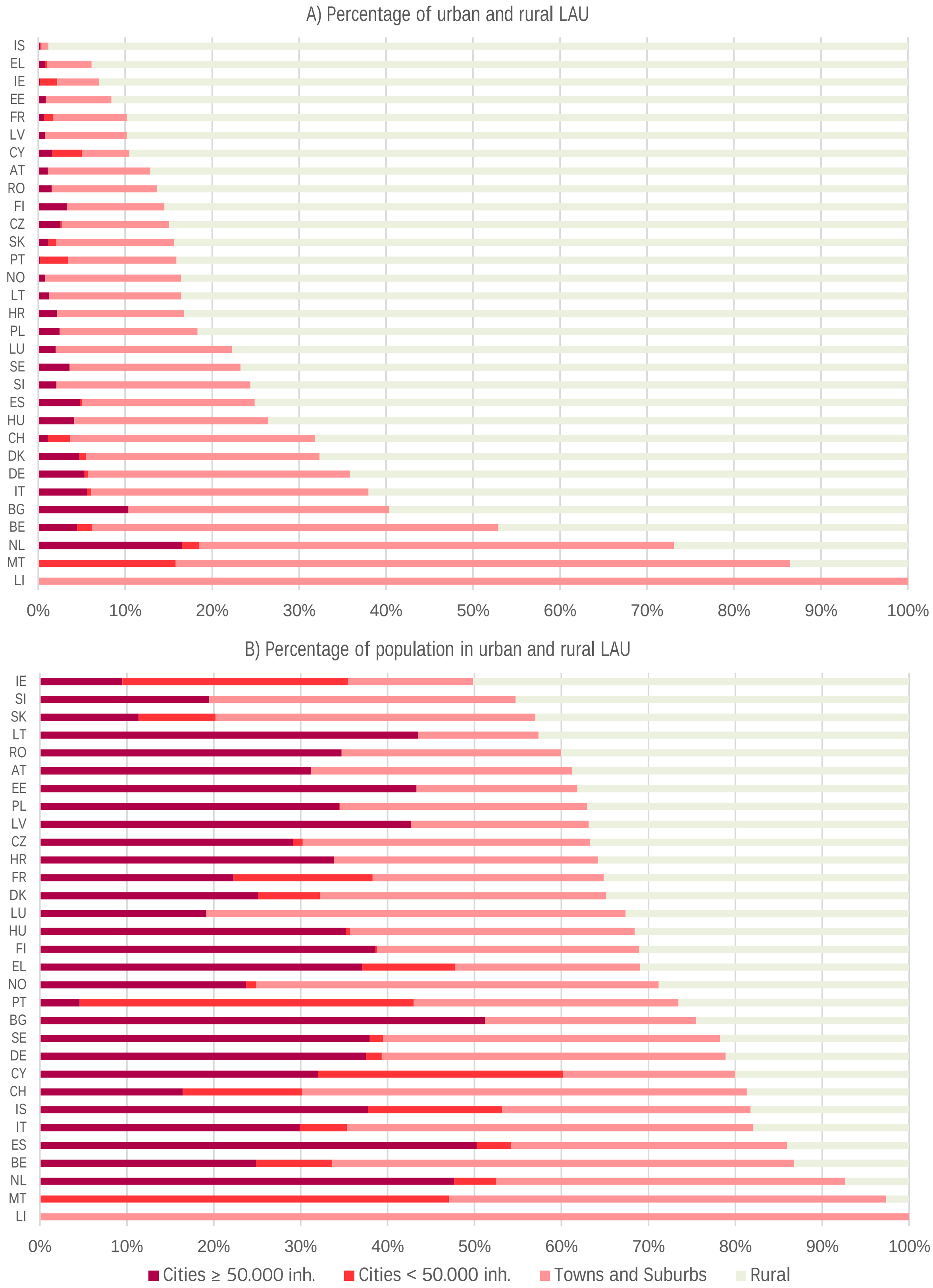
* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

Source: JRC analysis

Despite urban Settlement and other artificial areas (Figure 3), and in a minor extent urban ecosystems as a whole (Figure 4a), represent a small fraction of EU-27 and EFTA MS' territory, they are still a key environmental theme. As Figure 4b illustrates, in all cases at least a 50% of the population lives in urban ecosystems, being all the households located in Settlement and other artificial areas. Cases such as Iceland (IS) are very illustrative because urban LAU represent less than a 2% of its territory, but more than an 80%

of its population. This clearly justifies thematic accounts on urban ecosystem in terms of extent, condition, and services supplied, demanded, and their potential mismatch.

Figure 4. Distribution of urban and rural local administrative units (LAUs) per EU-27 and EFTA MS in 2018. Distribution based on share of their territory (A) and on share of their inhabitants (inh.) (B).



Source: JRC analysis

3.3.2 Urban ecosystem accounts per type of urban local administrative unit, and their differentiation in ecosystem types and sub-types

Regarding the distribution of different types of urban LAU, Figure 4 shows that towns and suburbs are relevant in terms of area and total population covered. This can also be easily grasped in a spatially explicit way in Figure 2b. For all the MS, they represent more than 50% of the area covered by all types of urban LAU, and in most they also cover more than 50% of the population present in urban LAU. Cities above 50,000 inhabitants represent in most countries the second type of urban LAU in terms of area (Figure 4a), being the exceptions Iceland (IS), Ireland (IE), Cyprus (CY), Slovakia (SK), Portugal (PO), Switzerland (CH), and Malta (CH). In general, cities above 50,000 inhabitants also covered, together with towns and suburbs, most of the population in urban LAU, being still the exceptions Ireland, Portugal and Malta. Hence, in general terms, EU policies targeting an overall enhancement of urban ecosystem condition and ecosystem potential to deliver services at national level should not disregard towns and suburbs and cities above 50,000 inhabitants, due to the large amount of area and population covered by them.

In terms of the composition of urban ecosystems, Figure 5 shows that in more than half of the MS Cropland is the largest ecosystem type, in a third part of them Forest and woodland is the largest, and only in Ireland (IE) and Iceland (IS) Heathland and shrubland and Grassland are the largest ecosystem type. These numbers showcase how relevant are Cropland and Forest and woodland for the condition of urban ecosystems and the local supply of services. As Figure 6a showcases this is especially relevant in the case of towns and suburbs, where Croplands can occupy easily around a 50% of the whole urban ecosystem, such as it occurs for Spain (ES), Italy (IT) or Hungary (HU). It is anyway, relevant for all the other types of urban LAU, where Forest and woodland or Cropland form at least a 20% of their area. In general terms, this means that EU policies looking to enhance the overall condition and capacity of urban ecosystem should not only target urban Settlements and other artificial areas, but also other ecosystem types. As highlighted above some of them make a great extent of urban ecosystems or, like Rivers, are key for their functioning.

With respect to the share of Settlements and other artificial areas in urban ecosystems, Figure 5 shows that in some MS States it is not even the third largest ecosystem type. Especially relevant is the case of Scandinavian countries (Finland, Sweden and Norway), where Settlements and other artificial areas form less than a 6% of urban ecosystems. In those cases, besides differences in the typical urban ecosystem structure, usually quite green, this low values illustrate potential issues associated with the size of LAU. Compared to countries such as France or Italy, Scandinavian countries organise their territory in larger municipalities. This issue might make less suitable the use of LAU for the definition of urban ecosystem accounting areas. It might be particularly relevant if policy targets relate to the entire accounting areas without applying an additional filtering.

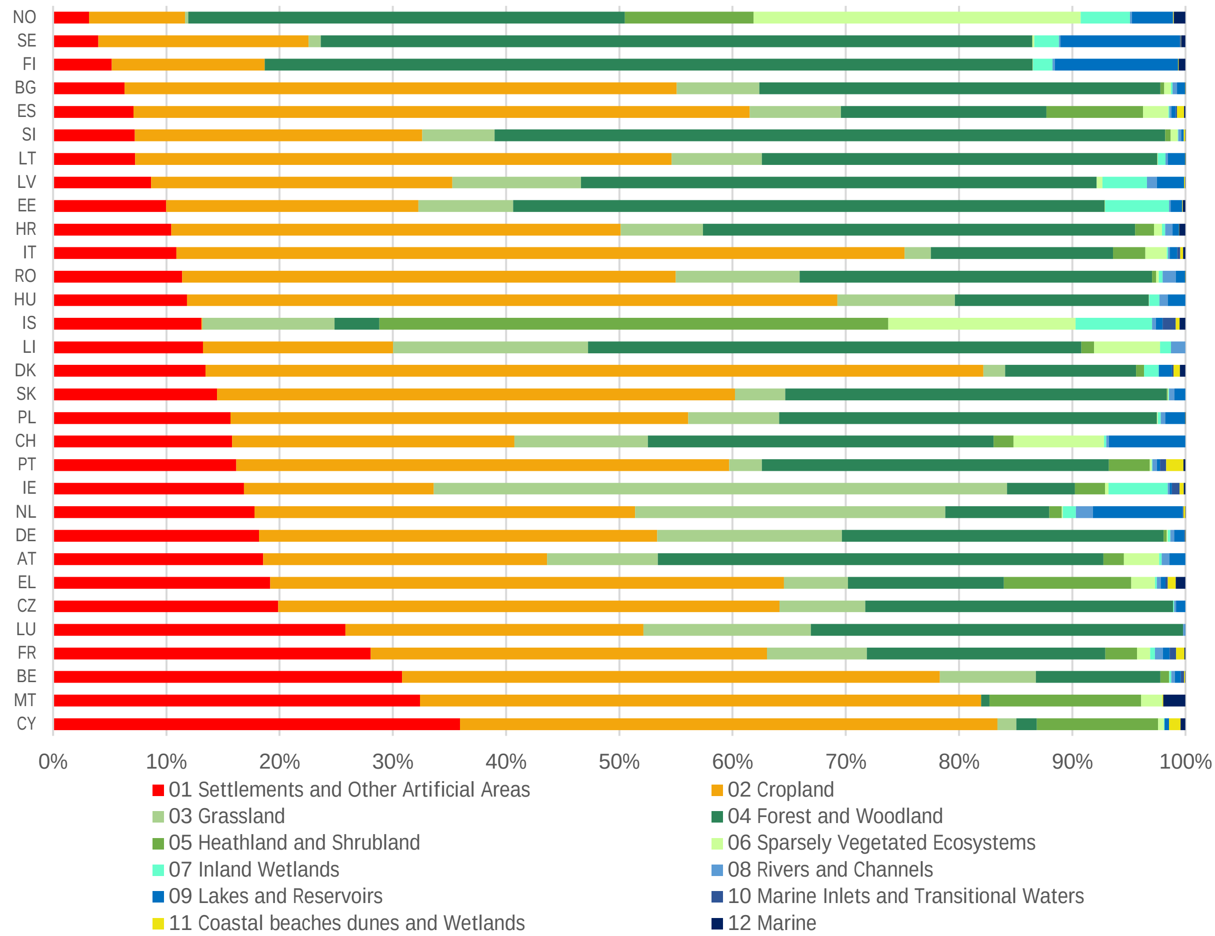
When looking at the distribution of Settlements and other artificial areas by type of urban LAU, Figure 6 showcases some unexpected results. As it can be expected, towns and suburbs are the type of urban LAU with the lowest percentage of Settlements and other artificial areas this ecosystem in all MS. Instead, in some MS, cities below 50,000 inhabitants are more artificial than more populated cities. This is the case of MS such as Spain (ES), Italy (IT), Poland (PL) or Denmark (DK). This output might look as an artefact of the aggregation of land cover classes in ecosystem types. However, this is not the case. When looking at Figure 7 and 8, where ecosystem types are differentiated in sub-types represented by CLC+Backbone land cover classes, this interpretation remain consistent. Figure 7 clearly showcases that at European level Settlements and other artificial areas in cities above and below 50,000 inhabitants have a very similar land cover composition. Figure 8 also shows that the fraction of sealed surfaces in urban Settlements and other artificial areas for MS such as Spain, Italy, Poland and Denmark remain quite similar. This means that the outputs of Figure 6 are not an artefact of the spatial aggregation of EU ecosystem types Level 1. Results such as those of Figure 6 could be used as an early signal to control changes in ecosystem extent for cities below 50,000 inhabitants that lead to an increase in artificial areas, and an associated potential diminishment in ecosystem condition and supply of services.

A more detailed look to urban ecosystem sub-types (Figure 7) shows that at European level natural features in urban Settlements and other artificial areas are mainly represented by broadleaved deciduous trees (~10-15%) and permanent herbaceous (~20-25%). In Croplands, besides periodically herbaceous, it is also significant the amount of broadleaved trees, especially deciduous, which cover around a 15% of this ecosystem type. These results showcase the relevance that deciduous trees and permanent herbaceous have in urban ecosystems.

At MS (Figure 8), a similar dominance of ecosystem sub-types is kept. There are few exceptions such as Finland and Southern MS. In Finnish Settlements and other artificial areas, the share of woody-needle leaved trees is similar to (or higher than) the one of broadleaved deciduous trees. In Southern countries (i.e., Spain (ES), Portugal (PT), Italy (IT), Greece (EL), Cyprus (CY) and Malta (MT)), Settlements and other artificial areas have a share of woody vegetation below 5%. For most of those countries, a low presence of woody vegetation, compared to the European average, is also occurring in other ecosystem types such as Grassland or Forest and Woodland. These commonalities might be partially explained by geographical or climatic factors, and should be considered when defining urban greening policy targets.

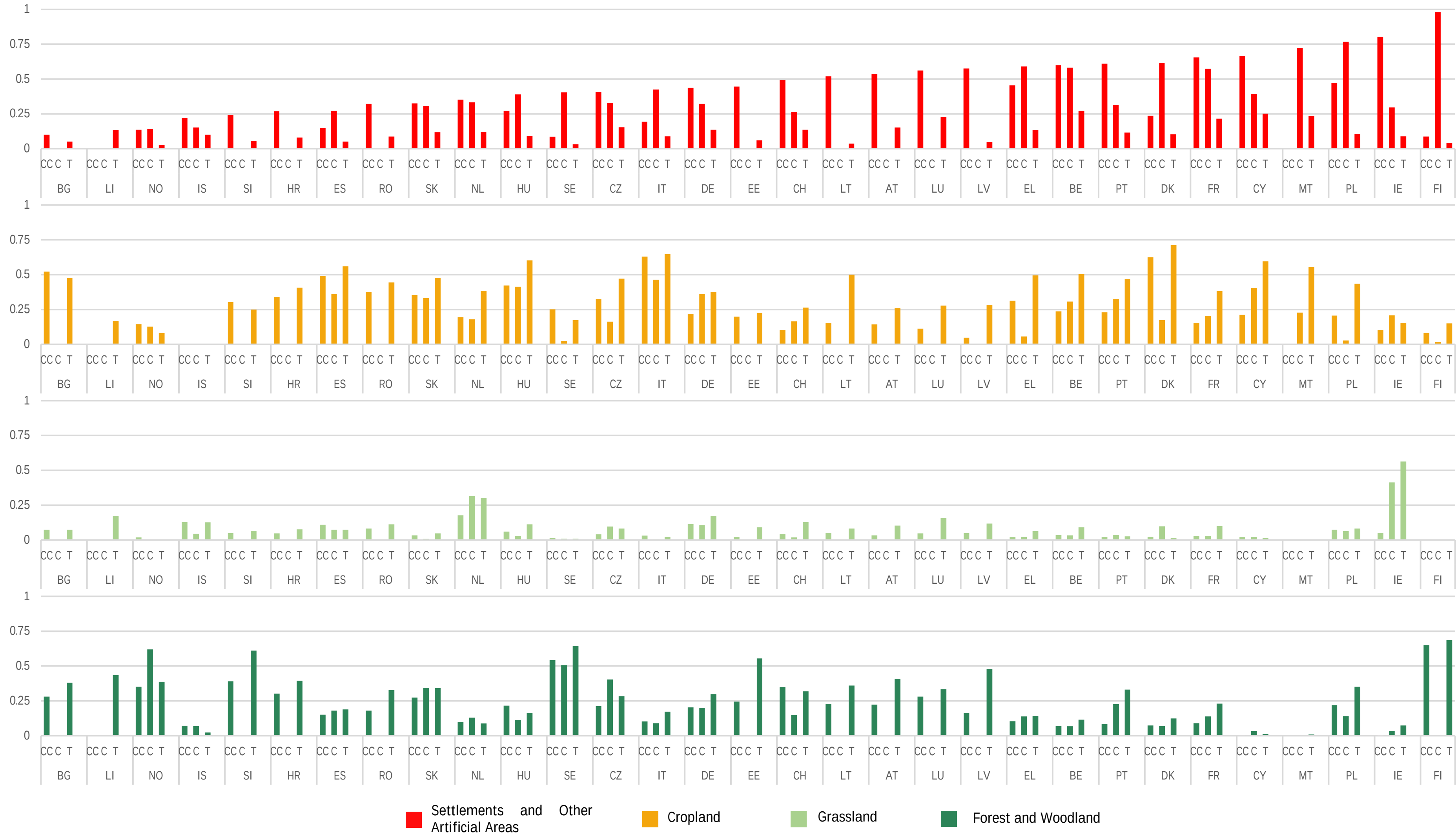
As a last insight, related to practical bottlenecks for implementation (as presented in Table 1), Table 4, Figure 5 and 7 illustrate the importance of rules for data quality standards. Table 4 and Figure 5 present a small share of Marine ecosystems in MS with access to sea. However, the administrative units of urban LAU in EU and EFTA MS do not overpass the coastline. Then, in this case Marine ecosystem extent is an artefact generated due to the spatial accuracy of the official LAU datasets and the spatial resolution of CORINE dataset, the basis for the definition of ecosystem types. Similarly, in Figure 7 Marine ecosystems include classes beyond water. This is because CORINE cells used to delineate Marine ecosystems due to the resolution included more than Marine ecosystems, and this is reflected when further dividing those ecosystem types in sub-types. On purpose, to illustrate these issues, refinement was not applied to the data presented in Table 4 and Figure 5 and 7. Because of their very low value those data issues do not influence the interpretation of results presented. This example clearly illustrates that without agreed rules for data quality standards, including input data refinements, errors such as the above ones could end appearing in mandatory ecosystem accounts. It also justifies the importance that training schemes, guidance notes and illustrative pilots would have for professionals in charge of ecosystem accounts.

Figure 5. Percentage of EU ecosystem types Level 1 in the urban ecosystems of each MS (MS) in 2018. MS are sorted from smallest to largest percentage of *Settlements and Other Artificial Areas*.



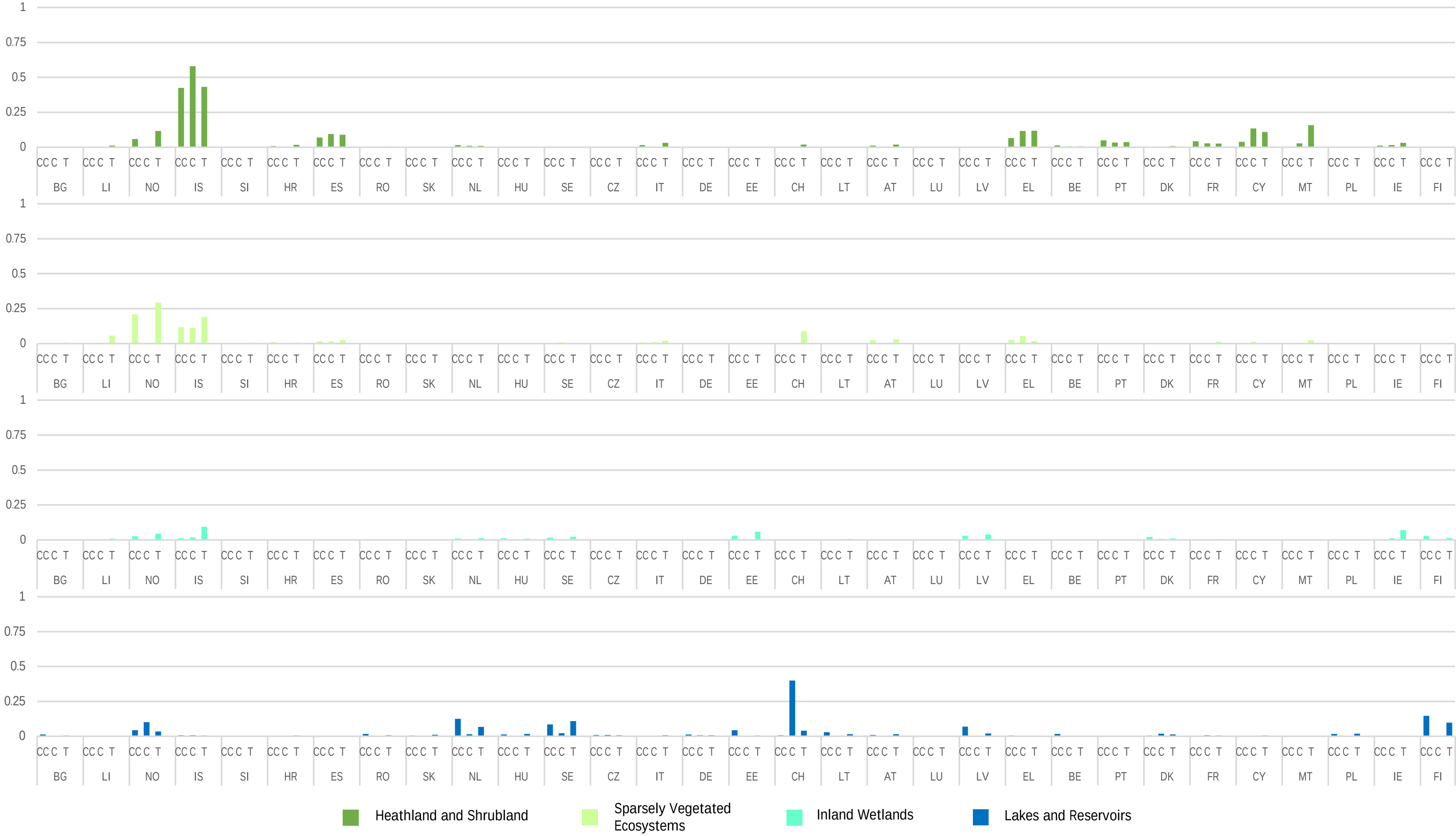
Source: JRC analysis

Figure 6. Percentage of ecosystem type extent in MS aggregated by type of urban local administrative units (LAUs) in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values of settlements and other artificial areas.



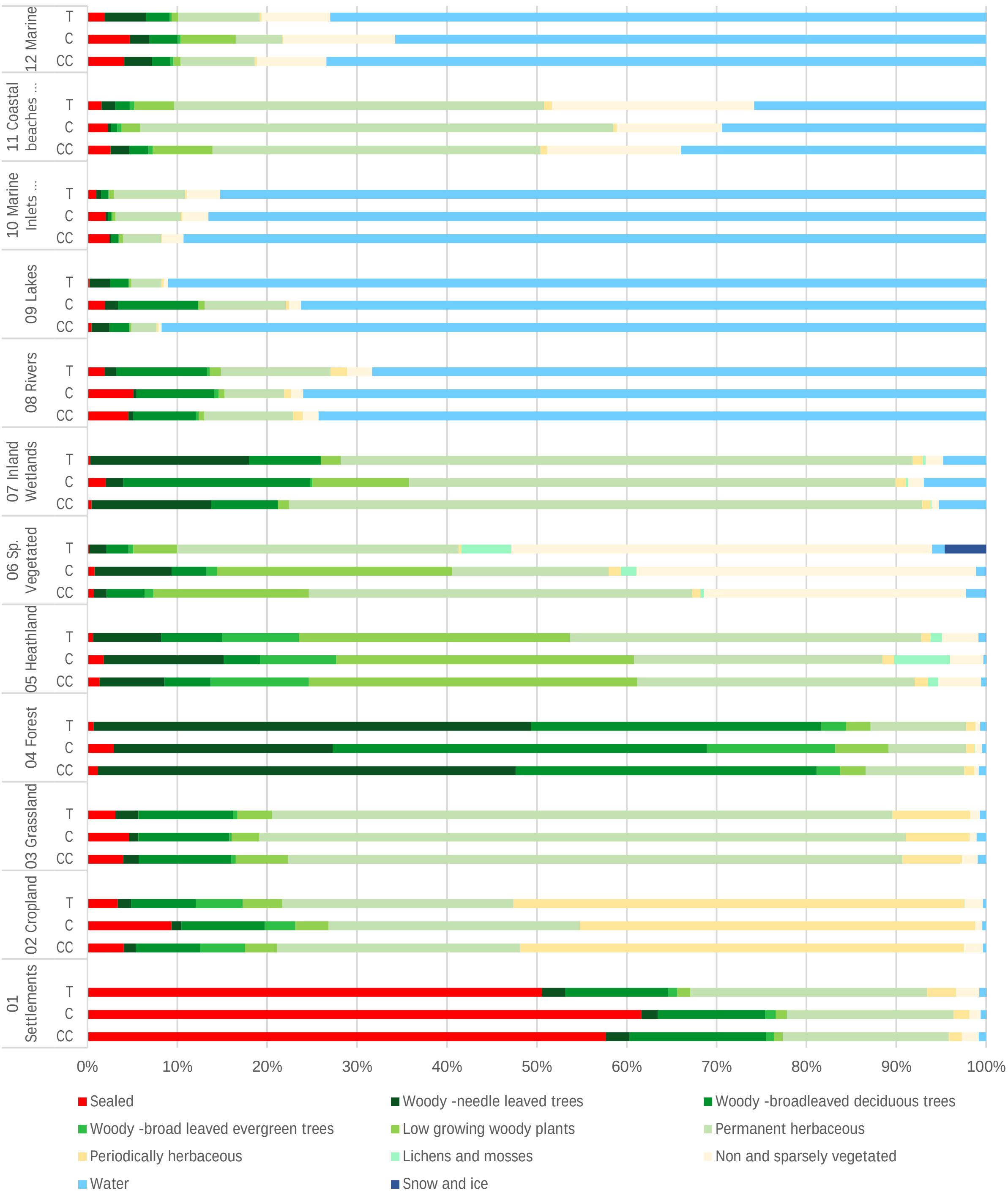
Source: JRC analysis

Figure 6b. Percentage of ecosystem type extent in MS (MS) aggregated by type of urban local administrative units (LAUs) in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values of settlements and other artificial areas.



Source: JRC analysis

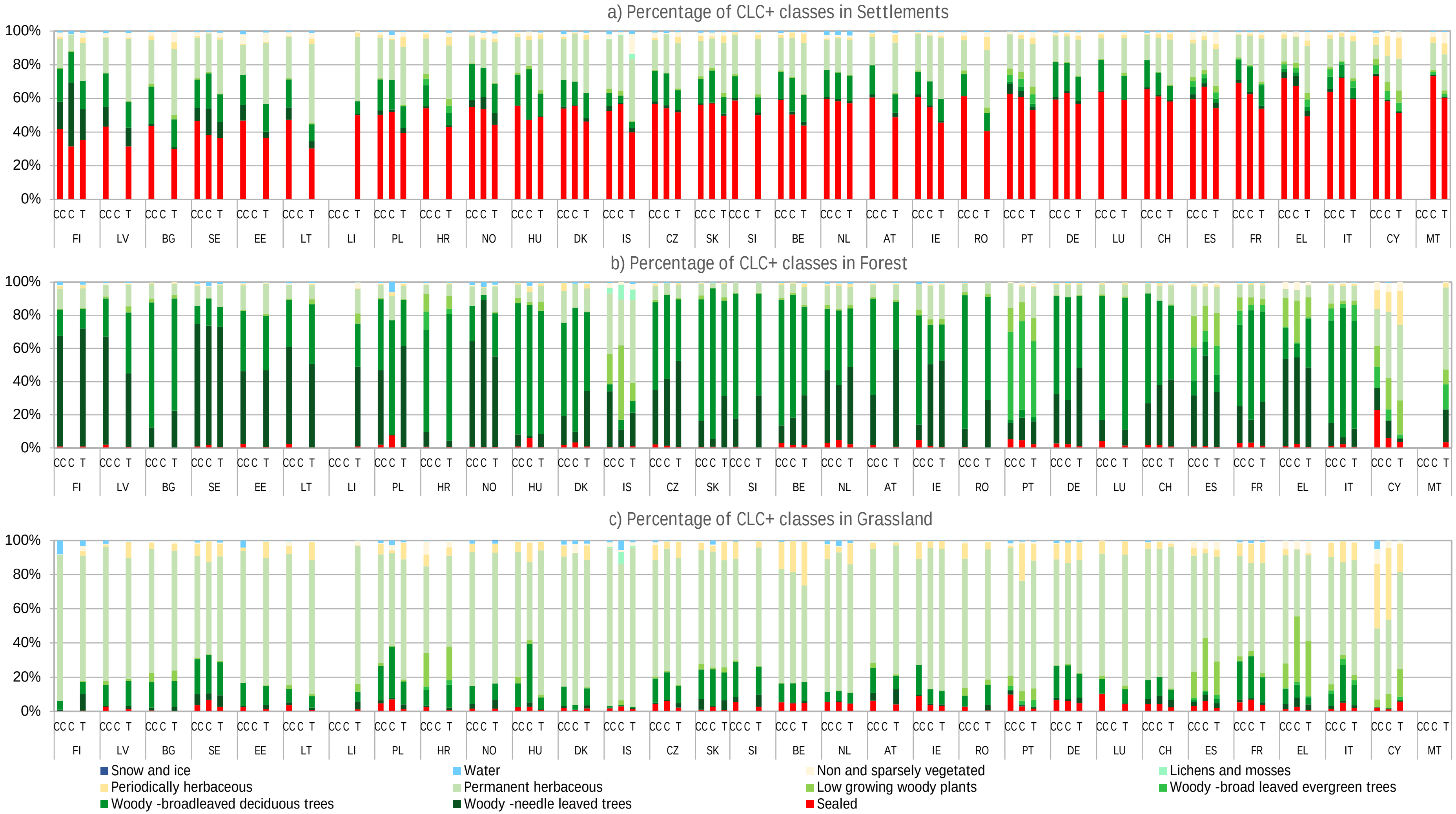
Figure 7. Percentage of CLC+ classes per ecosystem type aggregated by type urban local administrative units (LAUs) for the entire EU-27 and EFTA MS in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs).



Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

Source: JRC analysis

Figure 8. Percentage of CLC+ classes in Settlements and Other Artificial Surfaces (a), Forest and Wooodlands (b) and Grassland (c) aggregated by type urban local administrative units (LAUs) in each MS in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs. MS are sorted from minimum to maximum percentage of sealed land cover in Settlements and Other Artificial Surfaces.



Source: JRC analysis

3.4 Key Messages

Learnt lessons on urban ecosystem extent accounts

- The definition of ecosystem accounting areas for settlements and other artificial areas and urban ecosystems should follow two different approaches (general and thematic);
- The use of local administrative units (LAU) as minimum reporting units permits the development of urban ecosystem accounts suitable for national and local policy purposes;
- To ensure interoperability between accounts, thematic urban ecosystem accounts should make use of the same ecosystem typology used in general national ecosystem accounts;
- EU policies looking to enhance the overall condition of urban ecosystems should not only target actions for urban Settlements, since on average in EU-27 and EFTA MS make less than a 50% of the extent of cities and towns;
- At EU-27 and EFTA level, natural features in urban Settlements are mainly formed by broadleaved deciduous trees (~15% of its extent) and permanent herbaceous (~15-25% of its extent).

4 Urban Ecosystem Condition Accounts

A reference condition is a condition against which past, present and future ecosystem condition is compared to, in order to measure relative changes over time. It represents the condition of an ecosystem that is used for setting the upper reference level ('optimal' endpoint) of ecosystem condition variables.

Ecosystem integrity implies an unimpaired condition of being complete or undivided (Karr, 1993). Ecosystem integrity is defined as the ecosystem's capacity to maintain its characteristic composition, structure, functioning and self-organisation over time within a natural range of variability (Pimentel et al., 2000; United Nations, 2021).

Definitions of other relevant concepts are included in the Glossary at the end of this report.

As introduced in Chapter 2 and recognized in the most recent urban ecology paradigms, ecology *of* cities and ecology *for* cities, urban ecosystems are truly socio-ecological-technological systems (McPherson et al., 2016, Picket et al., 2016). This generates certain challenges, as mentioned in Table 1 (Chapter 2), when developing SEEA EA ecosystem condition accounts, which are defined to suit especially non-anthropogenic ecosystems. Chapter 4 briefly discusses potential solutions (or adjustments in SEEA EA rules) for some of those challenges. It briefly discusses the use of condition variables beyond pure ecological ones and approaches to define reference conditions in urban ecosystems. It introduces the selection of a minimum set of condition variables for urban ecosystems, and develops a pilot condition account for a subset of them:

- imperviousness per inhabitant (and share of imperviousness),
- share of tree canopy cover,
- share of green spaces (and green spaces per inhabitant),
- air pollutant concentration (PM10 and PM2.5).

As reminded in Chapter 3, this technical report is strongly related to previous and parallel research activities. In the case of Chapter 4, activities were developed in coordination with the EU-wide Methodology (Vallecillo et al., 2022), where a minimum set of condition variables for urban ecosystems was already presented. This Chapter briefly introduces the minimum set, but it mainly focuses on the subset for which pilot accounts are developed. For further details about the minimum set of urban condition variables, Chapter 4 refers to specific sections of the EU-wide Methodology. Hence, Chapter 4 briefly discusses potential solutions for challenges related to urban condition accounts (Section 4.1), introduces a minimum set of condition variables (Section 4.2), and presents pilot condition accounts for a subset of them (Section 4.3).

4.1 Urban ecosystem condition variables beyond the ecological dimension, approaches and methods to estimate their reference conditions

As socio-ecological-technological systems, besides the ecological dimension, the social and technological dimensions are also relevant in urban ecosystems (Elmqvist et al., 2018). This means that humans and their processes/functions, including those related to artificial structures and processes (e.g. human mobility, waste generation), should also be monitored to fully understand urban ecosystem dynamics, how they influence ecosystem condition, services supply and demand. Hence, in the case of urban ecosystems, the conceptualisation of ecosystem condition should include the following adaptations:

- Leaving aside a classical understanding of ecological integrity. In urban ecosystems, pristine (unimpaired) states or absence of human modifications should not be associated with optimal ecological integrity, neither should represent a valid reference of ecosystem condition.
- Ecological integrity, resilience and health, concepts underpinning urban ecosystem condition, should integrate humans as a core component. Urban ecosystems are anthropogenic ecosystems where humans are a dominant component (Alberti et al., 2003; Alberti 2010), aspect that should be reflected in the monitoring and assessment of urban ecosystem condition.
- Optimal urban ecosystem health and resilience requires capacity to satisfy societal demand for ecosystem services as well as to guarantee its long-term ecosystem capacity. This implies

that monitoring urban ecosystem condition should inform on how biotic and abiotic variables, including human and technology related variables, influence ecosystem resilience and health of the urban ecosystem itself and of others onto which it depends. In other words, urban ecosystems are global ecological forcing functions (Alberti et al., 2003), i.e., they deeply influence condition of ecosystems located beyond urban boundaries, and cannot sustain their functions based only on their own ecosystem capacity. Consequently, when monitoring urban ecosystem condition, changes on local (urban ecosystem) and global (elsewhere) ecosystem resilience and health should be considered. Therefore, as important as to consider how urban ecosystem condition influences supply of local ecosystem services would be to consider how it influences demand of ecosystem services produced in the urban ecosystem or elsewhere.

Suitable social and technology-related variables for ecosystem condition accounts should represent attributes or processes that influence ecological integrity, resilience and health of urban ecosystems. Variables from the social and technological dimensions should be included because in socio-ecological-technological systems the different dimensions are strongly interrelated. However, the main purpose of urban ecosystem condition accounts is still to monitor changes in ecological conditions. Consequently, monitoring of ecological conditions requires consideration of attributes, processes or functions beyond the ecological dimension, but which influence it. As mentioned in Chapter 2 – Section 2.2.3, the identification of suitable social and technology-related variables for urban ecosystem condition accounts still require further investigation.

Regarding the definition of reference conditions in urban ecosystems, in Chapter 2 best-attainable approach was already suggested as a default suitable approach in the literature (Section 2.2.2) and by experts (Section 2.2.3). According to SEEA EA (Annex 5.2), best-attainable condition is the expected condition of a socio-ecological stable ecosystem under best possible management practices (United Nations, 2021). A best-attainable condition as a reference condition can be estimated through four methods (United Nations, 2021):

— Modelled reference conditions,

— Statistical approaches based on ambient distributions,

— Prescribed levels,

— Expert opinion.

As mentioned in Section 2.2.2, Guo et al. (2002) suggested to assess urban ecosystem health making use of comparative assessments between existing independent urban ecosystems and/or potential future scenarios for them. In this context, scenarios mean a represented future reality (of an existing urban ecosystem) to inform whether current actions (e.g., restoration activities) would help to achieve possible and desirable futures (Godet 2001). In other words, Guo et al. (2002) suggests a combined (or alternative) use of modelled reference conditions and statistical approaches based on ambient distributions for estimating a reference urban ecosystem health, and therefore, a reference condition.

In the EU-wide Methodology (Vallecillo et al., 2022), expert opinion is also suggested in combination with the above two methods (Section 4.1.3). The combined use of expert opinion and modelled conditions could be relevant for corroborating potential desirable scenarios. For example, Iungman et al. (2023) modelled urban ecosystem scenarios where tree cover increased up to a 30%. This threshold was previously defined on an evidence-based guideline that strongly relied on expert opinion (Knoijnendijk, 2022). The EU-wide Methodology also suggested the use of prescribed levels for condition variables for which environmental laws, guidelines or standards already exist. For example, in the case of air pollutant concentration (PM10 and PM2.5) as a condition variable, the Air Quality Directive[11] already dictates legal thresholds based on scientific evidence. Those can be used as prescribed levels to define reference conditions. Therefore, depending on the specific condition variables for which reference condition should be estimated one of the above methods or a combination of several of them might be more or less suitable.

[11] The European Commission has proposed a revision of the Air Quality Directive which is better aligned with the stricter thresholds proposed on the most recent World Health Organisation's guideline on the topic (WHO 2021) (https://environment.ec.europa.eu/publications/revision-eu-ambient-air-quality-legislation_en).

As urban ecosystem condition is highly influenced by the human component, and their perception, it may vary across different geographic regions and cultures (Ryder, 2000). As discussed in Chapter 2, it is necessary to split urban ecosystems in sub-functional groups, for which specific reference conditions should be defined. The EU-wide Methodology (Vallecillo et al., 2022), in Section 4.1.3 points to the need of classifying urban ecosystems into clusters of "homogenous urban areas" to ensure that operational meaningful reference levels could be defined. Among the characteristics suggested to define clusters, the use of population and population density (to define discrete classes of urban ecosystems) was mentioned. In fact, as anticipated in Section 3.1, by classifying individual LAU according to the Degree of Urbanisation, this report already clusters (in simple terms) urban ecosystems based on their population and population density. Therefore, the physical and socio-economic characteristics of urban ecosystems, including human perception, influences the definition of reference levels, which should be specific for each sub-functional group.

4.2 Selection of a set of condition variables for urban ecosystems

A set of condition variables for urban ecosystem condition accounts[12] at European level was already presented in the EU-wide Methodology (Vallecillo et al., 2022). This set is a result of the parallel research activities of the EU-wide Methodology and the ones presented in this report. For simplicity, Table 5 briefly summarises the set of condition variables included in the EU-wide methodology, and it highlights the subset for which pilot urban ecosystem condition accounts are developed in this report (Section 4.3). Annex III – Table III.1 includes a brief description of each condition variable.

In this report there are three updates on the set of condition variables presented in the EU-wide methodology.

T**he definition of 'green spaces'** has been updated, making it more specific regarding its components, the ownership and built-up character of the land where these spaces occur. Additionally, the definition of green spaces is not associated anymore to CORINE land cover classes. These changes clarify better what is (and what is not) an urban green space in condition accounts. It also avoids operational constraints by not linking its definition to land use classes of a specific dataset (CORINE). In the updated definition, urban green spaces correspond to any piece of urban land covered with mosses and lichens, permanent herbs, shrubs, or trees. Urban green spaces can be of public, semi-private, or private ownership and be present in land of different built-up character (e.g. ground open space, building rooftop, building façade). Additionally, to facilitate the monitoring of urban green spaces, a definition of their specific land cover components (e.g., herbs, shrubs) has been prepared, and the type of green spaces in which they can be present enumerated (see Annex III – Table III.2). For the same purpose, a descriptive list of common types of urban green spaces as land use classes has been drafted (see Annex III – Table III.3). In terms of policy uses, the above updates and clarifications should facilitate the reporting of green spaces to measure the progress towards urban targets of the proposed Nature Restoration Law.

When the EU-wide Methodology was published, one of the preferred data sources (CLC+) for the condition variables "green spaces per inhabitants" and "patch richness of land cover types" was still not available, being classified as "Type: Coming Soon". This data source became recently available, and it has been reclassified as "Type: Optimal". In fact, this source has been used for the calculation of the sub-set of pilot condition accounts presented in Section 4.3. In addition, Table 5 only refers to condition variables relevant for the thematic approach (thematic urban ecosystem accounts), whilst EU-wide Methodology referred to both the thematic and general approach.

[12] The set of condition variables follow the structure of the Ecosystem Condition Typology of the SEEA EA. For details about this typology, please consult Vallecillo et al. (2022) or United Nations (2021).

Table 5. Set of condition variables proposed in the EU-wide methodology for urban ecosystem condition accounts of EU-27 and EFTA MS. The subset of variables included in the pilot urban ecosystem condition account are shaded in green, only values for 2018 are used. The temporal series available refer to the availability for that source.

Condition Typology	Variable	Units	Source of the variable at EU level	Temporal series available	Spatial Resolution	Type[13]
A1. Physical state	Imperviousness per inhabitant (share of imperviousness)	ha/inhabitant	Copernicus HRL Land + GEOSTAT population grid (or GHS pop)	2006-2012-2018 (Copernicus HRL); 2006-2011-2018 (GEOSTAT); 1975-1990-2000-2015 (GHS pop)	10 m (Copernicus HRL); 1 km (GEOSTAT); 250 m (GHS pop)	Optimal
	Waste generated per inhabitant	kg waste/ inhabitant	Eurostat[14] (env_wasmun, env_wasgen, env_wassd, env_wasflow, env_wastrt)	2000-2020 (annual data collection)	Country	Complementary (very coarse spatial scale)
	Normalised Difference Moisture Index (NDMI)	Dimensionless	LANDSAT	1982 to date (freq. 16 days)	30 m	Optimal
	Noise pollution exposure	Inhabitants	Urban agglomerations (Environmental Noise Directive)	2012-2017 (every 5 years)	Urban agglomeration	Complementary (not full EU coverage, no consistent reporting unit)
A2. Chemical state	Air pollutants concentration (NO_2, PMx, O_3, SO_2, CO)	μg/m^3	EMEP	2000-2018 (from EMEP modelled data updated)	0.1°	Optimal / Modelled
			CAMS	2018 (CAMS expected to be updated regularly)	0.1°	
			Annual AQ statistics from	2003-2022	Ground monitoring points	

[13] Optimal data: spatially explicit data covering the full EU territory, frequently and regularly collected/measured and made available in a timely manner; Modelled data: variables derived from modelling to provide spatially explicit and regular time series at the EU level; Complementary data: data that does not match some of the conditions of optimal data; Data gap: condition variable for which there is no data available for the entire EU territory and which is not expected to be developed soon.

[14] The online data codes included correspond to Eurostat datasets currently available from where waste generated per capita, and related specific waste variables per capita, can be calculated. Variable options related to specific waste categories, materials, treatments and management operations despite the data is available at national level is not presented to avoid overcomplications. Further analysis might identify necessary calculation by specific waste-related categories.

Condition Typology	Variable	Units	Source of the variable at EU level	Temporal series available	Spatial Resolution	Type[13]
			European Environment Agency	(Annual AQ Statistics)		
	Soil organic carbon stock	kg C/ha	Biogeochemical models and soil monitoring databases	-	-	Data gap
	Heavy metals in soil	µg/g	Soil databases (e.g. LUCAS)	-	-	Data gap
B1. Compositional state	Autochthonous woody vegetation species	Number of species (traits)	-	-	-	Data gap
	Urban bird species richness	Number of species	-	-	-	Data gap
	Pressure by invasive alien species	Dimensionless	JRC-EASIN	No	10 km	Complementary (currently no time series)
B2. Structural state	Greenness - annual max NDVI	Dimensionless	LANDSAT	1982 to date (freq. 16 days)	30 m	Optimal
	Share of tree canopy cover	%	HRL Land	2012-2015-2018	10 m	Optimal
	Share of green spaces and/or green spaces per inhabitant	% or ha/inhabitant	LANDSAT	1982 to date (freq. 16 days)	30 m	Optimal
			CLC+	2018	10 m	Optimal
	Semi-natural and natural riparian land cover	%	Riparian Zones Copernicus & Copernicus HRL Land	2012-2018	0.5 ha & 10 m	Optimal
B3. Functional state	Plant evapotranspiration	mm/d	PML V2 model	2002-2020	500 m	Modelled
C1. Landscape and seascape	Integrity of the green network	%	Copernicus HRL Land	2006-2012-2018	10 m	Optimal
	Fragmentation of the green network	%	Copernicus HRL Land	2006-2012-2018	10 m	Coming soon
	Riparian fragmentation	meters	Riparian Zones Copernicus Land & Copernicus HRL Land	2012-2018	0.5 ha & 10 m	Coming soon
	Patch richness or	Dimensionless	CLC (or CLC+)	1990-2000 - 2006-2012-	100 m (CLC);	Optimal

Condition Typology	Variable	Units	Source of the variable at EU level	Temporal series available	Spatial Resolution	Type[13]
	Shannon diversity index of land cover types			2018 (CLC); 2018 (CLC+)	10 m (CLC+)	

Source: Modified from the EU-wide Methodology (Vallecillo et al., 2022)

4.3 A pilot urban ecosystem condition account

The subset of variables included in this pilot were selected because they might help to inform current EU law proposals, test the added value of technology-related variables, and illustrate connections between condition and services accounts. Regarding law proposals, for two condition variables (share of green spaces and tree cover) there are urban targets in the proposed Nature Restoration Law. Share of imperviousness, green spaces and atmospheric concentration of particulate matter are also included as condition variables in the proposed amendment of the Regulation on environmental accounts. Imperviousness also represents a technology-related attribute, which influences the supply of local ecosystem services (e.g., water infiltration, local climate regulation). Imperviousness per capita might inform how urban ecosystems influence ecological resilience and health of other ecosystems in which it depends. Finally, the four condition variables included in this report are related to air purification and or local climate regulation as ecosystem services, which are included in the pilot of urban ecosystem services accounts (Chapter 5).

4.3.1 Share of imperviousness and imperviousness per inhabitant

Imperviousness condition accounting values for urban ecosystems aggregated at country level are visualised in Table 6. In terms of the overall share of imperviousness and imperviousness of urban Settlements and other artificial areas, Malta (MT) is the MS with the highest share of imperviousness (59.9%), which is much higher than average values at EU-27 and EU-27 and EFTA levels (25% and 25.8%). However, Malta is also the MS with the lowest imperviousness per inhabitant, also much lower than values at EU-27 and EU-27 and EFTA levels. From one side, this means that urban ecosystems in Malta might have reduced in a greater extent their local natural water infiltration capacity and their local climate regulation capacity compared to other MS. From the other side, it also means that urban ecosystems in Malta, compared to those of other MS, seem to be more efficient in terms of sealed surface per inhabitant. This implies that a lesser amount of the urban ecosystem is artificial per inhabitant. It also implies that urban ecosystems in Malta might have had a more efficient consumption of artificial built-up materials (e.g., concrete) per inhabitant. This means that they might have required a lower demand of raw materials and land (from urban ecosystems and elsewhere) per each inhabitant compared to urban ecosystems in other MS. This case clearly illustrates a situation where urban local ecosystem capacity for some services (e.g. water infiltration) seems more hampered compared to other countries, whilst urban demand for other services (e.g. provisioning of inorganic materials) seems more efficient.

From Table 6, it also stands out that urban Coastal beaches, dunes and wetlands have a very low share of imperviousness (0.1% at EU-27 and EU-27 and EFTA levels). It seems to be an artefact of how ecosystem types are delineated, because when the share of imperviousness is very high, the land use is usually classified as an artificial land uses classes, which are allocated to Settlements and other artificial areas. This means that the level of imperviousness in these areas cannot be interpreted as a relevant driver in the condition when monitoring environmental health of Coastal beaches, dunes and wetlands. For example, the proposed amendment of the Regulation on environmental accounts includes as a mandatory condition variable "the share of artificial impervious area cover, present in coastal areas that includes ecosystem type coastal beaches, dunes and wetlands". Depending on how this share is measured, values might be informative or not. If the share of imperviousness is measured only in the ecosystem type Coastal beaches, dunes and wetlands the values will not be informative. Instead, if the estimation extends to other ecosystem types present in the "coastal area" the value will be informative, providing information on urban sprawl in coastal areas. However, in that case what is understood as "coastal area" compared to "coastal beaches, dunes and wetlands" should be defined. As a third alternative, the ecosystem types Coastal beaches, dunes and wetlands and Settlements and other artificial areas should be defined differently, i.e., not mainly based on land use class allocation, to better capture artificial encroaching in coastal areas.

An analysis of imperviousness per type of urban LAU (Figure 9), show larger differences among MS than among types of urban LAU inside each MS. In other words, there are not evident commonalities among the same type of urban LAU in different MS. This implies that, at least for this variable, type of urban LAU as single characteristic might not be enough to split urban ecosystems in homogeneous clusters. This is especially evident for the share of imperviousness in urban Settlements and other artificial areas (Figure 9a), where values for different types of urban LAU are very similar in many MS. However, when looking at imperviousness per inhabitant, a different output emerges (Figure 9c). In that case, cities above 50,000 inhabitants in different MS share a great similarity. Most of them have an approximate range value of 100 to 150 m^2 of impervious land per inhabitant. For cities below 50,000 inhabitants and for towns and suburbs, this similarity across MS is not maintained.

A spatial analysis of imperviousness at LAU level illustrates that a great part of urban LAU in Southern and Western Europe (i.e., Spain, Italy, France, north of Belgium, Netherlands, Luxembourg, France, and Malta) have a higher share of imperviousness than the rest (Figure 10a). These pattern is not maintained when values are analysed as imperviousness per inhabitant (Figure 10b). Only most of the West of Poland (PL), Slovakia (SK) and Romania (RO) maintain a low imperviousness per inhabitant and a low share of imperviousness.

Table 6. Average imperviousness per ecosystem type (in percentage) and overall imperviousness (in percentage and in m^2 of land surface per inhabitant) in urban local administrative units of EU-27 and EFTA MS in 2018. Values are rounded to the first decimal digit and MS are sorted in alphabetical order.

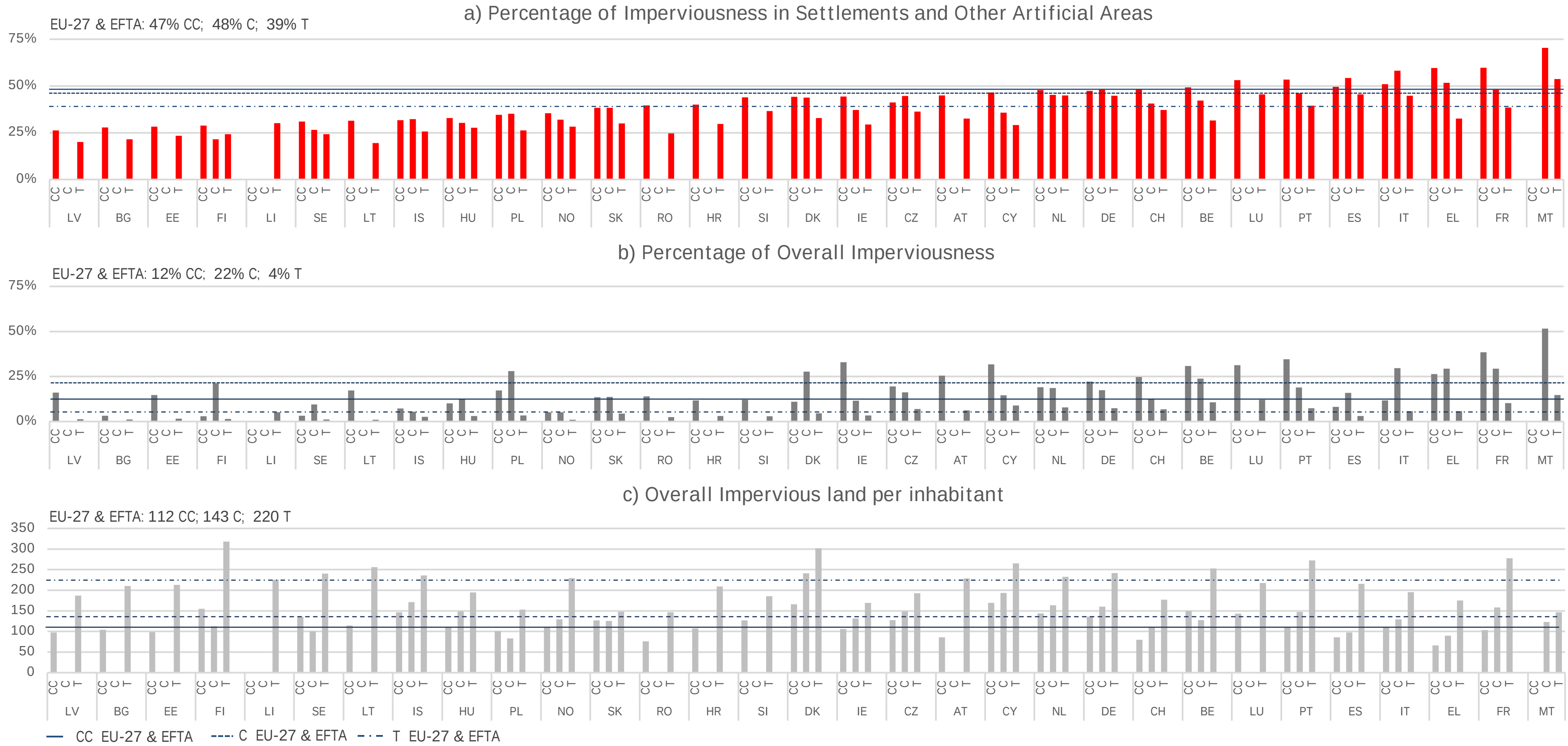
	Ecosystem Type *													
	1	2	3	4	5	6	7	8	9	10	11	12		
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.**	Lake & Res.**	Mar. Inllets	Coastal B.	Marine**	Overall (%)	Overall (Ha/inhabitant)
AT	32.7%	3.5%	1.7%	0.9%	0%	0%	0.1%	1.8%	0.8%	0%	0%	0%	7.8%	156.0
BE	33.7%	3.6%	3.0%	1.2%	1.8%	0%	0.2%	2.3%	0.6%	0.4%	0.2%	0%	12.8%	210.5
BG	22.8%	0.6%	0.3%	0.1%	0%	0.1%	0.1%	0.3%	0.4%	0%	0.1%	0.1%	1.6%	138.4
CH	37.5%	4.3%	0.8%	0.8%	0%	0%	0.1%	0.9%	1.8%	0%	0%	0%	7.8%	146.6
CY	32.5%	2.8%	0.7%	1.6%	0.6%	0.5%	0%	0%	0.2%	0%	0.2%	2.8%	14.2%	201.7
CZ	36.6%	2.5%	1.2%	0.8%	0%	0%	0%	0.4%	0.3%	0%	0%	0%	9.2%	162.3
DE	45.0%	2.4%	3.5%	1.1%	0.1%	0%	0.1%	0.6%	0.5%	0.1%	0%	0.1%	9.7%	189.6
DK	36.7%	3.1%	1.3%	1.6%	0%	0%	1.8%	0%	1.3%	0.3%	0.6%	2.7%	6.1%	242.9
EE	24.2%	3.1%	1.8%	1.2%	0%	0%	0.4%	1.1%	0.3%	0%	0.1%	3.4%	3.0%	132.8
EL	39.3%	3.8%	0.6%	0.6%	0.5%	0.4%	0%	0%	0%	0%	0.3%	2.8%	9.2%	103.6
ES	46.5%	3.6%	3.4%	0.7%	1.0%	0.2%	0.1%	0.3%	0.1%	0.5%	0.6%	0.8%	4.2%	134.6
FI	24.9%	1.3%	0%	0.8%	0%	0%	0%	0.4%	0.2%	0%	0.1%	0.9%	1.7%	226.4
FR	40.9%	3.8%	2.0%	1.4%	0.4%	0%	0.1%	1.1%	0.5%	0.4%	0.2%	0.3%	14.0%	188.2
HR	30.5%	1.9%	0.7%	0.4%	0.1%	0%	0.3%	0.5%	0.3%	0%	0.6%	2.1%	4.2%	155.7
HU	28.0%	1.1%	1.0%	0.3%	0%	0%	0.2%	0.2%	0.4%	0%	0%	0%	4.1%	151.7
IE	35.2%	2.3%	2.1%	0.7%	0.1%	0%	0.3%	0.6%	0%	2.7%	0.4%	1.4%	6.6%	137.8
IS	27.6%	0.2%	1.0%	0.4%	0.3%	0%	0.2%	0%	0%	0.7%	0%	3.8%	4.0%	182.3
IT	45.8%	5.2%	0.5%	0.7%	0.1%	0.1%	0%	0.3%	0.1%	0%	0.5%	0.9%	6.9%	160.4
LI	30.1%	2.5%	0.8%	0.8%	0%	0%	0.2%	2.9%	0%	0%	0%	0%	5.1%	225.4
LT	23.7%	2.7%	1.0%	0.5%	0.6%	0%	0.1%	0.6%	0.2%	1.5%	0%	0.2%	2.2%	148.6
LU	45.7%	2.5%	3.1%	1.1%	0%	0%	0%	1.9%	0%	0%	0%	0%	13.7%	196.7
LV	21.2%	2.3%	1.4%	0.8%	0%	0%	0.2%	1.8%	0.3%	0%	0.1%	0.3%	2.3%	126.3
MT	60.8%	8.3%	0%	0%	1.1%	0%	0%	0%	0%	0%	1.3%	11.2%	21.4%	135.0
NL	45.5%	6.6%	3.3%	1.9%	0.3%	0%	0.6%	1.8%	1.3%	0.2%	0.1%	0.2%	10.6%	183.7
NO	28.8%	1.8%	0.1%	0.3%	0.1%	0.1%	0.1%	0.6%	0.1%	1.2%	0%	4.4%	1.2%	188.1
PL	27.3%	2.2%	1.4%	0.8%	0%	0%	0.1%	0.3%	0.3%	0%	0%	0.1%	5.3%	124.2
PT	42.0%	8.4%	0.7%	3.2%	0.7%	0%	0%	0.3%	0.1%	0.5%	0.5%	0.4%	10.0%	196.7
RO	25.9%	1.0%	0.8%	0.3%	0%	0.1%	0.4%	1.1%	0.3%	0%	0.1%	0.1%	3.8%	106.0
SE	25.3%	1.4%	1.4%	0.6%	0%	0%	0.1%	0.5%	0.1%	0.4%	0.1%	1.3%	1.4%	186.8
SI	36.9%	2.8%	1.2%	0.3%	0%	0%	0%	1.0%	0.6%	0%	0.3%	1.2%	3.8%	165.0
SK	31.2%	1.9%	0.4%	0.3%	0%	0%	0%	0.6%	0.3%	0%	0%	0%	5.7%	140.0
EU	40.8%	3.8%	1.9%	1.1%	0.3%	0.1%	0.1%	0.7%	0.4%	0.2%	0.2%	0.5%	6.0%	165.4
EU & EFTA	40.5%	3.8%	1.8%	1.1%	0.3%	0.1%	0.1%	0.7%	0.4%	0.2%	0.2%	0.5%	5.8%	165.3

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Values corrected to avoid accounting incoherencies result of limitations in the spatial resolution of the input data used for the delimitation of ecosystem types.

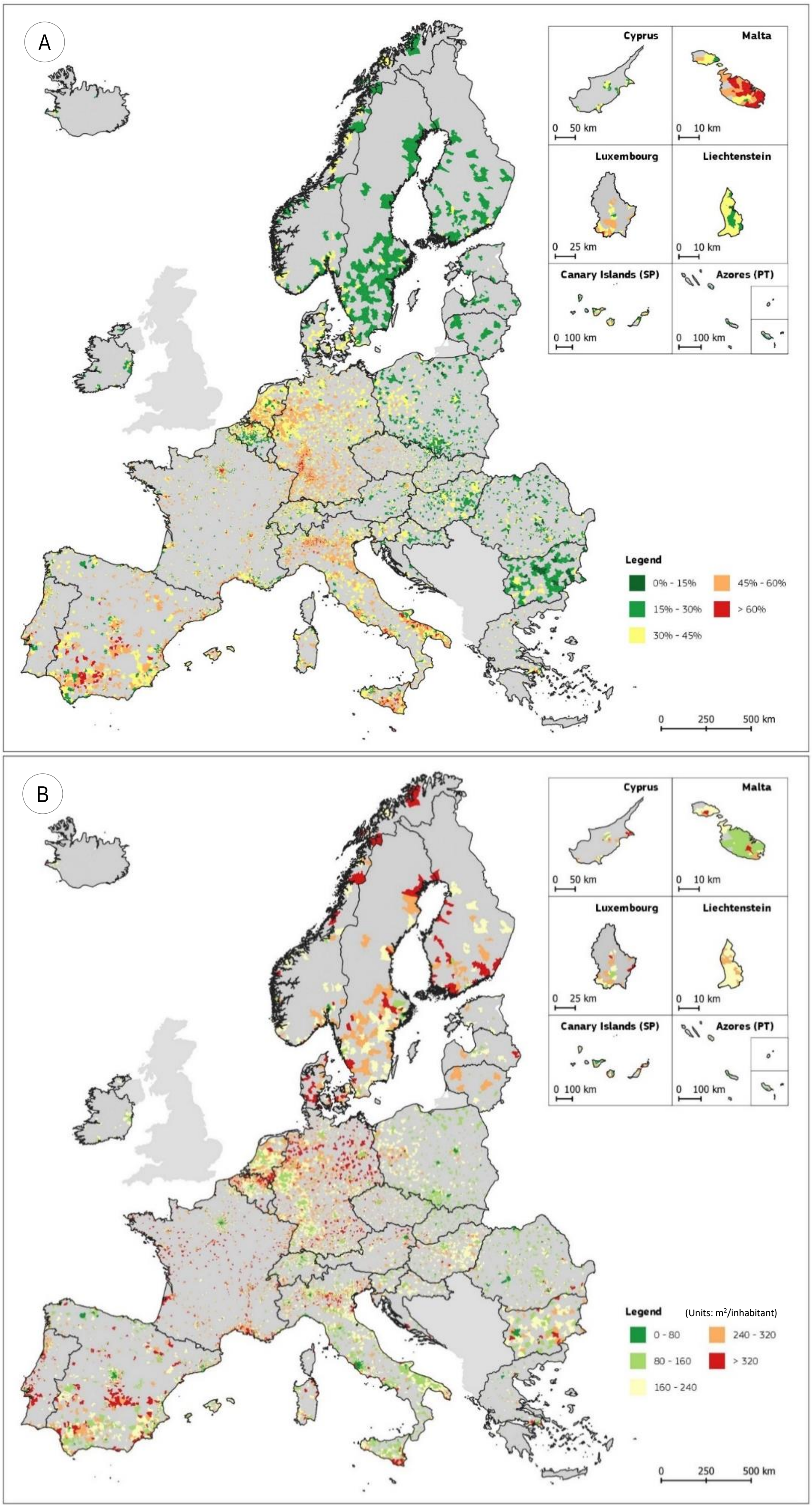
Source: JRC analysis.

Figure 9. Average imperviousness of EU-27 and EFTA MS aggregated by type of urban local administrative units (LAUs) in 2018. a) Average percentage of imperviousness in urban *Settlements and Other Artificial Areas*; b) Overall average percentage of imperviousness considering the entire urban ecosystem; c) Average amount of impervious land (m^2) per inhabitant considering the entire urban ecosystem. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in settlements and other artificial areas (a).



Source: JRC analysis

Figure 10. Map of imperviousness per urban local administrative units (LAU) of EU-27 and EFTA MS in 2018. A) Share of imperviousness (%) of *Settlements and Other Artificial Areas*. B) Impervious land (m^2) per inhabitant



Source: JRC analysis

4.3.2 Share of urban green and urban green per inhabitant

Values of green spaces[15] for urban ecosystems aggregated at country level are visualised in Table 7. Based on the values of Table 7, we can derive that in most Southern European countries urban Settlements and other artificial areas have a share of urban green in between 30 and 40%, in line with the average EU-27 and EU-27 and EFTA values (40& and 41%). When looking at those values disaggregated per type of urban LAU (Figure 11a), the pattern is maintained, but also cities and towns and suburbs of many other MS show a similar share of green in urban Settlements and other artificial areas. Both the aggregated and disaggregated results also show that Northern European countries (e.g. Finland, Poland, Sweden, Estonia) tend to have a higher share of green in their urban Settlements and other artificial areas. From these results, it seems that in part similarities and differences in the share of urban green are influenced by regional factors.

Comparing these results to those of imperviousness, also some commonalities can be seen. Malta (MT) is the MS with the lowest share of green spaces in urban ecosystems and the one with the largest share of imperviousness. Results for both condition variables reinforce potential reduced ecosystem potential to deliver water infiltration and local climate regulation. Additionally, results at MS level for share of urban green and imperviousness, despite not being a perfect inversion (i.e., high imperviousness always corresponds to low share of green spaces), is close to it as it could be expected. On the contrary, this is not the case between imperviousness per inhabitant and share of urban green or urban green per inhabitant.

A spatial analysis of the share of green spaces in urban Settlements and other artificial areas (Figure 12a) seem to be also kind of a specular image of the map of share imperviousness (Figure 10a). Instead, values of urban green spaces per inhabitant seem to be related to the types of urban LAU in Europe. Figure 11c clearly shows that cities (above and below 50.,000 inhabitants) in most MS have less than 0.1 hectares of urban green per inhabitant (LAU represented in red and orange in Figure 12b), while on average towns and suburbs easily overpass this threshold.

Figure 12 suggests that values of green spaces per inhabitant, and values of overall share of green spaces in urban ecosystems, are influenced by the size of LAU. Then, to reduce the risk of biases in policy targets linked to these condition variables, the targets should be established relative to the LAU, or to its artificial surfaces, and not as absolute values. For example, for urban green spaces, an option could be to make targets relative to the extent of Settlements and other artificial areas inside urban LAU. This could be articulated as an increase in green space equivalent to a certain percentage of the extent of urban Settlements and other artificial areas. Another alternative could be to avoid the use of LAU as a reporting accounting unit and policy reference unit. However, this alternative could have other drawbacks. As described in Section 3.2, in most EU-27 and EFTA countries, LAU correspond to municipalities making them suitable reporting units for ecosystem accounts that should also serve local policy purposes. In many European countries implementation of urban policies, or their derived actions occur at local level, making LAU also very suitable reference units for policy targets.

[15] As indicated in Section 4.2, as urban green space is understood any piece of urban land covered with mosses and lichens, permanent herbs, shrubs, or trees.

Table 7. Average green spaces per ecosystem type (in percentage) and overall green spaces (in percentage and Ha/inhabitant) in urban local administrative units of EU-27 and EFTA MS in 2018. Values are rounded to the first decimal digit and MS are sorted in alphabetical order.

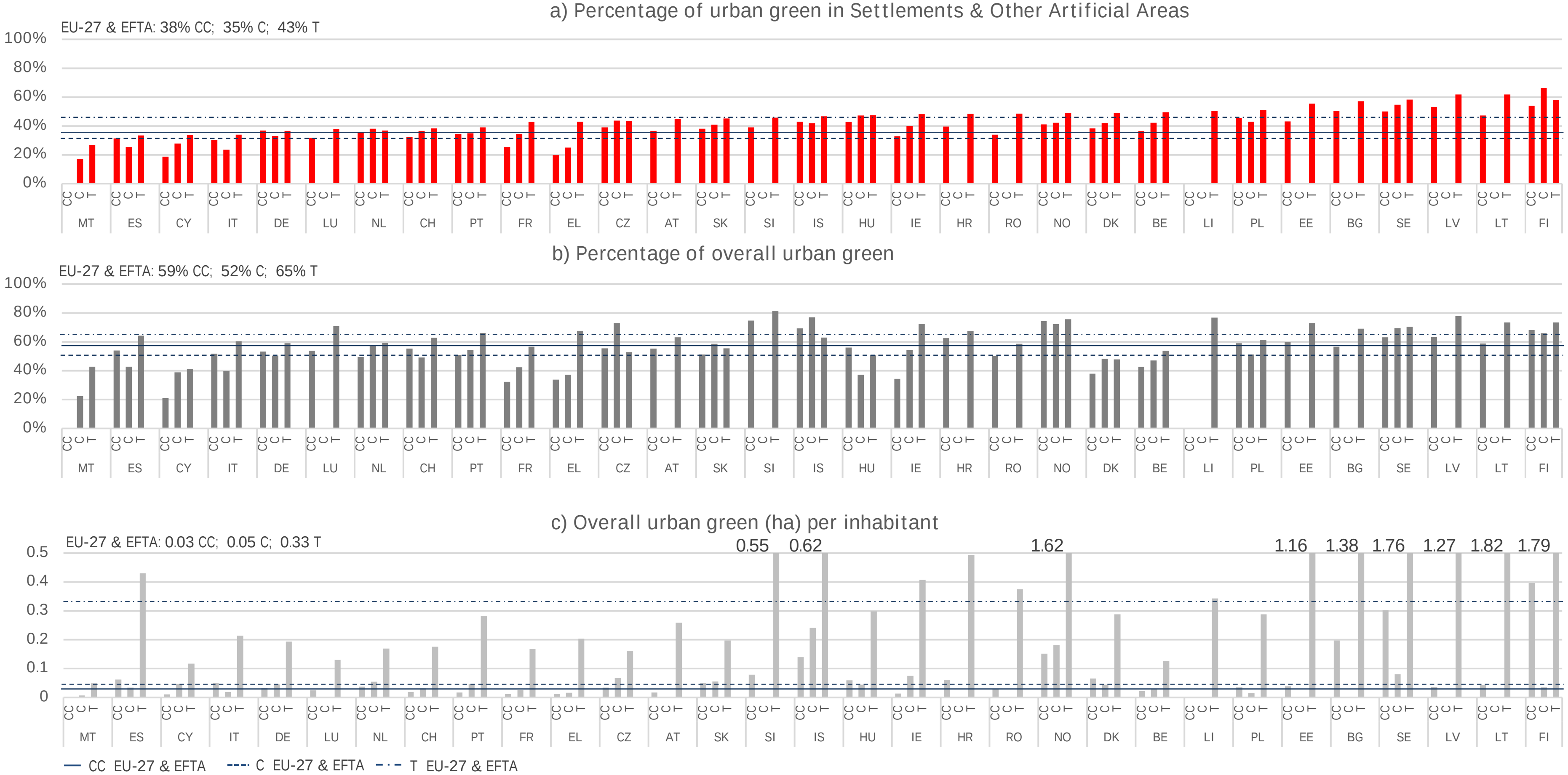
	Ecosystem Type *												Overall (%)	Overall (Ha/inhabitant)
	1	2	3	4	5	6	7	8	9	10	11	12		
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.**	Lake & Res.**	Mar. Inlets	Coastal B.	Marine**		
AT	44.9%	52.1%	87.7%	89.6%	94.9%	51.5%	93.0%	0%	0%	-	-	-	63.0%	0.14
BE	47.9%	50.8%	68.9%	76.3%	82.6%	70.4%	86.8%	0%	0%	17.3%	51.3%	0%	52.4%	09
BG	55.8%	53.3%	92.2%	97.7%	96.5%	75.6%	88.0%	0%	0%	0%	21.2%	0%	66.6%	0.58
CH	38.0%	57.0%	87.8%	89.4%	95.1%	40.2%	86.9%	0%	0%	-	-	-	61.5%	0.12
CY	30.7%	38.9%	61.9%	33.7%	76.4%	60.6%	38.1%	0%	0%	0%	54.4%	0%	39.1%	05
CZ	43.1%	40.1%	84.0%	87.7%	0%	0%	74.4%	0%	0%	-	-	-	53.0%	0.10
DE	36.4%	34.3%	81.3%	91.9%	93.0%	36.9%	89.2%	0%	0%	17.8%	81.7%	0%	58.6%	0.11
DK	46.2%	45.4%	86.5%	84.9%	96.8%	96.7%	87.9%	0%	0%	27.2%	78.1%	0%	46.8%	0.18
EE	53.3%	72.5%	88.6%	95.9%	98.9%	94.1%	87.5%	0%	0%	0.%	38.1%	0%	70.6%	0.37
EL	37.0%	71.7%	90.8%	51.2%	90.6%	64.8%	83.2%	0%	0%	21.9%	60.9%	0%	58.1%	07
ES	32.6%	58.8%	81.5%	76.2%	90.7%	69.6%	70.8%	0%	0%	14.0%	41.9%	0%	61.8%	0.20
FI	57.5%	47.6%	86.5%	92.7%	0%	65.1%	76.1%	0%	0%	0.%	70.7%	0%	72.6%	1.00
FR	40.6%	49.1%	80%	76.0%	90.3%	65.8%	81.4%	0%	0%	15.3%	46.0%	0%	53.3%	08
HR	47.7%	59.3%	84.3%	95.7%	90.3%	75.9%	77.0%	0%	0%	2.9%	37.4%	0%	67.1%	0.27
HU	47.2%	36.7%	89.9%	94.0%	0%	76.2%	89.5%	0%	0%	-	-	-	51.0%	0.17
IE	42.1%	57.5%	89.6%	57.3%	97.0%	81.6%	89.4%	0%	0%	13.2%	67.6%	0%	58.4%	0.16
IS	45.4%	90.8%	92.6%	75.9%	90.1%	23.1%	93.4%	0%	0%	15.1%	35.4%	0%	66.4%	0.33
IT	33.3%	61.2%	84.5%	66.6%	93.6%	72.3%	73.8%	0%	0%	19.0%	35.6%	0%	58.9%	0.14
LI	50.4%	67.6%	95.8%	94.7%	86.1%	26.4%	94.0%	0%	0%	-	-	-	76.8%	0.34
LT	56.7%	63.0%	87.3%	96.8%	44.4%	59.9%	88.7%	0%	0%	4.0%	37.3%	0%	68.3%	0.47
LU	37.4%	62.0%	85.8%	96.6%	0%	0%	0%	0%	0%	0%	0%	0%	70.3%	0.10
LV	60.2%	75.5%	90%	96.2%	0%	65.0%	80.4%	0%	0%	0%	25.9%	0%	75.4%	0.44
MT	22.6%	45.9%	0%	6.0%	67.8%	77.1%	0%	0%	0%	0%	20.1%	0%	34.1%	03
NL	36.7%	56.0%	78.8%	77.6%	93.8%	48.7%	80.4%	0%	0%	21.0%	48.0%	0%	57.3%	0.10
NO	48.2%	65.2%	91.9%	94.7%	90.3%	68.6%	91.8%	0%	0%	23.6%	47.6%	0%	75.5%	1.11
PL	50.2%	50.3%	83.6%	92.6%	96.9%	55.9%	89.1%	0%	0%	20.3%	30.8%	0%	61.2%	0.15
PT	37.5%	64.5%	83.0%	79.6%	89.7%	52.2%	86.6%	0%	0%	14.6%	43.3%	0%	61.8%	0.14
RO	47.3%	48.7%	89.3%	88.1%	93.7%	59.7%	73.2%	0%	0%	0%	33.2%	0%	58.0%	0.17
SE	57.0%	58.1%	87.3%	94.0%	81.6%	81.2%	93.6%	0%	0%	26.5%	63.1%	0%	69.3%	1.02
SI	45.4%	73.0%	88.2%	98.1%	80.1%	65.7%	96.0%	0%	0%	0%	39.0%	0%	81.0%	0.39
SK	44.5%	44.3%	89.3%	84.5%	99.9%	63.9%	81.6%	0%	0%	-	-%	-	55.7%	0.15
EU	40%	51.7%	81.0%	81.2%	67.0%	20.4%	61.1%	0%	0%	16.8%	45.2%	0%	56.9%	0.25
EU & EFTA	41.5%	53.0%	83.2%	89.0%	91.0%	67.0%	88.2%	0%	0%	17.4%	45.8%	0%	62.1%	0.28

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Values corrected to avoid accounting incoherencies result of limitations in the spatial resolution of the input data used for the delimitation of ecosystem types.

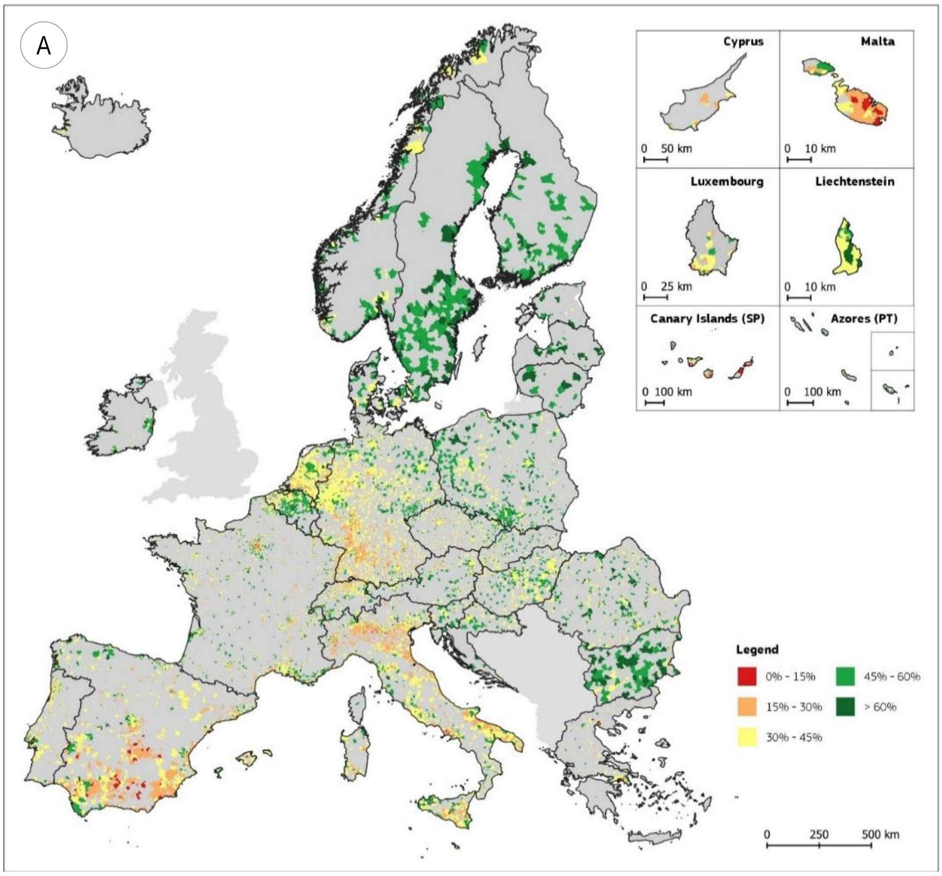
Source: JRC analysis

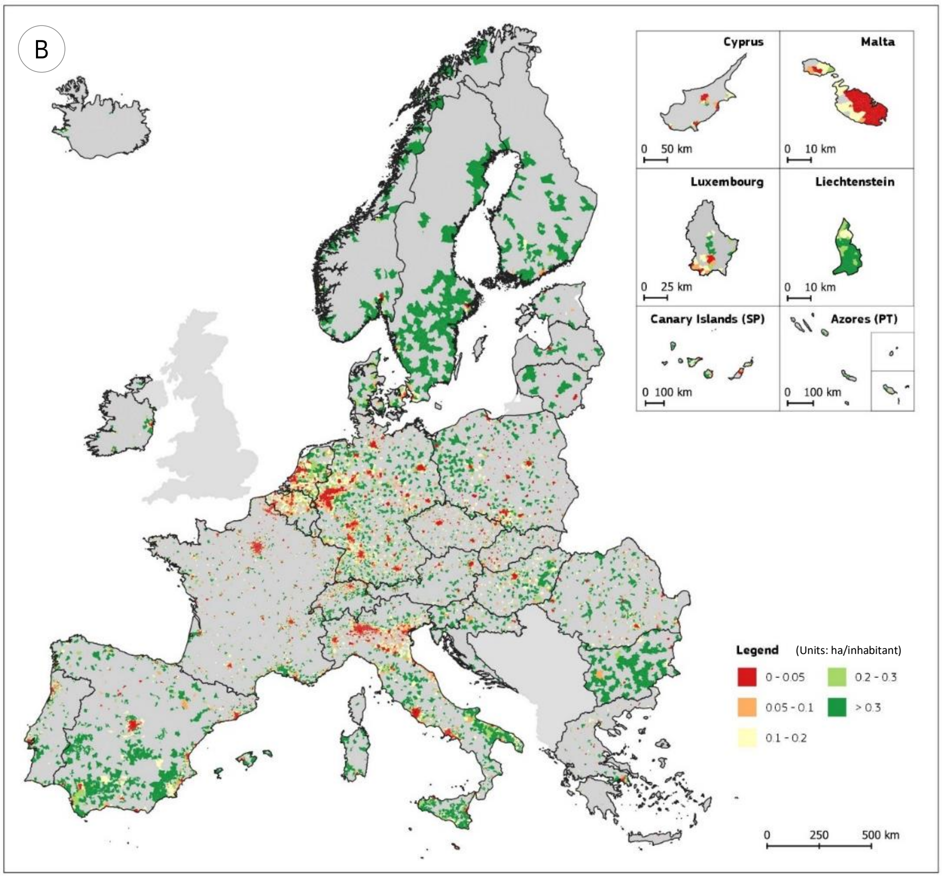
Figure 11. Average percentage of urban green in MS aggregated by type of urban local administrative units (LAUs) in 2018. a) Average percentage of urban green in *Settlements and Other Artificial Areas;* b) Overall average percentage of urban green considering all ecosystem types; c) Average amount of urban green (Ha) per inhabitant (values above 0.5Ha are indicated numerically). LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in settlements and other artificial areas (a).



Source: JRC analysis

Figure 12. Green spaces in urban local administrative units of EU-27 and EFTA MS in 2018. A) Share of green in urban *Settlements and Other Artificial Areas*. B) Urban green (ha) per inhabitant in urban ecosystems.





Source: JRC analysis

4.3.3 Share of tree cover

Values of share of tree cover for urban ecosystems aggregated at country level are visualised in Table 8. In terms of commonalities among urban ecosystem types, Settlements and other artificial areas, Croplands, and Grasslands show values below 20% for most MS. For the other ecosystem types, values are more variegated. This pattern also emerges when values are disaggregated per type of urban LAU (Figure 13a). Regarding commonalities among countries, it can be seen that Scandinavian countries (Norway (NO), Sweden (SE) and Finland (FI)) have the highest overall share of tree cover in urban ecosystems and in their Settlements and other artificial areas. Disaggregated values also show that in these countries high values of tree cover are maintained across all types of urban LAU (Figure 13). Cyprus (CY), Malta (MT) and Iceland (IS) are the only countries with an overall share of tree cover below a 5% (Table 8). From all the countries, only Iceland have a higher share of tree cover inside urban Settlements and other artificial areas (slightly above 5%) than in the overall urban ecosystem.

A minimum 10% of tree cover in all cities, towns and suburbs by 2050 is included as a target for urban ecosystems in the proposed Nature Restoration Law (European Commission, 2022b). Condition accounting results of tree cover at national level, disaggregated per type of LAU and visualised in a spatial explicit form at LAU level can inform on where tree restoration actions are required. Results aggregated at country level show that Cyprus, Malta, Iceland and Ireland (IE) have an average overall share of tree cover in urban ecosystems below 10% (Table 8). A low value when compared it to the average value for EU-27 and EU-27 and EFTA (23.1% and 25.5%). Disaggregated results (Figure 13), showcase that besides the above MS, cities (above and below 50,000 inhabitants) in Greece, and cities above 50,000 inhabitant in Portugal (PT) also have an average overall share of tree cover below 10%. At LAU level, and in a spatialized form (Figure 14a), it can also be seen that a large part of urban LAU in Italy (IT), France (FR), Spain (ES), Greece (EL), Hungary (HU), Netherlands (NL), North western of Belgium and Eastern of Romania (RO) do not overpass a minimum 10% of tree cover. Many other countries, include also urban LAU that do not overpass this threshold. Therefore, for few countries (e.g. Malta, Ireland) restoration efforts should be generalised, others such as Portugal should focus on major cities (e.g. Lisbon or Oporto), and a third group such as Italy should focus in specific geographical contexts (e.g. Po Valley in the North of Italy).

Tree cover results can also inform about the potential feasibility of science-based targets tailored to specific ecosystem types. For example, Iungman et al. (2023) estimated that increasing the share of urban tree cover to 30% at grid-population level (1km x 1km) could avoid a 40% of deaths attributed to urban heat island. Simplifying this threshold from grid level to ecosystem type level, could be framed as a 30% of tree cover in urban Settlements and other artificial areas, since it is where population is mostly located. Results aggregated at country level (Table 8) already informs that on average no MS overpasses this threshold. It is also much higher than the average value for EU-27 and EU-27 and EFTA (8.4% and 8.8%). Disaggregated results show that on average only cities below 50,000 inhabitants in Finland overpass it (Figure 13). Spatialized results at urban LAU level confirm that very few cities, towns and suburbs in EU-27 and EFTA are close to this threshold (Figure 14b). In fact, most MS would need to triplicate (e.g., most urban LAU in Spain) or double (e.g., most urban LAU in Sweden) their share of tree cover in urban ecosystems to fulfil a proposed policy target based on this threshold. A less ambitious policy target could be to transpose the minimum 10% of tree cover of the proposed Nature Restoration Law directly onto urban Settlements and other artificial areas. For this second alternative, results at country level showcase that on average only Poland (PL), Lithuania (LT), Estonia (EE), Belgium (BE), Latvia (LV), Sweden (SE), Norway (NO) and Finland (FI) already overpass this threshold. Disaggregated results showcase that all except Lithuania and Estonia have an average value above 10% for all types of urban LAU (Figure 13). However, spatialized results at LAU level show that, except for Finland, Norway, Sweden and Estonia, most urban LAU in EU-27 and EFTA MS have values below a 10% of tree cover (Figure 14b). In simple terms, application of this second alternative still would require a generalised urban tree restoration effort in Europe, very significant in the case of countries with a very low share of urban tree cover such as Malta, Cyprus or Greece. The above examples illustrate how condition ecosystem accounts of specific variables, such as tree cover, could be useful also to inform the definition of policy targets.

Table 8. Average share of tree cover per ecosystem type and overall share of tree cover in urban local administrative units of EU-27 and EFTA MS in 2018. Values are rounded to the first decimal digit and MS are sorted in alphabetical order.

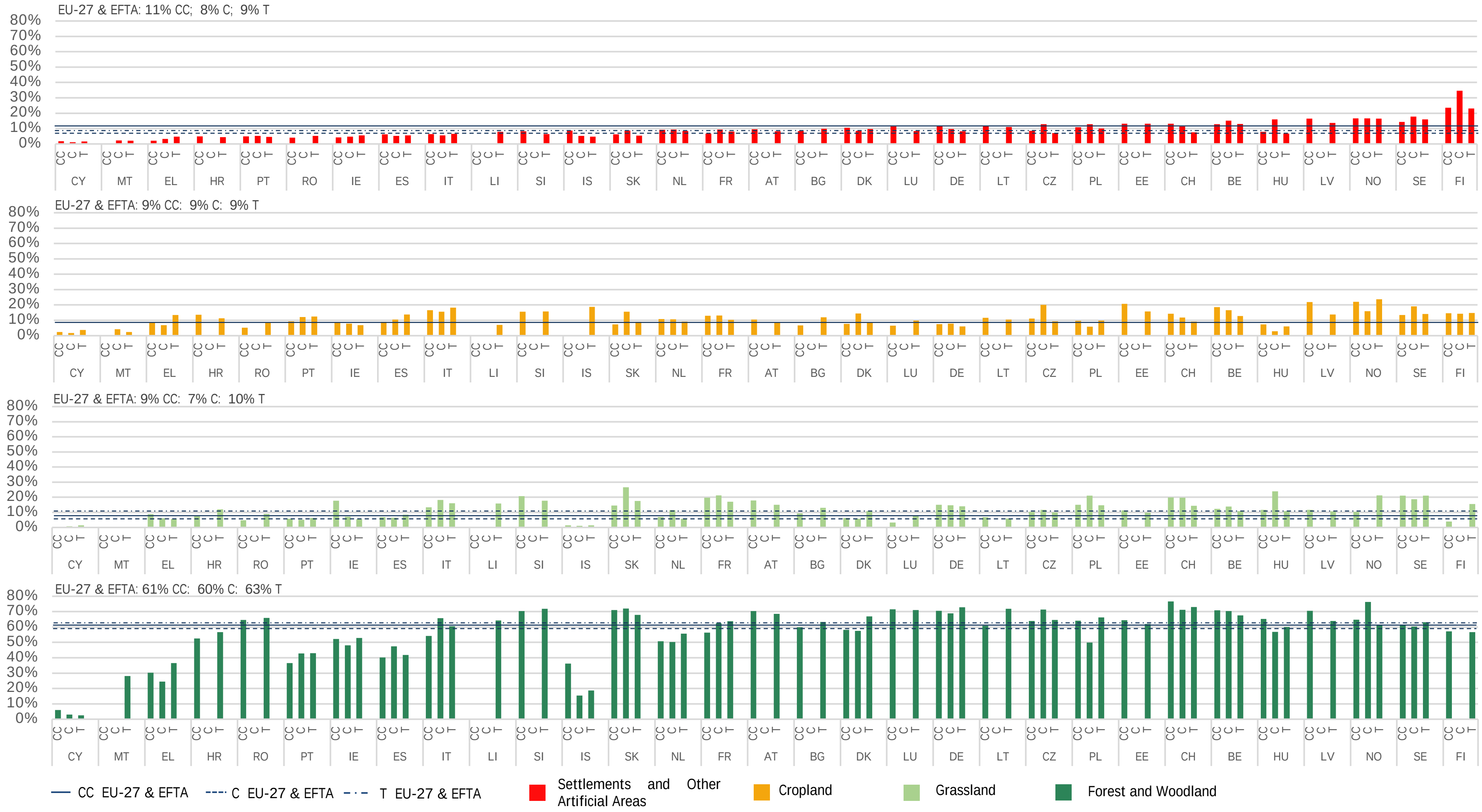
	Ecosystem Type *												
	1	2	3	4	5	6	7	8	9	10	11	12	
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine	Overall (%)
AT	8.2%	8.7%	15.2%	68.6%	37.5%	7.8%	24.1%	0%	0%	0%	0%	0%	29.0%
BE	13.3%	13.5%	11.1%	67.9%	33.4%	5.4%	26.8%	0%	0%	3.3%	4.0%	0%	17.8%
BG	9.6%	10.9%	12.2%	62.6%	17.0%	10.3%	18.6%	0%	0%	0%	1.6%	0%	28.2%
CH	8.0%	9.5%	14.7%	72.9%	23.7%	3.3%	20%	0%	0%	0%	0%	0%	27.3%
CY	1.5%	3.0%	1.0%	2.9%	2.0%	1.4%	4.9%	0%	0%	0%	1.8%	0%	2.2%
CZ	7.2%	9.5%	9.9%	64.7%	0%	0%	35.6%	0%	0%	0%	0%	0%	21.9%
DE	8.5%	6.2%	14.1%	72.6%	20.5%	7.3%	20.2%	0%	0%	1.5%	0.1%	0%	26.9%
DK	9.5%	9.8%	9.7%	64.4%	12.9%	36.3%	26.0%	0%	0%	1.3%	5.8%	0%	14.9%
EE	13.1%	16.7%	10.1%	62.4%	51.0%	26.2%	13.1%	0%	0%	0%	19.2%	0%	30.9%
EL	4.2%	12.5%	5.8%	34.0%	15.2%	3.3%	14.1%	0%	0%	0.2%	5.7%	0%	10.8%
ES	5.7%	13.1%	8.2%	41.9%	19.1%	6.9%	8.8%	0%	0%	1.9%	2.6%	0%	18.7%
FI	23.3%	14.7%	14.4%	56.7%	0%	26.5%	8.2%	0%	0%	0%	8.7%	0%	39.4%
FR	8.3%	10.9%	17.5%	63.4%	30.8%	13.3%	29.6%	0%	0%	2.0%	3.2%	0%	19.8%
HR	4.4%	11.5%	11.6%	56.4%	13.4%	2.9%	29.5%	0%	0%	0.5%	1.6%	0%	24.8%
HU	6.8%	6.1%	11.0%	60.3%	0%	0.1%	19.0%	0%	0%	0%	0%	0%	18.0%
IE	5.0%	7.5%	7.2%	50.6%	6.1%	2.6%	9.0%	0%	0%	0.8%	3.6%	0%	6.3%
IS	5.2%	18.8%	1.3%	20%	1.2%	0.4%	0.8%	0%	0%	0.7%	0.1%	0%	2.5%
IT	6.5%	18.0%	15.8%	60.4%	31.7%	16.0%	19.9%	0%	0%	3.5%	5.1%	0%	22.6%
LI	7.9%	7.1%	15.8%	64.3%	42.8%	8.8%	30.2%	0%	0%	0%	0%	0%	31.8%
LT	11.3%	10.9%	6.3%	68.0%	15.0%	14.3%	27.2%	0%	0%	1.6%	10.6%	0%	29.0%
LU	8.5%	9.7%	8.0%	71.0%	0%	0%	0%	0%	0%	0%	0%	0%	30.3%
LV	14.1%	15.3%	10.8%	65.1%	0%	21.0%	17.7%	0%	0%	0%	6.1%	0%	32.8%
MT	2.1%	3.1%	0%	28.2%	1.4%	2.1%	0%	0%	0%	0%	2.3%	0%	2.4%
NL	8.7%	9.6%	6.5%	54.3%	18.1%	7.5%	15.9%	0%	0%	0.1%	0.7%	0%	11.6%
NO	16.5%	23.3%	20.4%	61.7%	19.3%	8.1%	29.8%	0%	0%	5.9%	13.5%	0%	36.4%
PL	10.2%	9.8%	14.7%	65.9%	11.3%	11.2%	26.0%	0%	0%	5.0%	7.1%	0%	25.2%
PT	4.9%	12.4%	5.8%	42.8%	19.9%	5.6%	15.7%	0%	0%	1.0%	2.7%	0%	17.6%
RO	5.1%	8.1%	8.5%	65.8%	23.9%	7.8%	7.5%	0%	0%	0%	4.3%	0%	20.4%
SE	15.8%	14.1%	21.0%	62.8%	17.2%	20.7%	22.6%	0%	0%	7.4%	11.0%	0%	36.8%
SI	6.5%	15.8%	17.8%	71.9%	27.7%	8.3%	29.4%	0%	0%	0%	1.8%	0%	42.7%
SK	5.9%	9.7%	17.9%	68.5%	6.2%	6.5%	39.7%	0%	0%	0%	0%	0%	25.8%
EU	8.4%	11.8%	11.5%	56.5%	16.2%	3.2%	13.2%	0%	0%	2.5%	3.5%	0%	23.1%
EU & EFTA	8.8%	12.2%	11.9%	61.7%	21.0%	8.6%	21.6%	0%	0%	2.6%	3.7%	0%	25.5%

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Values corrected to avoid accounting incoherencies result of limitations in the spatial resolution of the input data used for the delimitation of ecosystem types.

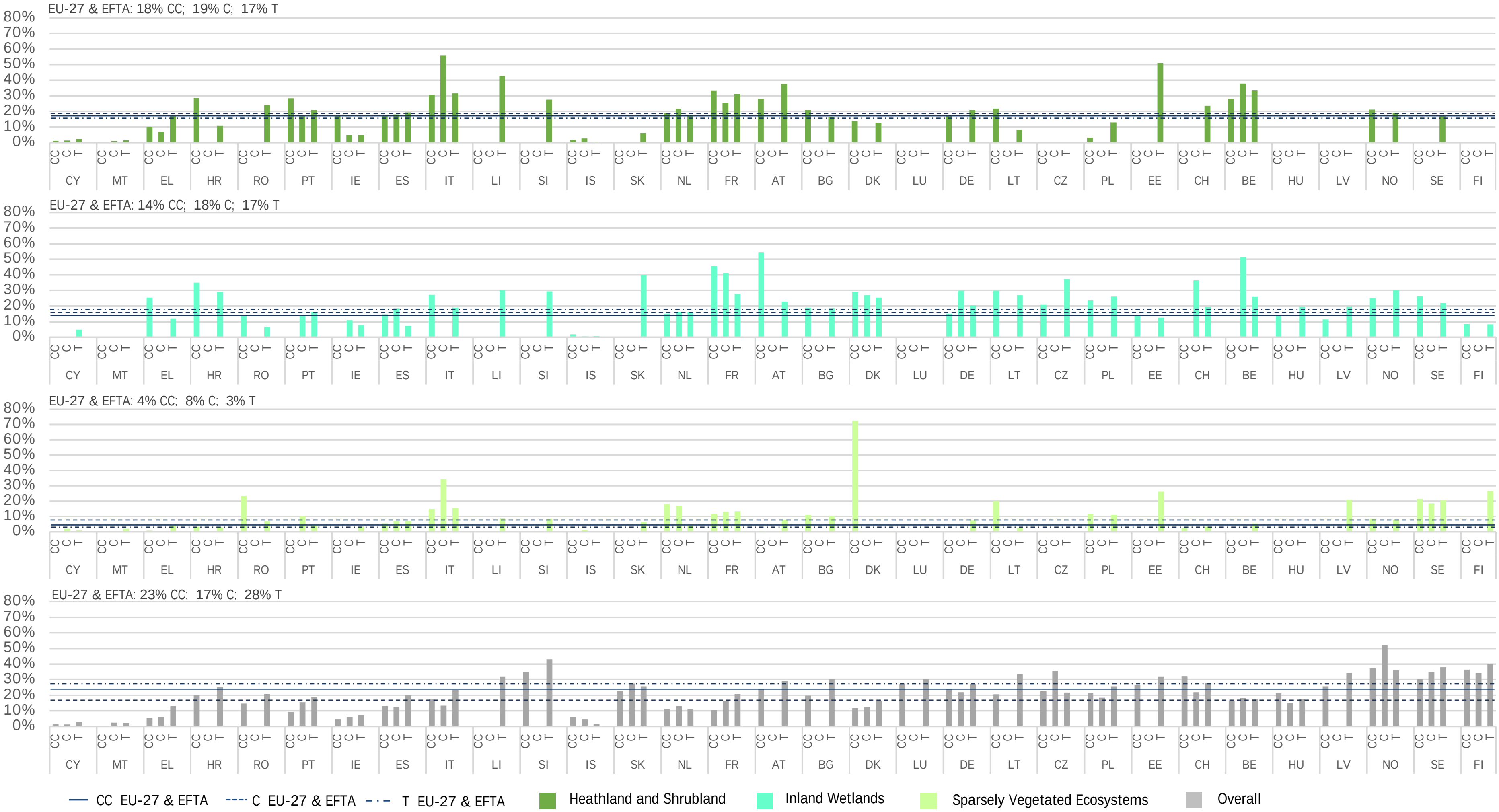
Source: JRC analysis

Figure 13a. Average share of tree cover per ecosystem type in MS (MS) aggregated by type of urban local administrative units (LAUs) in 2018. Values are only presented for those ecosystem types that overpass a value of 20% in one or more MS. Average overall share of tree cover values per type of LAU, beyond ecosystem types, are also represented. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in Settlements and other artificial areas.



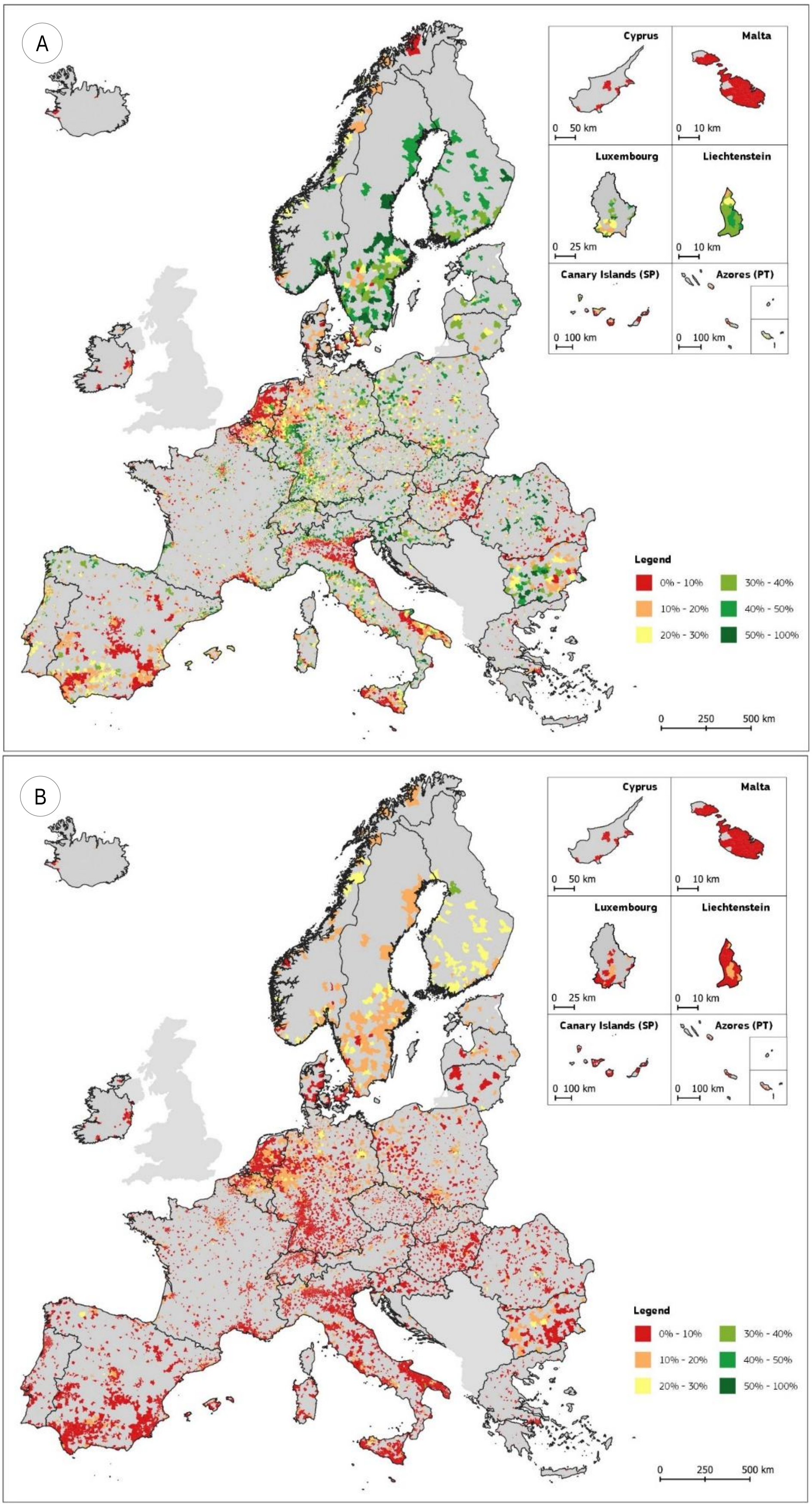
Source: JRC analysis

Figure 13b. Average share of tree cover per ecosystem type in MS (MS) aggregated by type of urban local administrative units (LAUs) in 2018. Values are only presented per ecosystem type (only those that overpass a value of 30% in one or more MS) and as overall average values per type of urban LAU. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in settlements and other artificial areas.



Source: JRC analysis

Figure 14. Tree cover in urban local administrative units (LAU) of EU-27 and EFTA MS in 2018. A) Overall share of tree cover. B) Share of tree cover in urban *Settlements and Other Artificial Areas.* Values are visualised per LAU.



Source: JRC analysis

4.3.4 Particulate matter concentration

Values of particulate matter in urban ecosystems aggregated at country level are visualised in Table 9 and 10. In terms of commonalities, Scandinavian and Baltic countries (Iceland (IS), Norway (NO), Sweden (SE), Finland (FI), Estonia (EE), Latvia (LV)) share low values of PM_{10} and $PM_{2.5}$ compared to other countries. These values are also very low compared to the average values of EU-27 and EU-27 and EFTA. Another commonality is that different ecosystem types inside the same MS have very similar average values. In part, this is because the area of scope is already limited, i.e., urban ecosystem accounting areas, and all ecosystem types are influenced by regional pollution levels occurring in each urban ecosystem. In fact, when differences are larger (e.g., Heathland and Shrubland compared to other ecosystem types in Switzerland (CH)), it is due to variations in the geographical distribution of those ecosystem types compared to the rest. For example, some ecosystem types, might be only be present (or more extensively present) in certain urban ecosystems with much lower or higher particulate matter concentration. Disaggregated results also confirm this pattern (Figure 15), where values per ecosystem type per type of urban LAU are quite similar per MS and major differences (e.g., Grasslands for towns and suburbs in Portugal (PT)) are a result of a different distribution of those urban ecosystem types in the MS.

The map at LAU level (Figure 17) also informs that differences are mainly associated with the geographical position of urban ecosystems and the ecosystem types present in them. This is evident in countries such as Italy (IT), Germany (DE) or Poland (PL), which clear regional differences in terms of PM10 and PM2.5 levels across its territory. In part, this similarity in results among ecosystem types is also influenced by constraints in the spatial resolution of the input data, which is provided at 0.1º (~11 km) and therefore cannot capture differences in air pollution levels at a detailed spatial scale. Therefore, for variables such as air pollution, condition accounting results per ecosystem type at MS level should be considered carefully for policy making and monitoring ecosystem condition, since might not represent the real conditions of urban ecosystems in specific regions.

Besides spatial issues, the use of annual average values of particulate matter could also hide relevant seasonal differences in ecosystem condition. A visualisation of monthly average PM_{10} values per ecosystem and MS makes evident this issue (Figure 16). Most countries do not have a similar PM_{10} concentration across the year, and in some cases few months have values that might double the concentration of many others. For example, in the case of Poland (PL) PM_{10} levels on February double the levels occurring from May to September. Monthly values also make evident that in many MS, those PM_{10} peak periods occur in specific winter months, especially February. Peak values in winter occur mainly in countries with a high dependency on fossil fuels, such as Poland. This seasonal differences are especially relevant since they influence ecosystem potential to mitigate air pollution pressures across the year. In general, trees in urban ecosystems of most MS have a dominant share of deciduous broadleaved woody plants, as shown in Chapter 3 – Figure 7 and 8. Especially, some ecosystem types, such as urban Settlements and other artificial areas are mainly composed of deciduous broadleaved trees. In many cases, also trees in urban Forests and Woodlands include a dominant (or relevant) share of broadleaved species (Figure 8). In practice, this means that in some MS during peak periods of PM_{10} levels, urban ecosystems might have a very low ecosystem potential, and therefore might be limited as mitigation solutions. Therefore, for condition variables such as air pollution condition accounting results calculated as annual averages might not fully capture relevant ecosystem condition issues that might be intermittent on time and can end being masked.

In terms of reference level, the EU-wide Methodology proposed the use of prescribed levels for air pollutant concentration. Building on this proposal, Figure 17 visualises annual PM_{10} (Figure 17a) and $PM_{2.5}$ (Figure 17b) values making use of the thresholds of the Air Quality Directive[16] and the recommended values of the last guidance note of the World Health Organisation (WHO 2021), which inform a proposal for the modification of the Air Quality Directive (European Commission, 2022c). Figure 17a shows clearly that all LAU fulfil thresholds for the Air Quality Directive. However, considering WHO recommended value, almost all the urban ecosystems in Poland, Czechia (CZ), Slovakia (SK), Croatia (HR), the Netherlands (NL) and Belgium (BE) will overpass the WHO recommendations in terms of air quality. It will also occur in several regions of other countries such as Italy (IT), Germany (DE) and Spain (ES). A very similar situation

[16] Threshold values for PM_{10} correspond to 40 µg/m^3 in the current Air Quality Directive and 15 µg/m^3 in the guidance of the World Health Organisation. Instead, threshold values for $PM_{2.5}$ correspond to 25 µg/m^3 in the current Air Quality Directive and 5 µg/m^3 in the guidance of the World Health Organisation

occurs for $PM_{2.5}$ (Figure 17b), but in that case already few urban LAU of Poland already overpass the thresholds established in the Air Quality Directive (25 µg/m^3). In this sense, if reference levels are based on thresholds set by the current Air Quality Directive, condition will be considered as optimal. However, the result would be not so optimistic when using WHO recommended values.

Table 9. Average yearly PM_{10} Concentration (µg/m3) per ecosystem type in urban local administrative units of EU-27 and EFTA MS in 2018. Values are rounded to the first decimal digit and MS are sorted in alphabetical order.

	Ecosystem Type *											
	1	2	3	4	5	6	7	8	9	10	11	12
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT	15.4	15.6	13.9	15.1	11.0	10.9	12.5	15.3	15.6	-	-	-
BE	18.8	18.8	18.8	18.6	18.6	18.6	18.5	18.7	19.4	20.3	19.0	18.4
BG	13.9	13.9	13.7	13.5	10.7	12.8	15.0	15.4	14.0	-	14.4	14.7
CH	13.1	13.1	11.6	13.0	8.5	8.3	12.2	13.6	12.4	-	-	-
CY	20.0	19.9	19.8	19.6	19.8	20.4	20.1	-	20.2	-	20.8	20.7
CZ	21.2	21.2	20.7	21.1	-	-	23.4	21.6	21.4	-	-	-
DE	15.0	15.1	15.0	15.0	15.4	14.1	15.1	15.5	15.5	15.5	15.6	15.1
DK	13.0	12.9	12.9	12.9	12.4	11.0	12.9	-	13.0	12.6	12.8	12.9
EE	7.7	7.6	7.6	7.6	7.9	7.4	7.7	7.9	7.7	-	8.0	7.8
EL	18.6	17.2	16.8	17.8	18.2	18.6	16.5	15.9	14.7	16.0	17.2	18.9
ES	13.5	13.4	13.3	13.1	13.1	11.6	14.0	13.9	12.9	14.8	13.6	12.7
FI	6.4	6.2	5.8	6.1	-	6.0	5.6	5.7	6.2	-	6.6	6.4
FR	15.1	14.9	14.5	14.7	14.1	13.7	15.5	14.7	14.9	15.0	14.8	15.6
HR	16.1	16.1	15.8	15.9	12.6	12.4	17.4	17.6	17.3	13.9	13.3	13.4
HU	18.0	18.0	18.0	17.9	-	17.1	17.8	18.1	17.9	-	-	-
IE	10.0	10.0	9.9	9.9	9.7	9.3	9.5	9.7	9.4	10.1	10.3	10.4
IS	6.2	5.0	5.9	5.9	5.6	5.6	5.3	4.6	6.8	6.0	5.7	6.6
IT	19.2	19.2	16.7	17.7	14.6	15.7	18.6	19.2	18.2	16.7	16.1	15.8
LI	10.2	10.3	9.6	9.8	9.0	9.3	10.7	10.2	-	-	-	-
LT	11.6	11.6	11.6	11.5	11.6	11.9	11.1	12.0	11.5	11.8	11.3	11.2
LU	15.7	15.7	15.7	15.7	-	-	-	14.4	14.0	-	-	-
LV	9.7	9.6	9.6	9.5	-	9.1	9.8	9.8	9.6	-	10.3	10.1
MT	22.0	22.0	-	21.3	22.1	22.0	-	-	-	-	21.2	22.1
NL	17.7	17.7	17.7	17.7	17.8	17.7	17.6	17.9	17.7	17.2	17.6	17.4
NO	8.0	7.7	7.4	7.4	6.7	6.5	6.7	7.1	7.3	6.0	6.1	8.1
PL	23.0	22.9	22.9	22.9	18.2	20.9	20.2	23.3	23.1	15.9	17.7	16.4
PT	13.5	13.4	10.8	13.4	12.2	10.0	13.7	14.0	12.2	16.7	16.1	10.0
RO	16.0	16.0	15.8	15.7	10.5	14.0	16.6	16.3	16.2	-	14.8	14.8
SE	8.4	8.3	8.3	8.1	8.2	7.6	7.5	6.8	7.8	7.3	8.9	9.3
SI	16.4	16.3	16.0	16.1	13.9	13.6	15.4	16.5	15.9	-	15.7	16.5
SK	19.7	19.7	19.1	19.5	17.2	16.8	19.7	20.6	20.3	-	-	-
EU	15.5	15.4	15.0	11.8	10.1	3.9	7.3	15.3	9.4	14.7	14.3	8.2
EU & EFTA	15.8	15.6	15.3	12.4	11.9	8.6	9.3	15.6	10.3	14.9	14.4	10.5

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

Source: JRC analysis

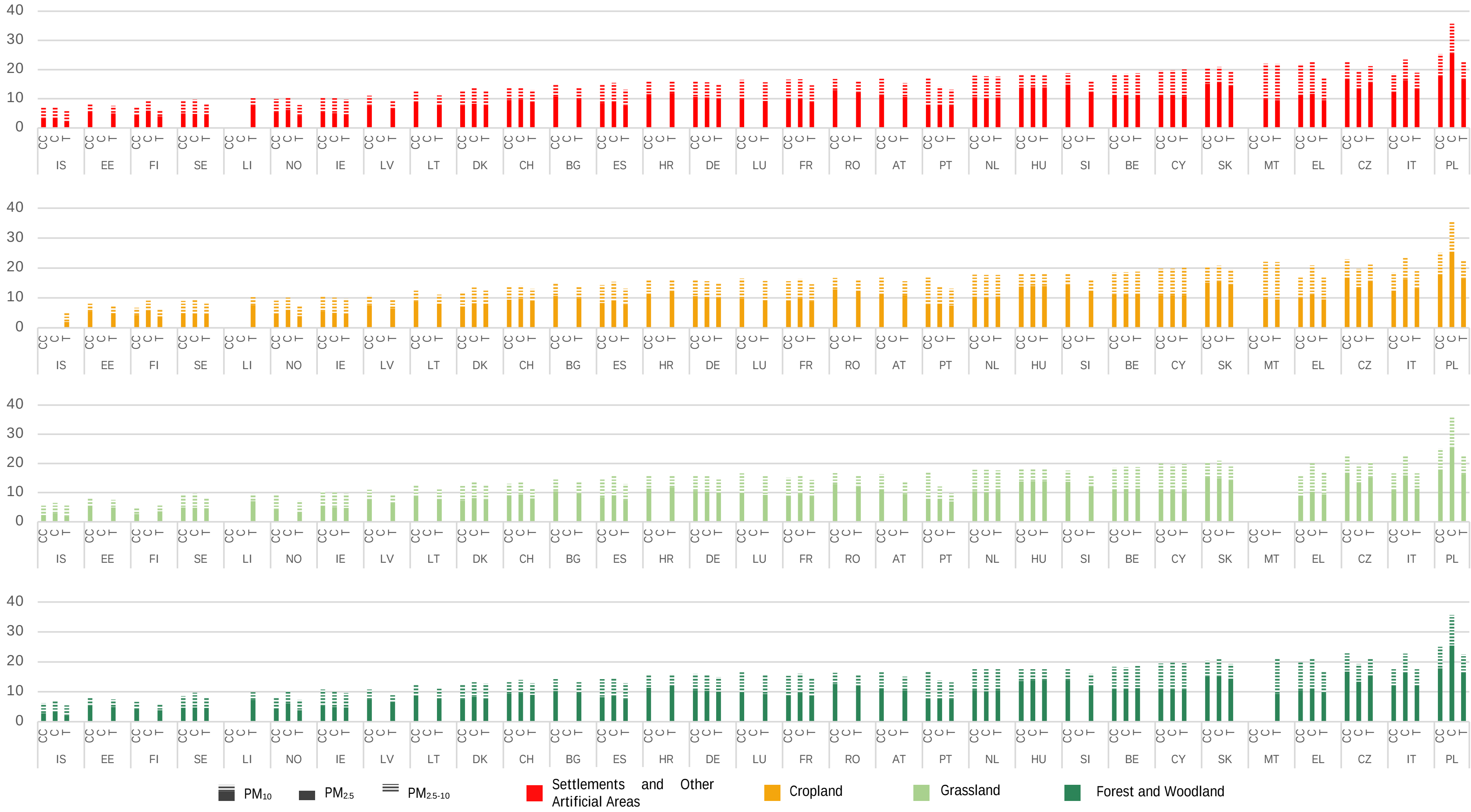
Table 10. Average yearly $PM_{2.5}$ Concentration (µg/m3) per ecosystem type in urban local administrative units of EU-27 and EFTA MS in 2018. Values are rounded to the first decimal digit and MS are sorted in alphabetical order.

	Ecosystem Type *											
	1	2	3	4	5	6	7	8	9	10	11	12
	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT	10.6	10.8	9.5	10.5	7.2	7.0	8.7	10.3	10.9	-	-	-
BE	11.3	11.3	11.3	11.2	11.1	11.2	11.2	11.2	11.7	11.9	11.0	10.7
BG	10.0	10.0	9.8	9.7	7.5	9.1	10.7	11.1	10.0	-	9.8	9.6
CH	9.1	9.1	8.1	9.1	6.0	5.8	8.6	9.5	8.7	-	-	-
CY	10.8	10.8	10.8	10.8	10.8	10.9	11.2	-	10.7	-	11.0	11.0
CZ	15.6	15.7	15.3	15.5	-	-	17.2	15.6	15.8	-	-	-
DE	10.2	10.2	10.1	10.1	10.0	9.5	10.0	10.4	10.4	9.6	9.5	9.1
DK	7.9	7.8	7.7	7.8	7.0	5.7	7.8	-	7.8	7.4	7.5	7.6
EE	5.1	5.1	5.1	5.1	4.9	4.5	5.1	5.4	5.2	-	4.9	5.0
EL	10.1	9.7	9.4	9.9	9.7	9.7	10.3	10.1	8.7	9.3	9.6	9.8
ES	7.9	7.9	7.7	7.7	7.6	7.2	7.8	7.7	7.2	7.5	7.8	7.8
FI	4.1	3.9	3.5	3.9	-	3.5	3.5	3.5	3.9	-	4.1	3.9
FR	9.1	9.0	8.7	8.9	8.2	8.0	9.1	8.9	9.0	7.7	7.7	8.2
HR	11.9	12.0	11.7	11.8	8.4	8.3	13.1	13.5	13.2	9.2	8.7	8.8
HU	13.9	14.0	13.9	13.9	-	13.3	13.7	14.0	13.8	-	-	-
IE	5.0	4.9	4.9	4.9	4.7	4.4	4.6	4.6	4.5	4.8	4.8	4.8
IS	2.6	2.0	2.3	2.5	2.2	2.0	2.0	1.9	2.6	2.5	2.0	2.7
IT	13.4	13.5	11.3	12.3	8.5	10.2	13.3	13.9	12.7	10.1	9.3	8.9
LI	7.5	7.6	7.1	7.3	6.7	6.9	7.9	7.6	-	-	-	-
LT	8.2	8.2	8.2	8.1	8.1	8.5	7.9	8.7	8.1	8.0	7.6	7.5
LU	9.3	9.3	9.3	9.3	-	-	-	8.6	8.2	-	-	-
LV	6.8	6.7	6.6	6.6	-	6.0	6.8	6.8	6.7	-	6.8	6.6
MT	9.6	9.6	-	9.3	9.5	9.3	-	-	-	-	9.3	9.6
NL	10.5	10.5	10.5	10.5	10.6	10.5	10.4	10.7	10.4	10.0	9.7	9.5
NO	4.2	4.1	3.5	4.0	3.3	3.1	3.5	3.9	3.9	2.9	2.5	4.1
PL	16.6	16.6	16.5	16.6	13.2	15.2	14.6	16.8	16.7	10.4	11.4	10.6
PT	7.7	7.6	7.3	7.6	7.3	7.1	7.7	7.3	6.8	8.1	7.7	7.1
RO	12.3	12.4	12.2	12.1	8.0	10.8	12.7	12.5	12.4	-	10.0	10.0
SE	4.8	4.7	4.7	4.6	4.5	4.1	4.3	3.9	4.4	4.1	5.0	5.1
SI	12.4	12.4	12.2	12.2	9.9	9.9	11.7	12.9	12.1	-	10.6	11.0
SK	14.7	14.7	14.3	14.5	12.8	12.2	14.5	15.2	15.0	-	-	-
EU	10.3	10.4	9.9	7.8	5.9	2.5	4.6	10.3	5.9	8.2	7.9	4.7
EU & EFTA	10.5	10.5	10.1	8.2	6.8	4.8	5.6	10.5	6.4	8.2	7.9	5.9

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

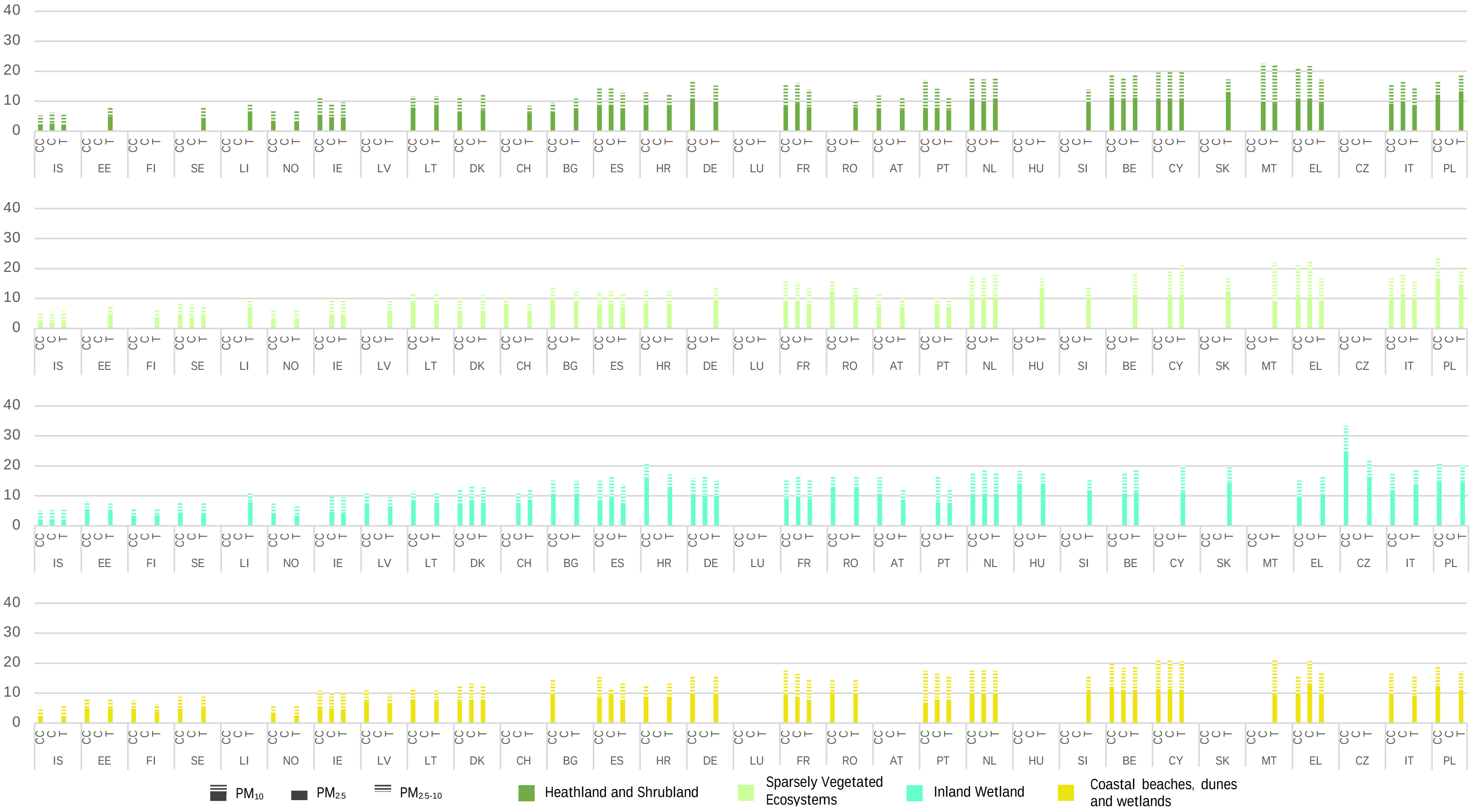
Source: JRC analysis

Figure 15a. Average annual concentration of $PM_{2.5}$ and PM_{10} ($\mu g/m^3$) per ecosystem type in MS (MS) aggregated by type of urban local administrative units (LAUs) in 2018. Values are only presented for terrestrial ecosystem types. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in settlements and other artificial areas.



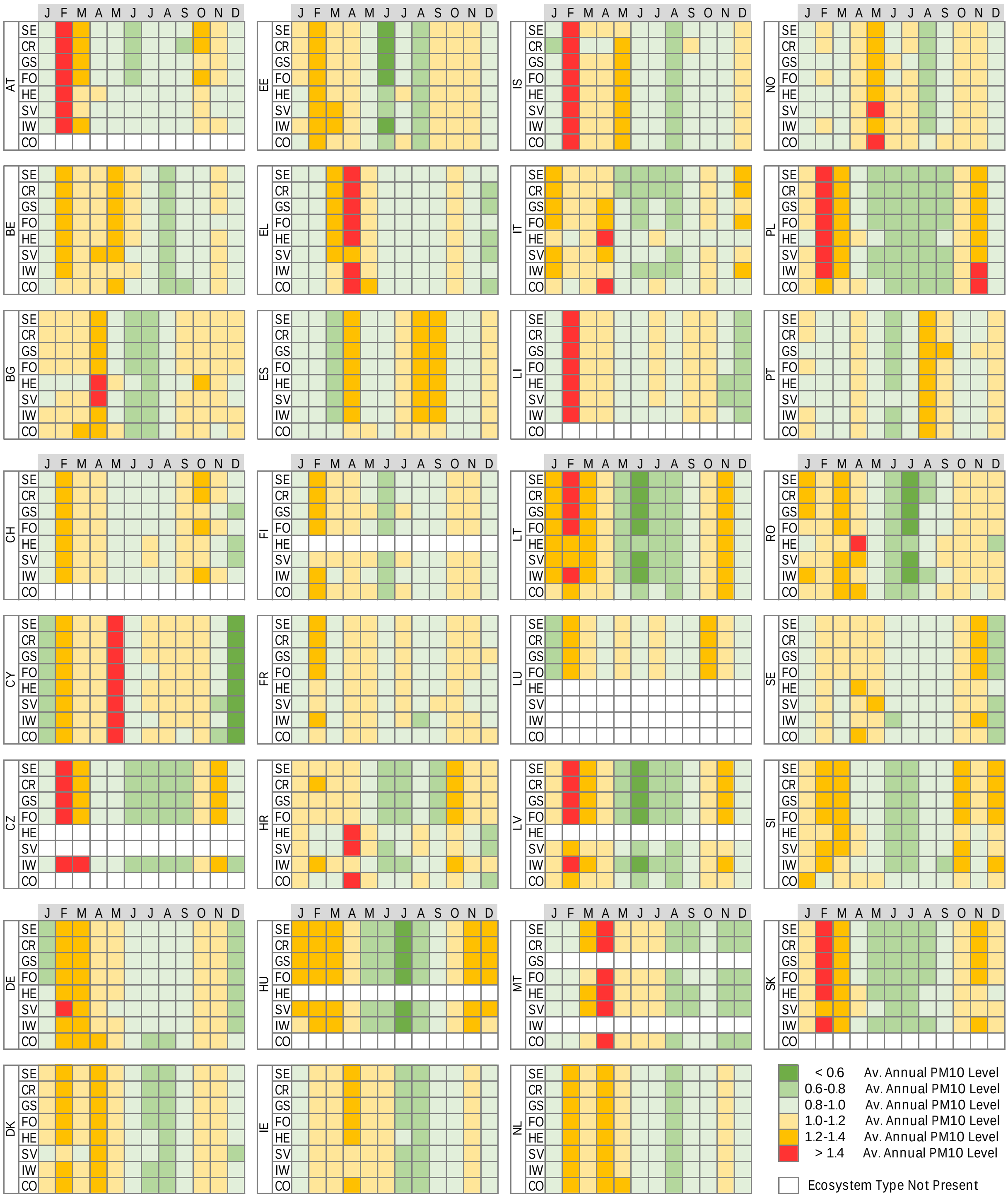
Source: JRC analysis

Figure 15b. Average annual concentration of $PM_{2.5}$ and PM_{10} ($\mu g/m^3$) per ecosystem type in MS (MS) aggregated by type of urban local administrative units (LAUs) in 2018. Values are only presented for terrestrial ecosystem types. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values in settlements and other artificial areas.



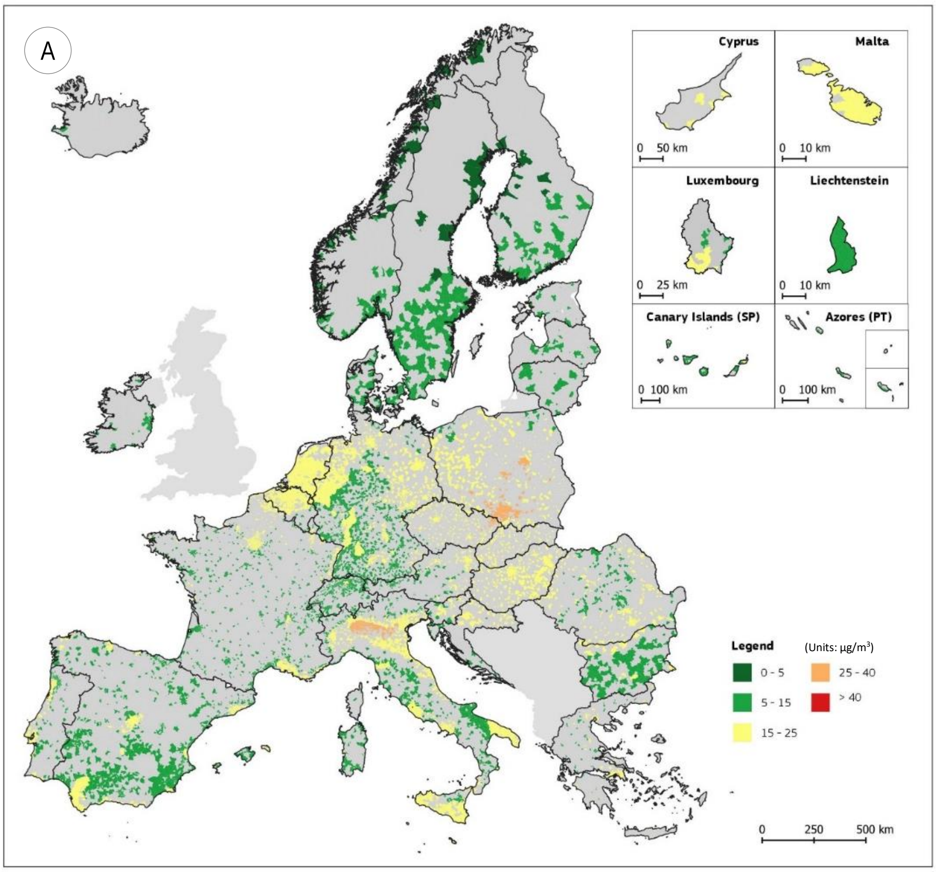
Source: JRC analysis

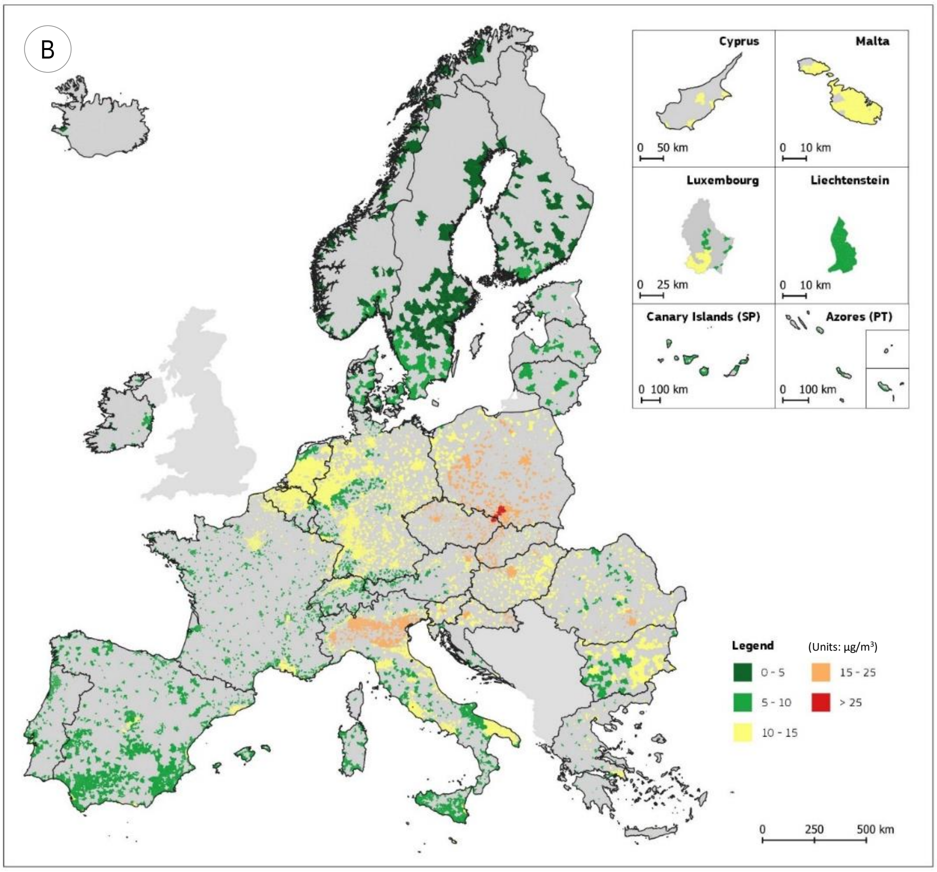
Figure 16. Variations in average monthly PM_{10} concentration per ecosystem type in each MS in 2018. The variations are represented compared to average annual PM10 concentration values and represented as percentages. SE = Settlement and other artificial areas; CR = Cropland; GS = Grassland; FO = Forest and Woodland; HE = Heathland and Shrubland; SV = Sparsely Vegetated Ecosystems; IW = Inland Wetlands CO = Coastal Beaches, Dunes and Wetlands.



Source: JRC analysis

Figure 17. Average annual particulate matter concentration (µg/m³) in urban local administrative units of EU-27 and EFTA MS in 2018. A) Average concentration of PM_{10}. B) Average concentration of $PM_{2.5}$. Values are aggregated and visualised at local administrative unit level.





Source: JRC analysis

4.4 Key Messages

Learnt lessons on urban ecosystem condition accounts

- For urban ecosystem condition accounts, besides the ecological dimension, the social and technological dimensions are also relevant.
- To determine if urban ecosystems are in good condition, both societal demand and local ecosystem potential to deliver services should be considered.
- Results for tree cover illustrate that to fulfil the tree cover target of the proposal for a Nature Restoration law, few EU-27 and EFTA MS should focus on cities above 50,000 inhabitants, others in specific regions and a third group distribute their efforts across the country.
- On average EU-27 and EFTA MS have only around an 8% of tree cover in their urban Settlements.
- In EU-27 and EFTA MS, atmospheric levels of particulate matter are in general below the thresholds recommended by the latest guidance note of the World Health Organisation.

5 Urban Ecosystem Services Accounts

> Ecosystem services are the contributions of ecosystems to the benefits that are used in economic and other human activity (United Nations, 2021).
>
> Ecosystem capacity is the ability of an ecosystem asset to generate an ecosystem service under current ecosystem condition, management and uses, at the highest use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem asset (United Nations, 2021).

As mentioned in Chapter 2 (Table 1), there are still discussions on the concept of ecosystem capacity, especially on the implications of a systemic definition, and its links to the concept of ecosystem condition. In the case of anthropogenic ecosystems, such as urban ecosystems, where humans are a fundamental component, identifying optimal ecosystem capacity could also help to identify optimal ecosystem conditions. For urban ecosystems, approaching ecosystem capacity from a systemic approach, instead of service by service, would have several advantages. For example, it would ensure consideration of limits associated with tipping points (United Nations, 2021), including those result of an unsustainable demand. As another example, it would also ensure that supply of few services up to their individual capacity would not generate drawbacks for the individual ecosystem capacity of others. Chapter 5 briefly discusses the concept of ecosystem capacity in relation to ecosystem condition and extent (Section 5.1). Afterwards, it presents urban ecosystem services accounts for air purification and local climate regulation for EU-27 and EFTA MS (Section 5.2). The accounting results are also used to illustrate specific links with the pilot extent and condition accounts for urban ecosystems already described in Chapter 3 and 4.

5.1 Ecosystem capacity and its links with ecosystem condition and extent accounts

SEEA EA indicates that the extent and condition of ecosystem assets influence ecosystem capacity and the supply of ecosystem services (Section 5.5.6 and 6.5 – United Nations, 2021). On the other hand, the use of ecosystem services might influence ecosystem condition (United Nations, 2021), and consequently, ecosystem capacity and the future supply of ecosystem services. Therefore, to ensure a sustainable flow of ecosystem services is relevant to estimate ecosystem capacity as part of ecosystem services accounts. However, there are still bottlenecks hampering an operational integration of ecosystem capacity accounts into SEEA EA:

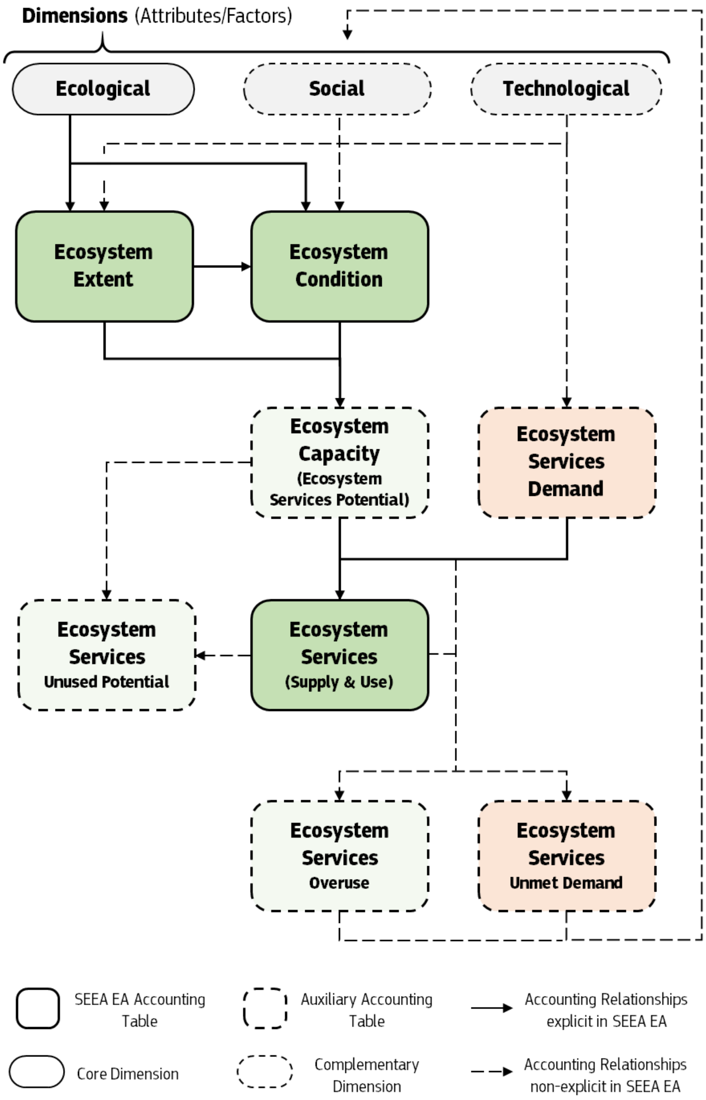
- Lack of agreement about the most suitable approach to estimate ecosystem capacity, a systemic perspective or a service by service basis. For operational purposes, SEEA EA suggests the service by service basis until further research is available on the systemic perspective (United Nations 2021).
- To estimate ecosystem capacity, consideration of management and use actions is acknowledged, but not the related social and technological attributes influencing them. In other words, social and technological dimensions, and therefore variables, are not considered explicitly.
- Ecosystem capacity accounting tables are not required in SEEA EA, their compilation is suggested but as auxiliary intermediate data.
- Ecosystem services demand, is not required either in SEEA EA. Together with ecosystem capacity, ecosystem services demand permits estimation of unused ecosystem services potential, overuse of ecosystem services and unmet ecosystem services demand.
- Unused, overused and unmet ecosystem services accounting tables are neither required in SEEA EA.

In urban ecosystem accounting (thematic approach), overcoming the above ecosystem capacity bottlenecks might not be only useful to estimate ecosystem services supply and use, but also reference ecosystem condition. As described in Chapter 2 and 4, a suitable approach to identify reference conditions would be via the best-attainable approach. For urban ecosystems, the best-attainable approach should also inherently reflect the best-attainable conditions for humans. In other words, the ecosystem condition for which ecosystem services supply and use are optimal from a sustainable perspective, and there is not unmet demand. For an ecosystem service flow to be sustainable there should not be overuse (La Notte et al., 2018; Vallecillo et al., 2019; La Notte et al., 2022, 2022a). In other words, there should not be ecosystem degradation, since it would diminish future ecosystem services potential, and therefore ecosystem capacity. The existence of ecosystem service unmet demand implies that there is an associated societal (urban) challenge (e.g., lack of air quality) that can be mitigated or addressed by nature, which is not completely addressed yet. Therefore, clarifying the ecosystem capacity approach, explicitly considering social and technological factors (related to management and use actions), and including accounting tables for ecosystem capacity, ecosystem services demand, ecosystem services overuse and ecosystem services unmet demand might help to solve challenges related to both, ecosystem service and condition accounts.

In urban ecosystems, overuse and unmet demand might be a consequence of land cover and use decisions, human consumption patterns or both. In urban ecosystems, overuse or unmet demand due to land cover and use decisions can be mitigated via actions such as implementation of nature-based solutions (NBS). Before NBS implementation, an understanding of the causal links between societal challenges, ecosystem services and NBS is required together with an estimation of their potential net impact over time in terms of ecosystem services supply (Babi Almenar et al., 2021, 2023). Hence, recording explicitly accounting tables on ecosystem capacity, ecosystem services demand, ecosystem services overuse and ecosystem services unmet demand, would also inform national and local policy making and planning of future restoration actions such as NBS.

An adaptation of the SEEA EA accounting scheme for urban ecosystem accounting (thematic approach), that takes into account the above reasoning, is summarised in Figure 18.

Figure 18. Scheme of SEEA EA adapted to thematic urban ecosystem accounting following the JRC INCA approach and an urban ecology perspective. Dashed boxes and lines refer to relationships and tables not explicitly included in SEEA EA.



Source: JRC own elaboration

5.2 A pilot urban ecosystem services account

Two ecosystem services, air purification and local climate regulation, are included in this pilot urban ecosystem services accounts. As anticipated in Section 4.3, both are influenced by the ecosystem condition variables included in the pilot urban ecosystem account of this report. They are also influenced by the extent of specific urban ecosystem types (and sub-types) presented in the pilot of urban extent account (Section 3.3). The description of accounting results draw lines to the results in Chapter 3 and 4, to illustrate with practical examples the relationships between extent, condition and services accounts.

For both ecosystem services, accounts are not complete, since this pilot is focused on estimating ecosystem services supply and use and drawing links to extent and condition accounts. In both ecosystem services it is assumed that demand overpasses potential.

5.2.1 Urban ecosystem service account for air purification

Many scientific studies and urban policy documents have identified lack of air quality, especially particulate matter (PM), as a major societal challenge in urban ecosystems (Babi Almenar et al., 2021). In fact, the EU Green Deal, include among its ambitions a substantial improvement in air, water and soil quality in EU. This ambition is translated into the Zero Pollution action plan (European Commission, 2021a[17]), which integrates as a target for 2030 the reduction of premature deaths due to air pollution by more than a 55%. Particulate matter ($PM_{2.5}$ and PM_{10}) has also been linked to many other health effects such as cardiovascular, respiratory diseases and lung cancer in a wide range of epidemiological studies. The last guidance note of the World Health Organisation (WHO) summarises the most updated scientific evidence (WHO, 2021).

PM removal from the atmosphere occurs through two environmental processes: wet deposition (particles in raindrops) and dry deposition (adsorption of particles by artificial and living surfaces).

According to SEEA EA (Section 6.2.5), wet deposition might not be related to an ecosystem service flow, but to an abiotic flow, since it depends exclusively on geophysical attributes, i.e., climate and the atmosphere (United Nations 2021). PM removal by wet deposition occurs during rain events and specific biotic and abiotic components of the ecosystem, besides the atmosphere, do not have a direct influence.

Instead, dry deposition on living surfaces of ecosystems relates to an ecosystem service flow. In terms of abiotic and biotic attributes, it mainly depends on PM atmospheric levels, atmospheric conditions (e.g., wind, rain, atmospheric stability), and properties of the vegetation surface where PM is deposited (Babi Almenar et al., 2021). In terms of vegetation surface properties, the amount of leaf surface (i.e., leaf area) is considered the most relevant biotic attribute (Marando et al., 2016).

Hence, in terms of air purification of PM, ecosystem capacity (ecosystem service potential flow) only reflects the dry deposition capacity of ecosystems, which in terms biotic and abiotic components of the ecosystem mainly depends on the amount of leaf area and the tolerance of vegetation to PM atmospheric levels.

5.2.1.1 Methods

As a proxy for air purification, only dry deposition of PM_{10} is estimated. The methodological procedure is an adaptation of the methods reported in Hirabayashi et al. (2022) and Manes et al. (2016) for ecosystem accounting purposes. As inputs, only data on leaf area, specifically leaf area index[18] (LAI) and atmospheric levels of PM_{10} are necessary[19]. For accounting purposes, the method assumes that dry deposition of PM_{10} is not very sensitive to changes in atmospheric conditions (e.g., wind speed), disregarding their influence. Since atmospheric levels of PM_{10} have fast variations over time, input data should be used at the highest temporal resolution possible. This pilot uses as input data the PM_{10} dataset of the Air Quality remote sensing product of the Copernicus Atmosphere Monitoring Service[2021] at a temporal resolution of 1 hour and a spatial resolution

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827

[18] Leaf area index corresponds to the amount of leaf area per area of ground surface.

[19] This report calculates supply and use ecosystem accounting tables, for ecosystem capacity it would be also necessary to know the tolerance of vegetation to PM atmospheric levels.

[20] https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-reanalyses?tab=overview

of 0.1° (3 hours and 0.75° for Azores and Canary Islands). In the case of LAI, data should be able to capture at least seasonal changes, therefore monthly time steps are suggested. This pilot combines the LAI300 product of the Copernicus Global Land Service (temporal resolution of 10 days and spatial resolution of 300 meters) and MODIS Terra+Aqua LAI product (temporal resolution of 4 days and spatial resolution of 500 meters). The methodological procedure is summarised in the following four steps:

- Preparation of the input data. In the case of PM_{10} the datasets are already refined. Instead for LAI, values are aggregated at monthly time step and data gaps are corrected. Data gaps occur mainly in Northern countries in winter months and in the centre of highly urbanised areas (see Annex IV – Figure IV.1).
- Calculation of Velocity Deposition: $Vd = \frac{0.0064*LAI}{6}\ (m/s)$. For PM_{10}, 0.0064 m/s is assumed as suitable average value of PM_{10} velocity deposition for a reference LAI value of 6 (Manes et al., 2016).
- Calculation of PM_{10} flux: $F = Vd * [PM_{10}] * time\ \text{step}\ (in\ seconds)\ (\frac{Mass\ unit}{m^2\ time\ unit})$. This pilot uses hour time steps (i.e., 3600 seconds).
- Calculation of PM_{10} deposited: $PM_{10}\ Deposition = F * Ecosystem\ \text{Asset}\ Cell\ \ (Mass\ Unit)$.

Once annual PM10 deposition is calculated per cell and time step, its accumulated annual value is estimated. Then values are aggregated per ecosystem type and urban LAU of each MS.

5.2.1.2 Results and discussion

Accounting tables for air purification supply and use in urban ecosystems, aggregated at country level, are visualised in Table 11 and 12 respectively. In Table 11, average deposition of PM_{10} per land unit (Ton/km^2) is included to facilitate comparisons In terms of use, it is considered that households is the only sector beneficiated (Table 12). Among MS, Iceland (IS) has the lowest deposition per land unit (0.13 Tn/km^2), which is a consequence of already low atmospheric levels of PM_{10} and a low amount of leaf area. It is also quite low compared to the average value in EU-27 and EU-27 and EFTA (0.70 and 0.66 Tn/km^2). Ecosystem condition accounting results for tree cover and PM_{10} atmospheric levels (Chapter 4 - Table 8 and Table 9) were also quite low, anticipating the results of IS for air purification. Norway (NO), Finland (FI) and Estonia (EE) are the MS with the lowest PM_{10} deposition per land unit, after IS. In this case, these results do not reflect a low amount of leaf area or tree cover. They reflect low atmospheric levels of PM_{10}. On the other side of the ranking, Slovenia (SI), Belgium (BE) and Netherlands (NL) are the countries with the highest deposition of PM_{10} per land unit. In the case of BE an NL, it is due to their high atmospheric levels of PM_{10} (as seen in Table 9). Instead for SI, it is a combination of high atmospheric levels of PM_{10} and high values of leaf area. As illustrated by the above examples, high (or low) values of air purification might not always reflect an optimal (or poor) ecosystem condition and therefore diminished capacity. Therefore, it is important that air purification supply and use tables are interpreted together with extent tables (to normalise by area, when comparisons among countries are done) and condition tables for a good understanding of the reasons underpinning results.

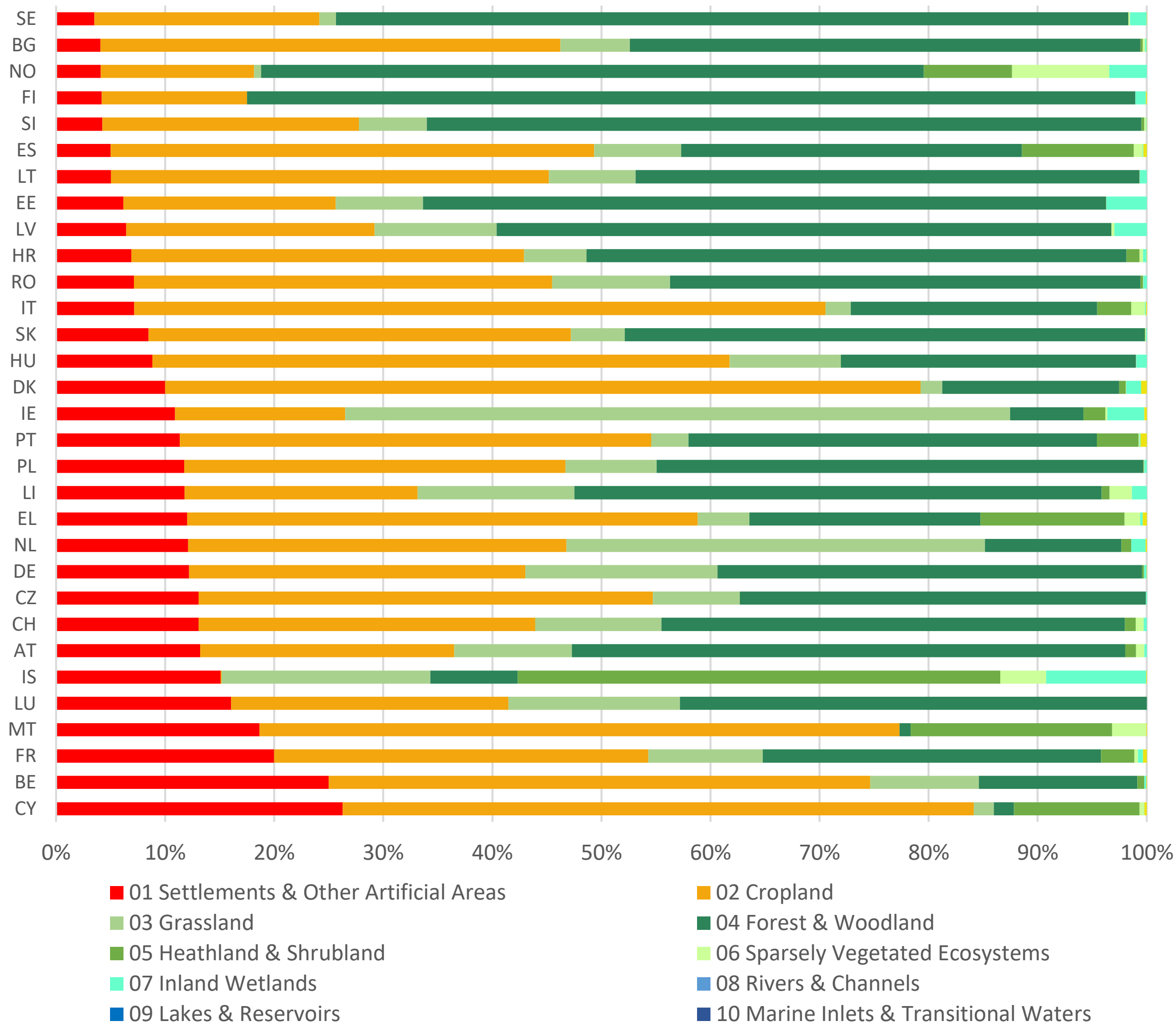
In terms of air purification per ecosystem type, Figure 19 summarises how much each ecosystem contributes in each MS. By comparing those results to the share of ecosystem types per MS (Chapter 3 – Figure 5), it can be seen that urban Settlements and other artificial areas contribute proportionally less than other ecosystems. In other words, this ecosystem type has a lower PM_{10} deposition per land unit than other ecosystem types. Figure 20 provides further insights about PM_{10} deposition per land unit, considering also variations per type of urban LAU. It confirms that Settlements and other artificial areas is the lowest performer for all type of urban LAU and MS due to its low amount of leaf area with respect to other ecosystem types. Cropland and Grassland have a similar level of performance, and depending on the MS and type of urban LAU one or the other is performing better. In most MS, Forest and Woodland are the best performers.

Comparing PM_{10} deposition over the year (Figure 21), and PM_{10} pollutant levels over the year (Chapter 4 – Figure 16), it can be seen that peak periods do not match in many MS. As it can be expected, for most countries the highest values of PM_{10} deposition occur from April~May to September~October (Figure 21), i.e., during the phenologically active periods, despite not being the periods with the highest atmospheric levels of

[21] https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=overview

PM_{10}. This seasonal mismatch make clear that in urban ecosystems of some MS air purification might not be available (or not perform at its best) when it is more needed and therefore, it should not be among the suitable strategies to consider for mitigating air pollution issues.

Figure 19. Percentage of PM_{10} deposited per ecosystem type in the urban local administrative unit of each MS (MS) in 2018. MS are sorted from minimum to maximum contribution of settlements and other artificial areas to the overall PM_{10} deposition in each of them



A map of air purification at LAU level show that Southern and Northern Europe have the lowest values of PM_{10} deposition per unit of land (Figure 22a). However, when the values are also adjusted to the atmospheric levels of PM10 (Figure 22b), it can be seen that only in the case of Southern Europe (Spain, Greece, Cyprus, Malta, South of Italy) performance remains low. These spatialized results reinforce that air purification values should be considered together with condition (e.g., atmospheric levels of PM10) to have a better understanding of the ecosystem potential for this service.

Table 11. Supply table of air purification in biophysical units (tonnes of PM_{10} deposited on vegetation) in urban local administrative units of each MS (MS) for the year 2018. Values are rounded.

	Economic Unit *					Ecosystem Type **												Deposition of PM10 per land unit (Tn/km2)
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	
	Int. Consum.	Government	Households	Gross C. F.	Exports	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine	
AT						1188	2095	969	4564	89	69	20	0	0	0	0	0	0.85
BE						3958	7861	1575	2302	102	0	27	0	0	0	7	0	0.99
BG						1392	14408	2172	15996	75	73	47	0	0	0	4	0	0.77
CH						1131	2672	1004	3678	86	64	23	0	0	0	0	0	0.71
CY						83	183	6	6	36	1	0	0	0	0	1	0	0.33
CZ						1459	4652	893	4157	0	0	9	0	0	0	0	0	0.95
DE						13045	32952	18833	41620	184	14	228	0	0	0	27	0	0.85
DK						831	5758	166	1350	51	0	116	0	0	0	42	0	0.61
EE						70	222	91	715	0	0	42	0	0	0	0	0	0.32
EL						611	2382	242	1077	673	73	12	0	0	0	18	0	0.64
ES						2504	22266	3996	15695	5137	421	29	0	0	0	151	0	0.4
FI						458	1463	2	8937	0	0	108	0	0	0	7	0	0.25
FR						8035	13798	4218	12462	1240	128	182	0	0	0	140	0	0.73
HR						573	2983	475	4104	99	27	26	0	0	0	2	0	0.89
HU						1521	9123	1759	4664	0	3	164	0	0	0	0	0	0.72
IE						379	542	2119	234	70	5	118	0	0	0	8	0	0.72
IS						23	0	29	12	67	6	14	0	0	0	0	0	0.13
IT						6445	57145	2078	20372	2800	1137	89	0	0	0	66	0	0.8
LI						11	20	14	46	1	2	1	0	0	0	0	0	0.61
LT						249	1983	392	2283	1	0	32	0	0	0	0	0	0.47
LU						90	143	88	240	0	0	0	0	0	0	0	0	0.97
LV						153	541	267	1340	0	6	71	0	0	0	0	0	0.37
MT						25	79	0	1	25	4	0	0	0	0	0	0	0.5
NL						3090	8851	9789	3195	230	0	338	0	0	0	25	0	1.03
NO						445	1525	72	6599	878	968	374	0	0	0	0	0	0.21
PL						6327	18801	4504	24020	25	13	127	0	0	0	0	0	0.96
PT						1081	4115	326	3566	366	7	8	0	0	0	55	0	0.66
RO						1658	8896	2504	10006	61	5	70	0	0	0	0	0	0.73
SE						1116	6582	484	23170	3	41	490	0	0	0	4	0	0.34
SI						226	1253	332	3491	15	7	3	0	0	0	1	0	1.08
SK						627	2869	366	3529	6	4	5	0	0	0	0	0	0.98
EU						57194	231946	58646	213096	11288	2038	2361	0	0	0	558	0	0.70
EU & EFTA						58804	236163	59765	223431	12320	3078	2773	0	0	0	558	0	0.66

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Values corrected to avoid accounting incoherencies result of limitations in the spatial resolution of the input data used for the delimitation of ecosystem types.

Source: JRC analysis.

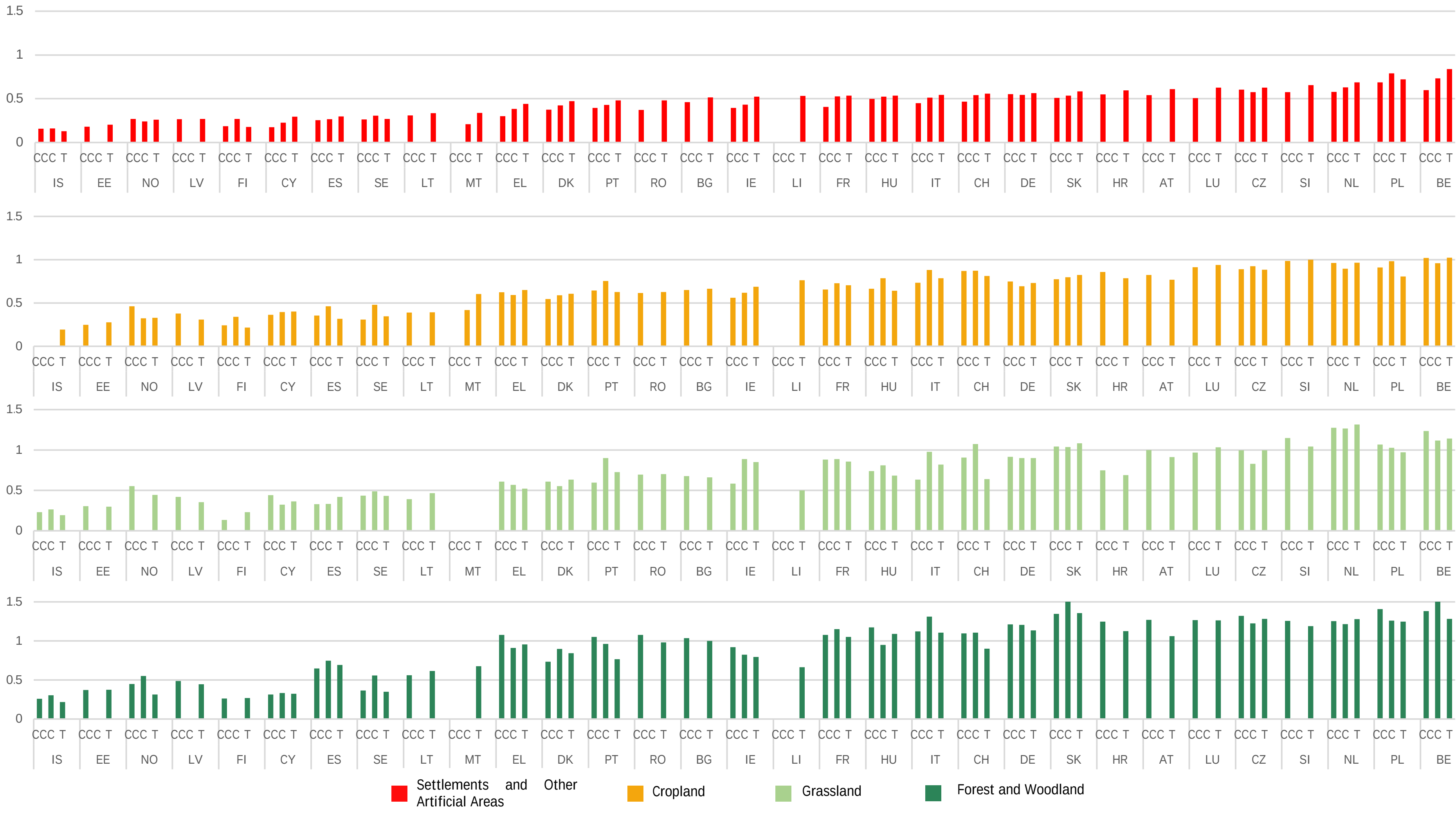
Table 12. Use table of air purification in biophysical units (tonnes of PM_{10} deposited on vegetation) in urban local administrative units of each MS (MS) for the year 2018. Values are rounded.

	Economic Unit *					Ecosystem Type **											
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12
	Int. Consum.	Government	Households	Gross C. F.	Exports	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT			8995														
BE			15832														
BG			34166														
CH			8658														
CY			316														
CZ			11170														
DE			106904														
DK			8315														
EE			1142														
EL			5088														
ES			50200														
FI			10976														
FR			40204														
HR			8287														
HU			17235														
IE			3475														
IS			151														
IT			90131														
LI			96														
LT			4940														
LU			560														
LV			2378														
MT			135														
NL			25519														
NO			10861														
PL			53817														
PT			9525														
RO			23199														
SE			31888														
SI			5327														
SK			7405														
EU			577129														
EU & EFTA			596895														

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

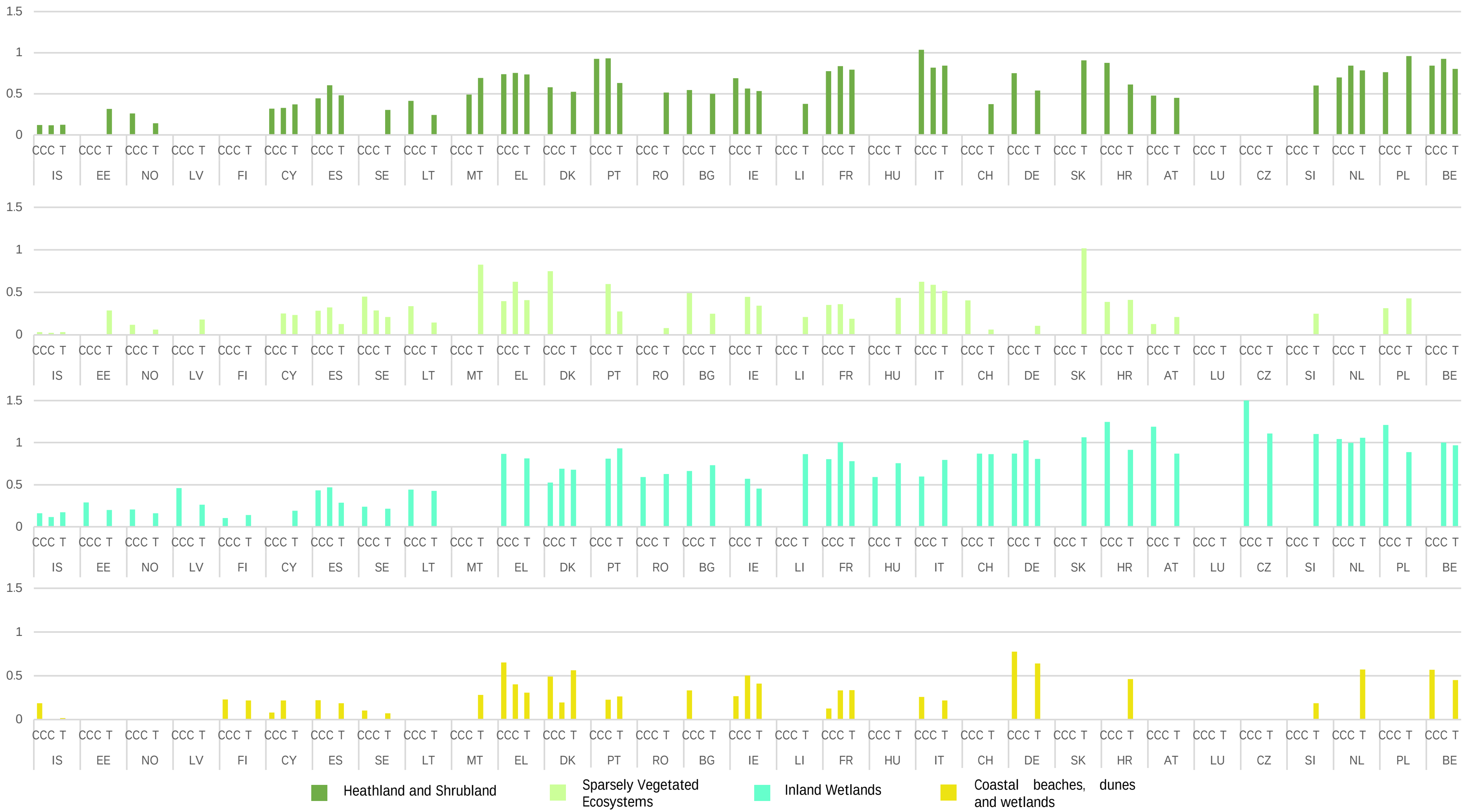
Source: JRC analysis.

Figure 20a. Normalised Annual PM_{10} (g/m^2 of land surface) deposited per ecosystem type in MS aggregated by type of urban local administrative units (LAUs) in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values of settlements and other artificial areas.



Source: JRC analysis

Figure 20b. Normalised Annual PM_{10} (g/m^2 of land surface) deposited per ecosystem type in MS aggregated by type of urban local administrative units (LAUs) in 2018. LAUs are split in three groups (CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs). MS are sorted from minimum to maximum normalised values of settlements and other artificial areas.

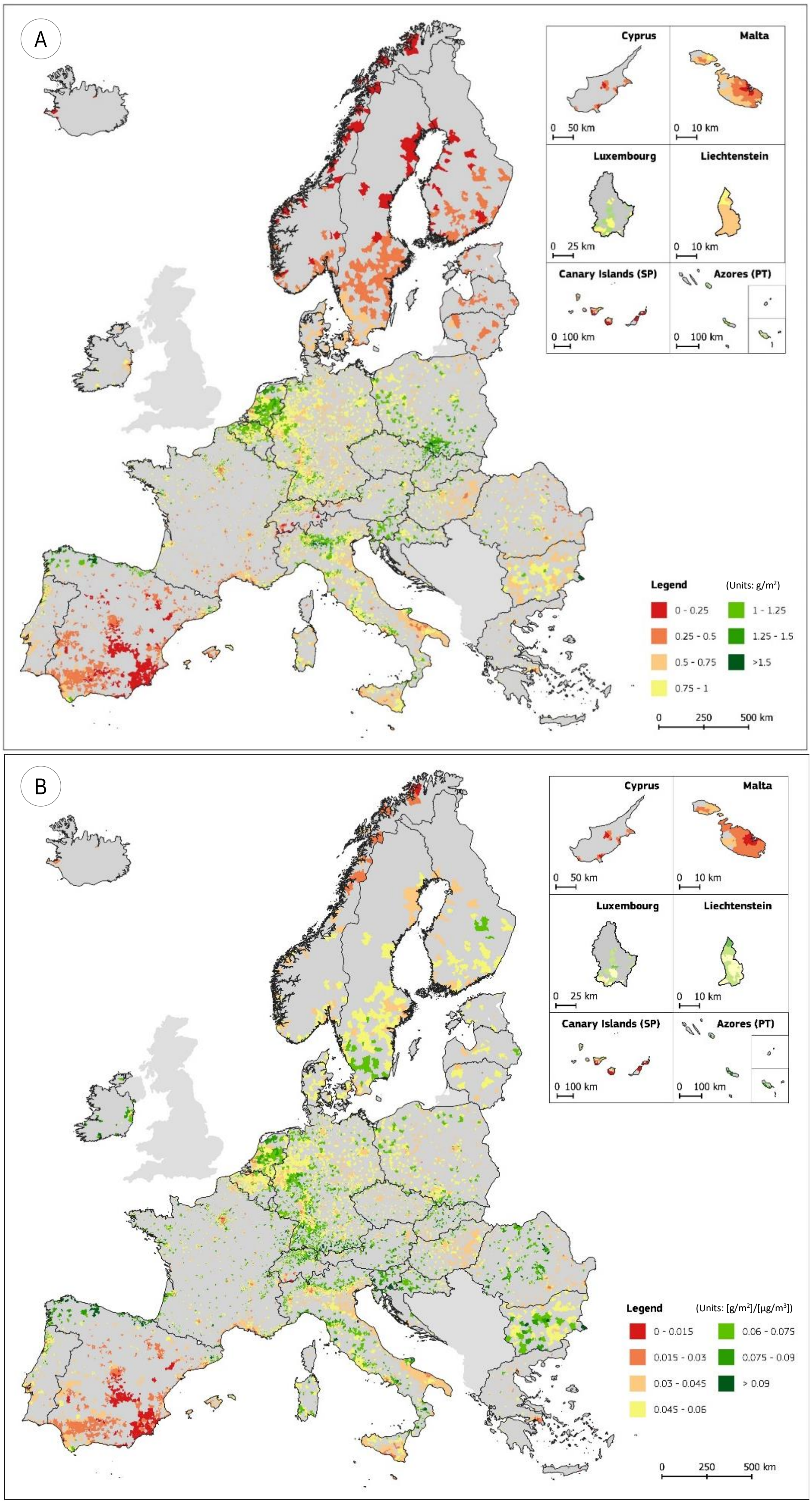


Source: JRC Analysis

Figure 21. Monthly contribution to the annual PM_{10} deposition per ecosystem type in each MS in 2018. The values are represented as percentages. In a hypothetical case of equivalent monthly contributions, each month would be around an eight percent of the annual PM_{10} deposition. Values in light red represent contributions lower than a hypothetical equivalent monthly contribution, while values in light green, green and dark green represent contributions higher than an equivalent monthly contribution. Values in yellow represent contributions inside a range closer to what would be expected under an equivalent monthly contribution. SE = Settlement and other artificial areas; CR = Cropland; GS = Grassland; FO = Forest and Woodland; HE = Heathland and Shrubland; SV = Sparsely Vegetated Ecosystems; IW = Inland Wetlands CO = Coastal Beaches, Dunes and Wetlands

Source: JRC analysis

Figure 22. Deposition of PM_{10} in urban local administrative units of EU-27 and EFTA MS in 2018. A) Deposition per land unit (g/m^2). B) Deposition per land unit (g/m^2) normalised by monthly atmospheric levels of PM_{10} ($\mu g/m^3$).



Source: JRC analysis

5.2.2 Urban ecosystem service accounts for local climate regulation

High temperatures are responsible for the greatest number of fatalities due to natural hazards in Europe (EEA, 2022), and their impacts are expected to increase in the future due to anthropogenic climate change. Urban areas are at elevated risk due to high population density and the urban heat island effect (UHI), a phenomenon where higher air temperature in urban areas compared to peri-urban and rural areas are observed (Ward et al., 2016). This is due to higher trapping of heat from concrete and other refractory materials that compose the urban matrix, as well as direct emission of heat due to anthropogenic activities. On the other hand, vegetation leads to a reduction in ambient temperature due to two main processes: shading and evapotranspiration. The ecosystem service provided by urban vegetation in reducing urban air temperature is referred to as “local climate regulation”.

In this urban ecosystem service account, local climate regulation has been estimated at LAU level using a process-based, spatially-explicit statistical model based on the work of Marando et al. (2023) and Heris et al. (2021). This model has been already applied and described in BiodiverCities Progress Report Section 4.1 (Zulian et al., 2021) and Marando et al. (2023), which can be consulted for detail explanations about the methodological procedure. A brief methodological explanation is included in the following lines.

5.2.2.1 Methods

In short, the approach consists in calculating the temperature difference between a real case scenario and a scenario without vegetation. In order to do so, land surface temperature (LST) from satellite data and air temperature data (from meteorological monitoring stations) are coupled to obtain a spatially explicit air temperature dataset. Given that this ecosystem service is usually provided during the summer months, the period from July to September is considered. The model runs for each LAU, individually, providing outputs at a high spatial resolution (grid cells of 100x100 m). LST is obtained through a single-channel algorithm from Landsat 8 OLI-TIRS thermal band data (Parastatidis et al., 2017), which is available at temporal resolution of 15 days. The main limiting factor in using satellite LST is data gaps due to the presence of clouds. The data gap problem is particularly relevant in Northern MS, where a significant amount of clouds is present even in the summer months. Therefore, all LST images within the aforementioned accounting period are considered, and a median is calculated. By taking the median of the different images the influence of clouds and shadows is removed and outliers in the form of very high and very low reflectance values are removed. In other words only valid pixels are retained.

In this model, the role of vegetation in reducing temperature has been estimated by including tree canopy cover (from Copernicus Tree Cover Density data) and evapotranspiration (from PML_V2 data, Zhang et al., 2019) as predictors. In fact, this model focuses on the role of trees in reducing temperature, given their higher efficiency in cooling ambient temperature compared to other vegetation forms, such as grass (Armson et al., 2012). However, the model estimates the temperature difference as a result of spatialy-explicit LST data, therefore taking also into account the effect of other land cover types in reducing temperature, in an indirect way. This means that in this modelling exercise all terrestrial ecosystem types are included for the estimation of the service. Rivers, Lakes, Marine Inlets and Marine ecosystems are not included because the role of blue infrastructure is not specifically analysed in this urban ecosystem accounting exercise. Since it is complex to disentangle the contribution of assets of different ecosystem types in reducing air temperature within the urban ecosystem, which as indicated in Chapter 3 are characterized by the presence of multiple ecosystem types, a more conservative approach is adopted. It is assumed that all ecosystem types contribute to reducing air temperature in an urban area, and not exclusively those located within the ecosystem type urban Settlements and other artificial surfaces.

5.2.2.2 Results and discussion

Accounting tables for local climate regulation supply and use in urban ecosystems, aggregated at country level, are visualised in Table 13 and 14 respectively. As showcased in Table 14 the ecosystem service use values, are entirely allocated to households. Only for Malta (MT) it was not possible to calculate the service due to lack of data. As showcased, in the pilot ecosystem condition accounts (Chapter 4 - Table 8), the share of tree cover in Malta is very low in all ecosystem types inside urban ecosystems. This generates input data issues, when calculating local climate regulation, since the method uses tree cover as a predictor. Furthermore, evapotranspiration data is not available either. Mostly, Settlements and other artificial areas present the lower supply values, whereas the highest can be observed for Forest and Woodlands and Inland Wetlands. The results for Settlements and Forests are consistent with the ones for air purification and like in their case are strongly related to ecosystem condition outputs (tree cover).

In Figure 23, the annual average local climate regulation (°C) per ecosystem type in MS aggregated by type of urban local administrative units (LAUs) is provided. MS are sorted from minimum to maximum values of urban Settlements and other artificial areas. Settlements and other artificial areas display the lowest contribution, compared to the other ecosystem types. Among MS, Settlements in Bulgaria (BG) and Iceland (IS) display the highest values for towns and suburbs. There is no evidence of a clear pattern among local climate regulation values observed in cities above and below 50,000 inhabitants or towns and suburbs. This indicates a heterogeneous structure of urban green among the different MS. Urban Croplands and Grasslands display slightly higher and similar values of cooling, ranging from 0.3 °C and up to 2 °C for urban Grasslands in Lithuanian (LT) towns. Forests and woodlands present generally higher values, around 2 °C, but with relatively low values in some cases such as in Cyprus (CY)' towns and in cities above 50,000 inhabitants in Portugal (PT). Largely, relatively high values of cooling for forests and woodlands in cities above 50,000 inhabitants are observed (up to 2.7 °C in Luxembourg (LU)). It highlights the critical role of this ecosystem type in reducing temperature even in the more urbanized and populated LAU. Urban Heatlands and shrublands, despite less represented in the EU-27 and EFTA LAU, present the highest peaks of cooling among the ecosystem types, with cities above 50,000 inhabitants displaying 5.5 °C of cooling, 2.8 °C in Polish cities (PL) above 50,000 inhabitants, and 3 °C for towns in Slovakia (SK). Sparsely vegetated areas present relatively high values of cooling and heterogeneity, whereas inland wetlands values are relatively constant among LAU types. Coastal beaches, dunes and wetlands are also scarcely represented among LAUs but their role in reducing temperature should not be underestimated.

In Figure 24a, spatialized local climate regulation values, aggregated at LAU level are provided. The majority of LAU display an average cooling between 0 and 1 °C. Some LAU present an average value of cooling equal to zero. It is particularly evident in southern LAU (e.g. Cyprus, Italy (IT)), where adverse environmental factors such as drought might impair the efficiency of vegetation in decreasing air temperature (e.g. through a lower evapotranspiration). However, a significant fraction of LAU present a relatively high value of cooling, particularly in Germany (DE), Poland (PL), Italy and Bulgaria.

In Figure 24b, the average local climate regulation in urban LAUs is presented as a spatially explicit map at a spatial resolution of 100 m x 100 m. Here, disaggregated cooling values can be observed in order to better identify areas providing the different degree of cooling. Generally, it can be noticed how the most urbanized areas characterized by a high degree of urban Settlements and other artificial areas present the lower values of cooling. Instead, green spaces and vegetated areas present the highest values of cooling, as it is shown for the case of Berlin illustrated in Figure 25. In the case of Berlin, urban green spaces provide generally lower cooling levels respect to forest and other semi-natural areas.

In terms of policy value, this pilot illustrates that the development of urban ecosystem accounts (thematic approach), informs on the biophysical reality of local climate regulation in urban ecosystem at local (LAU) level. This local climate regulation model was already applied in 93 European cities in the study developed by Iungman et al. (2023), already introduced in the tree cover condition accounts (Section 4.3.3). It estimated that increasing tree cover up to 30% would cut mortality attributed to urban heat island by one third. Those results clearly illustrate that ecosystem services, extent and condition in urban ecosystems are tightly interrelated. Their mix of natural, semi-natural and artificial ecosystem assets all likely contribute to the overall local climate regulation within the areas where people live, particularly if they are characterized by high tree canopy cover, such as forest and woodland ecosystems.

Table 13. Supply table of local climate regulation in biophysical units (average cooling in °C) in urban local administrative units of each MS (MS) for the year 2018. Values are rounded.

	Economic Unit *					Ecosystem Type **											
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12
	Int. Consum.	Government	Households	Gross C. F.	Exports	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT						0.08	0.62	0.77	1.58	0.95	0.69	1.37	0	0	0	0	0
BE						0.33	0.89	0.85	2.19	0.65	0	1.96	0	0	0	0.18	0
BG						0.68	0.89	1.11	2.19	2.18	1.20	2.32	0	0	0	0.27	0
CH						0.12	0.64	0.76	1.93	1.63	0.35	1.08	0	0	0	0	0
CY						0.15	0	0	0.09	0.02	0.12	0.49	0	0	0	0.49	0
CZ						0.38	0.52	0.72	2.28	0	0	1.55	0	0	0	0	0
DE						0.30	0.58	0.81	2.20	0.46	0.33	1.42	0	0	0	0.05	0
DK						0.11	0.54	0.80	1.65	0.79	1.39	1.27	0	0	0	0.80	0
EE						0.34	0.42	0.25	1.09	1.18	1.70	0.04	0	0	0	1.01	0
EL						0.18	0.65	0.42	1.77	1.00	0.43	1.66	0	0	0	0.27	0
ES						0.48	0.68	0.61	1.68	1.13	0.32	1.87	0	0	0	0.85	0
FI						0.19	0.66	0.88	0.81	0	0.03	0.39	0	0	0	1.04	0
FR						0.25	0.83	1.06	2.07	1.07	0.54	1.47	0	0	0	0.54	0
HR						0.19	0.84	0.76	1.67	0.72	0.62	1.61	0	0	0	0.10	0
HU						0.49	1.01	0.75	1.97	0	0	1.76	0	0	0	0	0
IE						0.07	0.65	0.50	1.29	1.16	0.38	0.37	0	0	0	0.35	0
IS						0.49	0.60	0.61	0.84	0.50	0.14	0.68	0	0	0	0.14	0
IT						0.21	0.76	1.02	2.37	1.42	1.14	1.65	0	0	0	0.96	0
LI						0.47	1.30	1.90	2.38	1.67	2.28	2.11	0	0	0	0	0
LT						0.27	0.46	0.44	1.36	0	0	0.83	0	0	0	0.08	0
LU						0.22	0.84	0.73	2.31	0	0	0	0	0	0	0	0
LV						0.47	0.59	0.63	1.34	0	0.21	0.53	0	0	0	0.28	0
MT***						-	-	-	-	-	-	-	-	-	-	-	-
NL						0.08	0.81	0.77	1.75	0.28	0	1.87	0	0	0	0.17	0
NO						0.18	0.83	0.42	1.17	0.31	0.01	0.65	0	0	0	0.35	0
PL						0.25	0.61	1.00	1.71	1.69	0.13	1.36	0	0	0	0	0
PT						0.28	0.88	0.40	1.22	0.74	0.70	1.37	0	0	0	1.50	0
RO						0.27	0.80	0.65	1.55	1.29	0.91	1.42	0	0	0	0.02	0
SE						0.03	0.46	0.58	0.88	0.76	0.46	0.30	0	0	0	0.28	0
SI						0	0.86	0.97	1.59	1.64	1.18	0.89	0	0	0	0.26	0
SK						0.23	0.74	0.97	1.99	2.99	1.60	1.32	0	0	0	0	0
EU						0.24	0.64	0.67	1.58	0.80	0.46	1.15	0	0	0	0.35	0
EU & EFTA						0.25	0.67	0.70	1.58	0.83	0.49	1.15	0	0	0	0.32	0

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Values corrected to avoid accounting incoherencies result of limitations in the spatial resolution of the input data used for the delimitation of ecosystem types.

*** Due to lack of input data, it was not possible to calculate values for Malta.

Source: JRC analysis.

Table 14. Use table of local climate regulation in biophysical units (average cooling in °C) in urban local administrative units of each MS (MS) for the year 2018. Values are rounded.

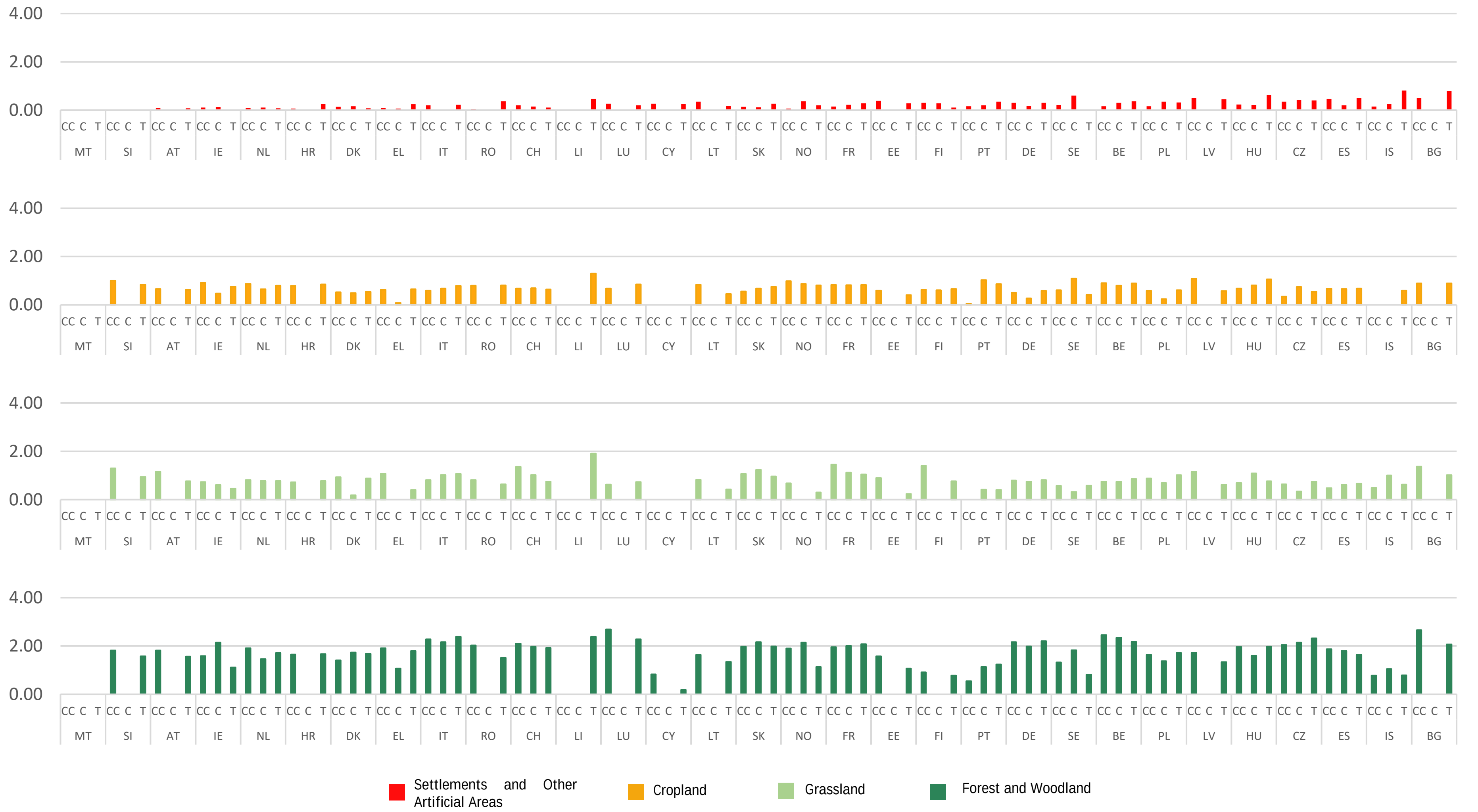
	Economic Unit *					Ecosystem Type **											
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12
	Int. Consum.	Government	Households	Gross C. F.	Exports	Settlements	Cropland	Grassland	Forest & Woodland	Heathland	Sp. Veget.	Inl. Wetland	Rivers & Ch.	Lake & Res.	Mar. Inllets	Coastal B.	Marine
AT			6.06														
BE			7.05														
BG			10.84														
CH			6.51														
CY			1.36														
CZ			5.45														
DE			6.15														
DK			7.35														
EE			6.03														
EL			6.38														
ES			7.62														
FI			4.00														
FR			7.83														
HR			6.51														
HU			5.98														
IE			4.77														
IS			4.00														
IT			9.53														
LI			12.11														
LT			3.44														
LU			4.10														
LV			4.05														
MT**			0.00														
NL			5.73														
NO			3.92														
PL			6.75														
PT			7.09														
RO			6.91														
SE			3.75														
SI			7.39														
SK			9.84														
EU			6.32														
EU & EFTA			6.63														

* Complete names of ecosystem types 1 = Settlement and Other Artificial Areas; 2 = Cropland; 3 = Grassland; 4 = Forest and Woodland; 5 = Heathland and Shrubland; 6. = Sparsely Vegetated Ecosystems; 7. = Inland Wetlands; 8 = Rivers and Channels; 9 = Lakes and Reservoirs; 10 = Marine Inlets and Transitional Waters; 11 = Coastal Beaches, Dunes and Wetlands; 12 = Marine.

** Due to lack of input data, it was not possible to calculate values for Malta.

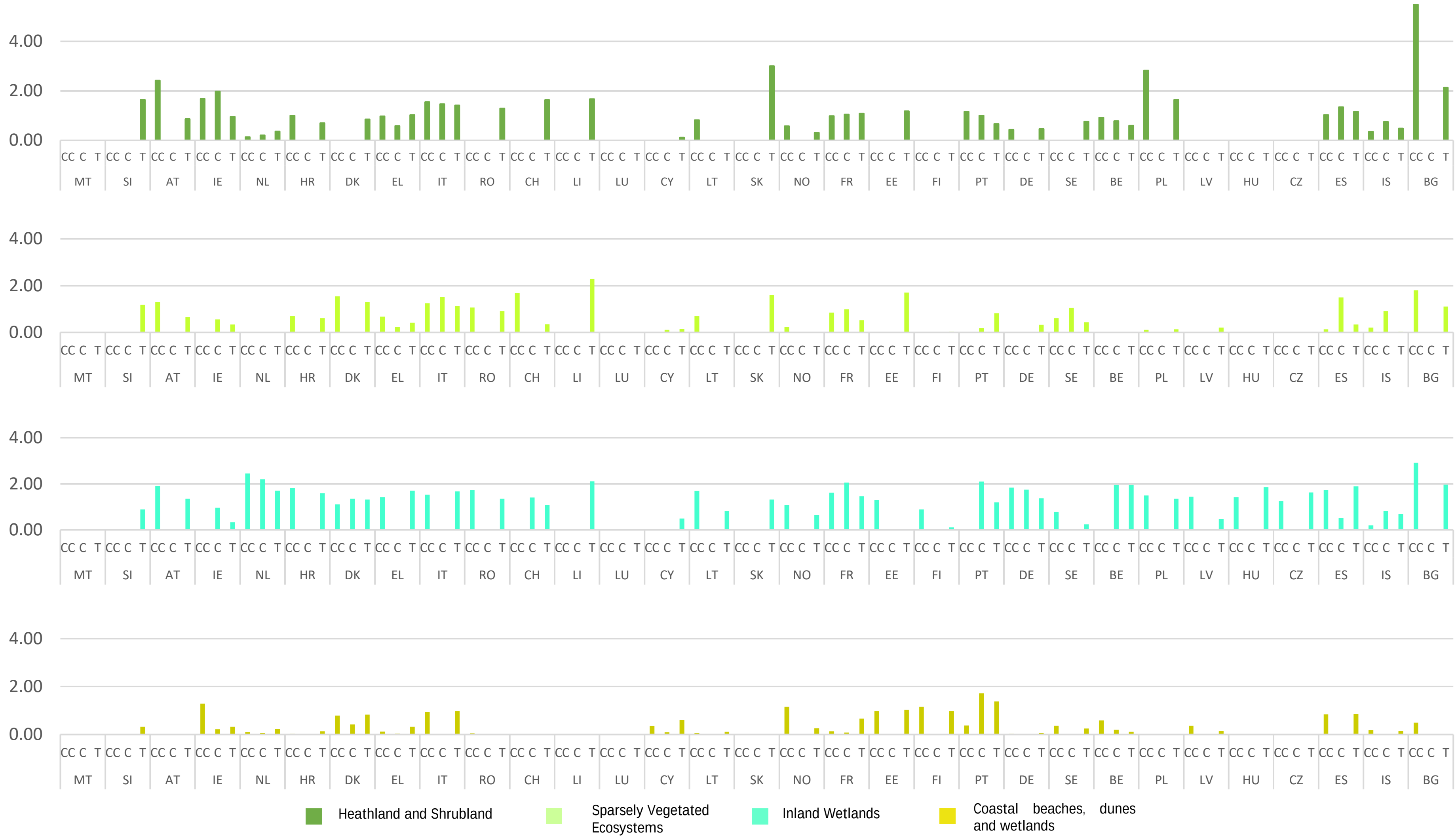
Source: JRC analysis.

Figure 23a. Annual average local climate regulation (°C) per ecosystem type in MS aggregated by type of urban local administrative units (LAU) in 2018. LAU are split in: CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs. MS are sorted from minimum to maximum values of settlements and other artificial areas.



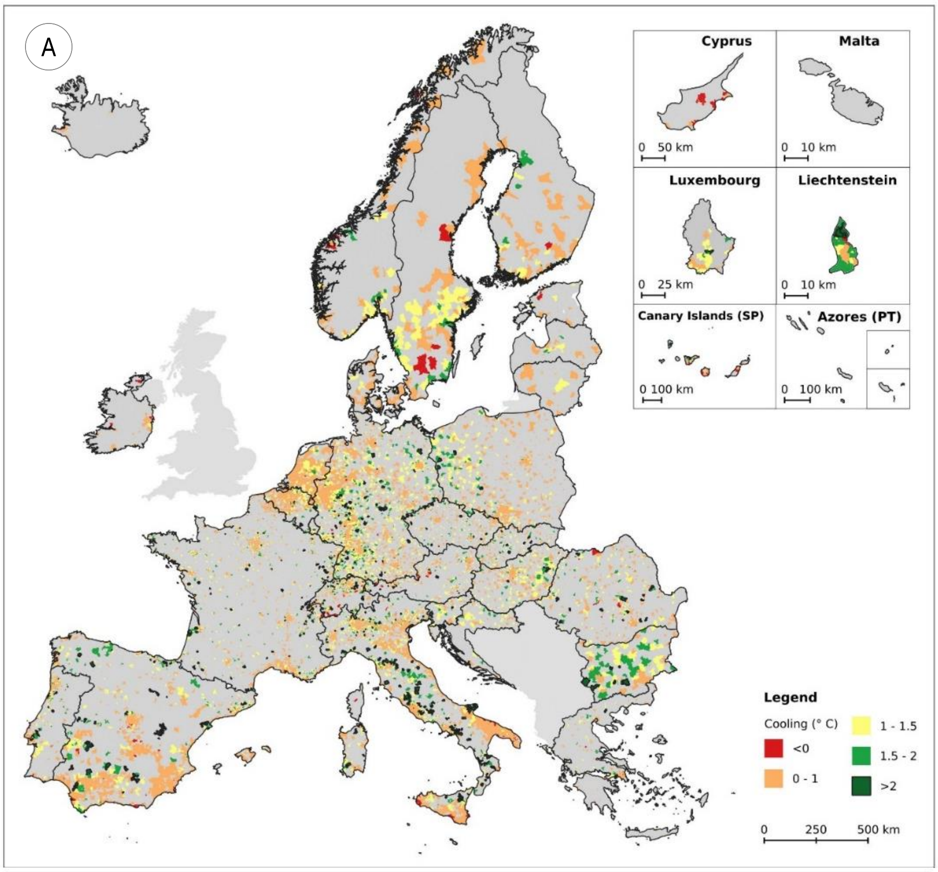
Source: JRC analysis

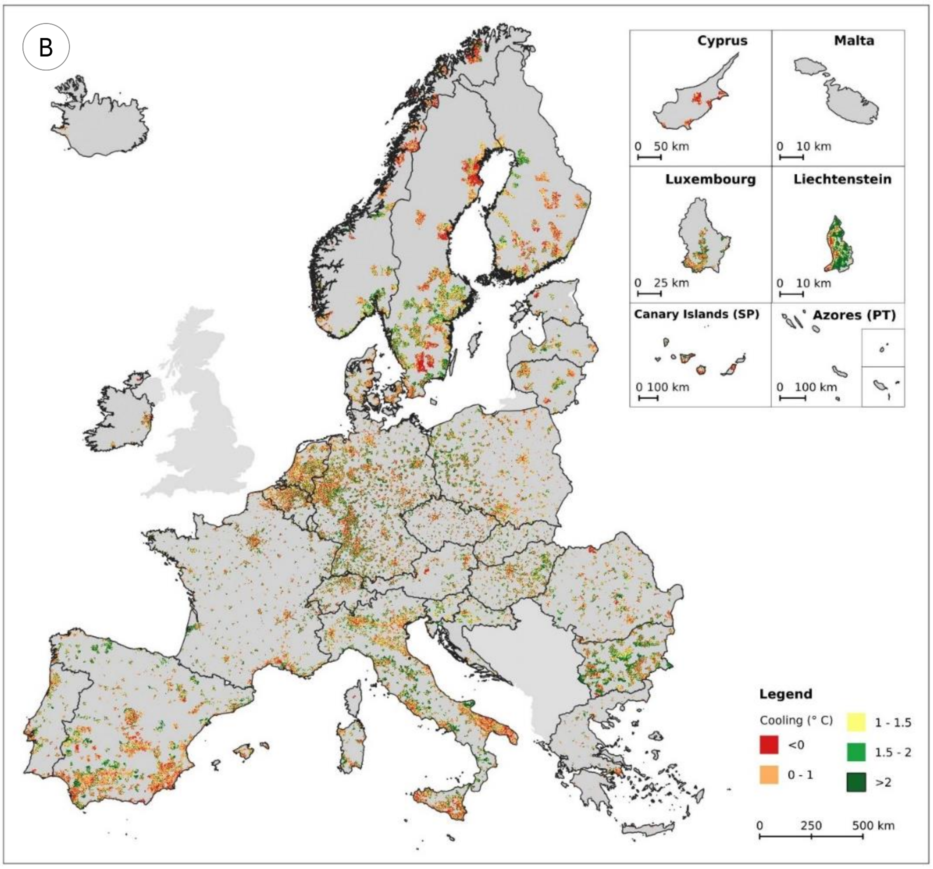
Figure 23b. Annual average local climate regulation (°C) per ecosystem type in MS aggregated by type of urban local administrative units (LAU) in 2018. LAU are split in: CC = cities above 50,000 inhabitants, C = cities below 50,000 inhabitants, T = towns and suburbs. MS are sorted from minimum to maximum values of settlements and other artificial areas.



Source: JRC analysis

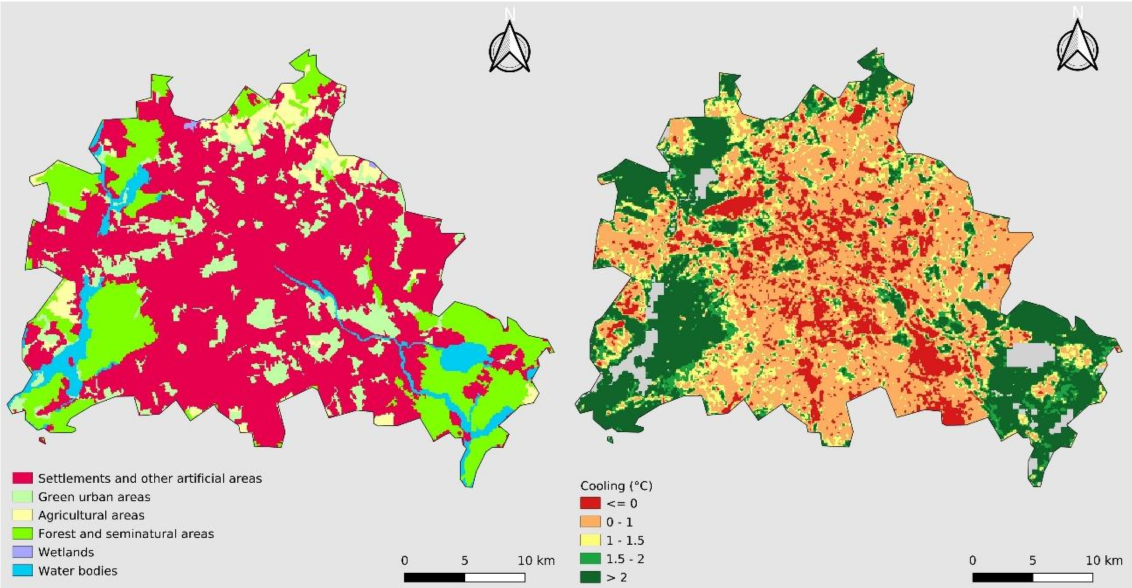
Figure 24. Average local climate regulation (°C) in urban local administrative units (LAU) of EU-27 and EFTA MS in 2018. A) Values are aggregated at LAU level; B) Values are aggregated per cell of 100x100 meters.





Source: JRC analysis

Figure 25. Map of the main land cover types and of the average local climate regulation in the LAU of Berlin in 2018. Values are provided in °C and represented in cells of 100 m x 100 m



Source: JRC analysis

5.3 Key Messages

Learnt lessons on urban ecosystem services accounts

1. Urban ecosystem capacity:

— Overcoming ecosystem capacity accounting bottlenecks, might permit to estimate sustainable ecosystem service supply as well as to identify ecosystem condition reference levels.

2. Air purification:

— Highest values of air purification might not always represent highest ecosystem capacity, might also represent high levels of air pollution.

— Highest seasonal values for air purification might not match highest seasonal values of particulate matter, i.e., there might be a mismatch between when the services is more needed and when it can be delivered.

— As expected, Forest and Woodlands are the most efficient ecosystem type in terms of particulate matter deposition per land unit.

3. Local climate regulation:

— High resolution, spatially explicit process-based models are a suitable tool to properly estimate local climate regulation provided by natural, semi-natural and artificial land covers within urban areas.

— Forest and Woodlands are highly efficient in reducing temperature compared to other ecosystem types.

— Settlements and other artificial areas contribute the least to reducing temperature in LAU.

— It is necessary to consider the contribution of all ecosystem types in reducing temperature within LAUs due to the fine-scale spatial heterogeneity which characterises urban areas.

6 Conclusions

This research have explicitly identified conceptual and operational challenges of SEEA EA in the application of urban ecosystem accounts, developed in this report. Many challenges originally identified for urban ecosystems are shared with many other ecosystem types. For most challenges, potential solutions have been also proposed based on literature and a workshop with experts. Some of those solutions have been tested and further discussed in a pilot urban ecosystem accounting for EU-27 and EFTA Member States presented in this report. As an overall result, this research provides useful insights for drafting urban ecosystem accounts according to SEEA EA statistical standard. Therefore, this pilot urban ecosystem account for EU-27 and EFTA MS can be used as an instructive example by national and local agencies that are starting to develop this kind of accounts.

For each type of ecosystem account (extent, condition and services), main challenges are discussed before the results of the pilots are presented. For each type of account, this research provided the following key insights:

<u>Extent</u>

- The policy level (e.g., national and local) and future policy uses should be clarified before selecting the reporting unit and delimiting the ecosystem accounting areas to ensure they will fit to purpose.
- In general for EU-27 and EFTA MS, LAU as minimum reporting units are recommended when urban ecosystem accounts should fulfil national and local policy uses.
- The difference between urban ecosystems and any kind of settlement and artificial surface, and the implications of those differences when developing ecosystem accounts and defining ecosystem accounting areas.
- The importance of interoperability between urban ecosystem accounts and general national ecosystem accounts in terms of ecosystem classification.

<u>Condition</u>

- The relevance of social and technological factors for estimating more comprehensible urban ecosystem condition.
- The importance of including humans and their health when evaluating and monitoring urban ecosystem condition.
- Difficulties for the identification of meaningful reference conditions, suitable approaches and methods for urban ecosystems.
- The use of prescribed levels should be applied with caution because different policy thresholds or recommended levels for the same condition variable might exist, which might lead to very different condition results
- The role of societal demand and local ecosystem capacity for the identification of reference condition in urban ecosystems.

<u>Services</u>

- The importance in accounts of assessing ecosystem service demand, overuse and unmet demand to inform more comprehensively policy making.
- The relevance of extent and condition accounting results for a full interpretation of ecosystem service results and to avoid misleading interpretations.
- Intra-annual temporal mismatch between demand and supply of ecosystem services. For some services, seasons with a high ecosystem service demand (e.g., poor air quality levels) have a low ecosystem service potential. This mismatch might have implications for the selection of suitable implementation actions to fulfil policy targets.

Despite the useful insights and the practical value of this pilot urban ecosystem accounting, there are some challenges that could not be discussed, or not with enough in detail, that should be further considered in future research.

In general terms, uncertainty of ecosystem accounting results have not been discussed, neither their potential implications for informing policies. Future researches should consider the added value of estimating quantitatively and qualitatively uncertainty to better inform policy making.

Regarding practical bottlenecks for developing ecosystem accounting systems, only two challenges were briefly considered. The end of Chapter 3 illustrated the importance of rules for data quality standards. The report itself provide a new illustrative pilot that increments the available documentation on ecosystem accounts. Future research should discuss further the relevance of upon agreed decisions on protocols and data infrastructure and if possible propose pilot protocols and data infrastructure systems.

In terms ecosystem extent, but related to condition and services, this pilot has only tested a simple clustering of urban ecosystems in cities (above and below 50.000 inhabitants) and towns and suburbs. However, future works should further investigate the development of clustering urban ecosystems in sub-functional groups, following the indicative list of clustering characteristics already compiled in the EU-wide methodology (Vallecillo et al., 2022).

Regarding ecosystem condition, specific reference levels have not been identified, although the use of prescribed levels from policy thresholds have been discussed. Future research should test the practical utility of the best-attainable approach and specific methods (e.g., statistical approaches based on ambient distributions) for estimating meaningful reference levels per condition variable and urban cluster.

The possible aggregation of condition variables into indices (per condition typology and overall) should be investigated, pointing out to the most suitable approach depending on the targeted policies or applications. For urban ecosystems, condition accounts have the potential to better inform ecosystem degradation, informing also how urban ecosystems influence the condition of ecosystems elsewhere through their demand of services. The integration of social and technological factors and learning from other lines of thoughts (e.g., (territorial) life cycle assessment or urban metabolism) could help on monitoring more comprehensively ecosystem degradation.

With respect to ecosystem services, the importance of considering ecosystem capacity (potential) together with demand has been highlighted, especially to understand sustainability issues (e.g. service overuse, ecosystem deficit or unmet demand). However, explicit accounting tables for ecosystem service demand, overuse and unmet demand have not been provided. Moreover, together with the research for ecosystem condition, it should be investigated the practical feasibility of approaching ecosystem capacity from a systemic perspective.

Finally, this research activity was focused on the biophysical ecosystem accounts. Future research should also provide insights for accounts on ecosystem service (monetary flows) and monetary ecosystem assets. Future research should also investigate the potential added value of complementary valuation of ecosystem services and assets besides monetary valuation.

References

Alberti, M., Marzluff J.M., Shulenberger, E., Bradley, G., Ryan C., and Zumbrunnen C. 2003. Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. *BioScience* 53, no. 12:1169-1179.

Alberti, M. 2010. Maintaining ecological integrity and sustaining ecosystem function in urban areas. *Current Opinion in Environmental Sustainability* 2, no. 3: 178-184.

Armson, D., Stringer, P., & Ennos, A. R. 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry & Urban Greening*, *11*(3), 245-255.

Babí Almenar, J., Elliot, T., Rugani, B., Philippe, B., Gutierrez, T. N., Sonnemann, G., & Geneletti, D. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. Land use policy, 100, 104898.

Babi Almenar, J., Petucco, C., Sonnemann, G., Geneletti, D., Elliot, T., & Rugani, B. 2023. Modelling the net environmental and economic impacts of urban nature-based solutions by combining ecosystem services, system dynamics and life cycle thinking: An application to urban forests. Ecosystem Services, 60, 101506.

Bagstad, K. J., Ancona, Z. H., Hass, J., Glynn, P. D., Wentland, S., Vardon, M., & Fay, J., 2020. Integrating physical and economic data into experimental water accounts for the United States: Lessons and opportunities. Ecosystem Services, 45, 101182.

Bagstad, K. J., Ingram, J. C., Lange, G. M., Masozera, M., Ancona, Z. H., Bana, M., ... & Uwera, C., 2020. Towards ecosystem accounts for Rwanda: Tracking 25 years of change in flows and potential supply of ecosystem services. People and Nature, 2(1), 163-188.

Bagstad, K. J., Ingram, J. C., Shapiro, C. D., La Notte, A., Maes, J., Vallecillo, S., Casey, C.F., Glynn, P.D., Heris M.P., Johnson, J.A., Lauer C., Matuszak, J., Oleson K.L.L, Posner, S.M., Rhodes, C., Voigt, B., 2021. Lessons learned from development of natural capital accounts in the United States and European Union. Ecosystem Services, 52, 101359.

Bereitschaft, B., & Debbage, K. 2014. Regional variations in urban fragmentation among US metropolitan and megapolitan areas. Applied Spatial Analysis and Policy, 7, 119-147.

Bignal, K.L., Ashmore, M.R., Headley, A.D., Stewart, K. and Weigert, K. 2007. Ecological impacts of air pollution from road transport on local vegetation. *Applied Geochemistry*, 22, 1265-1271. https://doi.org/10.1016/j.apgeochem.2007.03.017 117

Billings, S.A., Lajtha, K., Malhotra, A., Berhe, A.A., de Graaff, M.-A., Earl, S., ... Wieder, W. 2021. Soil organic carbon is not just for soil scientists: measurement recommendations for diverse practitioners. *Ecological Applications*, 31, e02290. https://doi.org/10.1002/eap.2290

Bordt, M., & Saner, M., 2018. A critical review of ecosystem accounting and services frameworks. One Ecosystem, 3, e29306

Bordt, M., 2018. Discourses in ecosystem accounting: a survey of the expert community. Ecological Economics, 144, 82-99.

Briffa, J., Sinagra, E. and Blundell, R. 2020. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, 6, e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

Bright, G., Connors, E., & Grice, J., 2019. Measuring natural capital: towards accounts for the UK and a basis for improved decision-making. Oxford Review of Economic Policy, 35(1), 88-108.

Bruzón, A. G., Arrogante-Funes, P., de Anguita, P. M., Novillo, C. J., & Santos-Martín, F., 2022. How the ecosystem extent is changing: A national-level accounting approach and application. Science of The Total Environment, 815, 152903.

Bukvareva, E., Grunewald, K., Klimanova, O., Kolbovsky, E., Shcherbakov, A., Sviridova, T., & Zamolodchikov, D., 2021. TEEB-Russia: Towards National Ecosystem Accounting. Sustainability, 13(12), 6678.

Cadenasso, M. L., Pickett, S. T. A., McGrath, B., & Marshall, V. 2013. Ecological heterogeneity in urban ecosystems: Reconceptualized land cover models as a bridge to urban design. Resilience in ecology and urban design: Linking theory and practice for sustainable cities, 107-129.

Capriolo, A., Boschetto, R. G., Mascolo, R. A., Balbi, S., & Villa, F., 2020. Biophysical and economic assessment of four ecosystem services for natural capital accounting in Italy. Ecosystem Services, 46, 101207.

Castellar, J. A., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., ... & Acuna, V. 2021. Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Science of the Total Environment*, *779*, 146237.

Cavalletti, B., & Corsi, M., 2022. The system of environmental and economic accounting and the valuation problem: a review of the literature. Journal of Environmental Planning and Management, 65(11), 1999-2028.

Chen, A., Yao, L., Sun, R., & Chen, L. 2014. How many metrics are required to identify the effects of the landscape pattern on land surface temperature?. Ecological indicators, 45, 424-433.

Chen, W., Van Assche, K. A. M., Hynes, S., Bekkby, T., Christie, H. C., & Gundersen, H., 2020. Ecosystem accounting's potential to support coastal and marine governance. Marine Policy, 112, 103758.

Cimburova, Z., & Barton, D. N., 2020. The potential of geospatial analysis and Bayesian networks to enable i-Tree Eco assessment of existing tree inventories. Urban Forestry & Urban Greening, 55, 126801.

Cimburova, Z., & Pont, M. B., 2021. Location matters. A systematic review of spatial contextual factors mediating ecosystem services of urban trees. Ecosystem Services, 50, 101296.

Clerici, N., Paracchini, M.L. and Maes, J. 2014. Land-cover change dynamics and insights into ecosystem services in European stream riparian zones. Ecohydrology & Hydrobiology, 14, 107-120. https://doi.org/10.1016/j.ecohyd.2014.01.002

Correa Ayram, C.A., Mendoza, M.E., Etter, A. and Salicrup, D.R.P. 2016. Habitat connectivity in biodiversity conservation:A review of recent studies and applications. Progress in Physical Geography: Earth and Environment, 40, 7-37. 10.1177/0309133315598713

Cryle, P., Pelletier, M.b, McInnes, C.c, Hills, T.d, Gunawardana, D.d, Cherian, M.d, Cowood, A.d, Romanovska, L. 2021. Practical Guidance Notes for Urban Ecosystem Accounting. A draft report by Working Group on Urban Ecosystem Accounting in Australia – URECAA, prepared for the Interjurisdictional Environmental-Economic Accounting Steering Committee.

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., Kiss, M., Obst, C., 2021. Selection criteria for ecosystem condition indicators. Ecological Indicators, 133, 108376

De Jong, R., Edens, B., Van Leeuwen, N., Schenau, S., Remme, R., & Hein, L., 2016. Ecosystem Accounting Limburg Province, the Netherlands. Part I: Physical supply and condition accounts. Statistics Netherlands & Wageningen University

Dijkstra, L., and Poelman H., 2014. A harmonised definition of cities and rural areas: the new degree of urbanisation. Working Paper 1 - DG REGIO

Dong, T., Jiao, L., Xu, G., Yang, L., & Liu, J. 2019. Towards sustainability? Analyzing changing urban form patterns in the United States, Europe, and China. Science of the Total Environment, 671, 632-643.

Dvarskas, A., 2019. Experimental ecosystem accounting for coastal and marine areas: a pilot application of the SEEA-EEA in Long Island coastal bays. Marine Policy, 100, 141-151.

Edens, B., Maes, J., Hein, L., Obst, C., Siikamaki, J., Schenau, S., ... & Alfieri, A., 2022. Establishing the SEEA Ecosystem Accounting as a global standard. Ecosystem Services, 54, 101413.

EFTEC, 2017. A study to scope and develop urban natural capital accounts for the UK - Final Report. London, UK

Elmqvist, T., Gatzweiler, F., Lindgren, E., Liu, J. 2019. Resilience Management for Healthy Cities in a Changing Climate. In: Marselle, M., Stadler, J., Korn, H., Irvine, K., Bonn, A. (eds) Biodiversity and Health in the Face of Climate Change. Springer, Cham. https://doi.org/10.1007/978-3-030-02318-8_18

European Commission 2015. The Added Value of Natural Capital Accounting for EU Policies. Available at: https://environment.ec.europa.eu/topics/nature-and-biodiversity/natural-capital-accounting_en. [Last Access: 20/12/2022].

European Commission, 2021. Applying the degree of urbanisation: a new international manual for defining cities, towns and rural areas: 2021 edition. LU: Available at: https://data.europa.eu/doi/10.2785/485951 Publications Office. [Last Access: 20/12/2022].

European Commission, 2021a. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:a1c34a56-b314-11eb-8aca-01aa75ed71a1.0001.02/DOC_1&format=PDF [Last Access: 20/12/2022].

European Commission. 2022a. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) No 691/2011 as regards introducing new environmental economic accounts modules COM/2022/329 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0329 [Last Access: 20/12/2022].

European Commission 2022b. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on nature restoration, Brussels, 22.6.2022, COM(2022) 304 final, 2022/0195 (COD), https://environment.ec.europa.eu/publications/nature-restoration-law_en [Last Access: 20/12/2022].

European Commission 2022c. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ambient air quality and cleaner air for Europe (recast) COM(2022) 542 final, 2022/0347 (COD), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A542%3AFIN [Last Access: 20/12/2022].

European Commission 2023. EU Regional and Urban Development – Sustainable urban development. https://ec.europa.eu/regional_policy/policy/themes/urban-development_en [Last Access: 20/02/2023].

European Environment Agency. 2020. The European environment-state and outlook 2020. Knowledge for transition to a sustainable Europe. In European Environment Agency (Vol. 60, Issue 3, pp. 391–394). https://doi.org/10.15196/TS600305 [Last Access: 20/12/2022].

European Environment Agency. 2022. Climate change as a threat to health and well-being in Europe: focus on heat and infectious diseases — 68 pp. — 21 x 29.7 cm ISBN: 978-92-9480-508-9 doi: 10.2800/67519

EUROSTAT. 2015. Population projections 2015 at national level. In Population on 1st January by age and sex. Eurostat.

EUROSTAT. 2018. Methodological manual on territorial typologies. 2018 Edition. General and Regional Statistics, Manuals and guidelines, 132. https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-18-008

FAO. 2016. Guidelines on urban and peri-urban forestry; edited by F. Salbitano, S. Borelli, M. Conigliaro and Y. Chen. FAO Forestry Paper No.178. Rome, Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i6210e/i6210e.pdf [Last Access: 20/12/2022].

Farrell, C., Coleman, L., Kelly-Quinn, M., Obst, C., Eigenraam, M., Norton, D., ... & Stout, J., 2021. Applying the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) framework at catchment scale to develop ecosystem extent and condition accounts. One Ecosystem, 6, e65582.

Fernandes, M.R., Segurado, P., Jauch, E. and Ferreira, M.T. 2016. Riparian responses to extreme climate and land-use change scenarios. Science of The Total Environment, 569-570, 145-158. https://doi.org/10.1016/j.scitotenv.2016.06.099

Framstad, E., Kolstad, A. L., Nybø, S., Töpper, J. & Vandvik, V. 2022. The condition of forest and mountain ecosystems in Norway. Assessment by the IBECA method. NINA Report 2100. Norwegian Institute for Nature Research

Fusaro, L., Salvatori, E., Mereu, S., Marando, F., Scassellati, E., Abbate, G. and Manes, F. 2015. Urban and peri-urban forests in the metropolitan area of Rome: Ecophysiological response of Quercus ilex L. in two green infrastructures in an ecosystem services perspective. Urban Forestry & Urban Greening, 14, 1147-1156. https://doi.org/10.1016/j.ufug.2015.10.013

Gacutan, J., Lal, K., Herath, S., Lantz, C., Taylor, M., & Milligan, B., 2022. Using Ocean Accounting towards an integrated assessment of ecosystem services and benefits within a coastal lake. One Ecosystem, 7, e81855.

Garnåsjordet, P.A., Garnåsjordet, P. A., Steinnes, M., Cimburova, Z., Nowell, M., Barton, D. N., & Aslaksen, I. 2020. Urban green. Integrating ecosystem extent and condition data in urban ecosystem accounts. Examples from the Oslo region. Discussion Paper 941. Statistical journal of the IAOS 37

Godet, M. 2006. Creating Futures: Scenario Planning as a strategic management tool (pp. 280). Washington, DC: Economica. *Economica Brookings diffusion*.

Grenier, M., Lantz, N., Soulard, F., & Wang, J., 2020. The use of combined Landsat and Radarsat data for urban ecosystem accounting in Canada. Statistical Journal of the IAOS, 36(3), 823-839.

Grêt-Regamey, A., Galleguillos-Torres, M., Dissegna, A., & Weibel, B. 2020. How urban densification influences ecosystem services—a comparison between a temperate and a tropical city. Environmental Research Letters, 15(7), 075001.

Grilli, G., Luisetti, T., Thornton, A., & Donovan, D., 2021. Developing ecosystem accounts for the marine and coastal environment: Limitations, opportunities and lessons learned from the United Kingdom experience. Journal of Ocean and Coastal Economics, 8(2).

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Zulian, G., Bouraoui, F., De Roo, A., Cardoso, A. C., 2019. Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters. Science of the Total Environment, 671, 452-465

Grondard, N., Hein, L., & Van Bussel, L. G., 2021. Ecosystem accounting to support the Common Agricultural Policy. Ecological Indicators, 131, 108157.

Grunewald, K., Schweppe-Kraft, B., Syrbe, R. U., Meier, S., Krüger, T., Schorcht, M., & Walz, U., 2020. Hierarchical classification system of Germany's ecosystems as basis for an ecosystem accounting-methods and first results. One Ecosystem, (2).

Guerri, G., Crisci, A., Messeri, A., Congedo, L., Munafò, M., & Morabito, M. 2021. Thermal summer diurnal hot-spot analysis: the role of local urban features layers. Remote Sensing, 13(3), 538.

Guo, X.R. 2003. Urban ecosystem health assessment—case study on Guangzhou City. Doctoral degree dissertation. Beijing: Beijing Normal University.

Guo XR, Yang JR, Mao XQ. 2002. Primary studies on urban ecosystem health assessment. China Environ Sci 22(6):525–9

Hamstead, Z. A., Kremer, P., Larondelle, N., McPhearson, T., & Haase, D. 2016. Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City. Ecological Indicators, 70, 574-585.

Hanssen, F., Barton, D. N., Venter, Z. S., Nowell, M. S., & Cimburova, Z., 2021. Utilizing LiDAR data to map tree canopy for urban ecosystem extent and condition accounts in Oslo. Ecological Indicators, 130, 108007.

Hanssen, F., D.N. Barton, M. Nowell, Z.Cimburova 2019. Mapping urban tree canopy cover using airborne laser scanning – applications to urban ecosystem accounting for Oslo. NINA Report 1677. Norwegian Institute for Nature Research.

Hein, L., Bagstad, K. J., Obst, C., Edens, B., Schenau, S., Castillo, G., Sioulard, F., Brown, C., Driver, A., Bordt, M., Steurer A., Harris, R., Caparrós, A., 2020. Progress in natural capital accounting for ecosystems. Science, 367(6477), 514-515.

Hein, L., Obst, C., Edens, B., & Remme, R. P. (2015). Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital. Current Opinion in Environmental Sustainability, 14, 86-92.

Hein, L., Remme, R. P., Schenau, S., Bogaart, P. W., Lof, M. E., & Horlings, E., 2020. Ecosystem accounting in the Netherlands. Ecosystem Services, 44, 101118.

Heris, M., Bagstad, K. J., Rhodes, C., Troy, A., Middel, A., Hopkins, K. G., & Matuszak, J., 2021. Piloting urban ecosystem accounting for the United States. Ecosystem Services, 48, 101226.

Hirabayashi, S., Kroll, C. N., Nowak, D. J., & Endreny, T. A. 2022. i-Tree Eco Dry Deposition Model Descriptions .Available at: https://www.itreetools.org/documents/60/i-Tree_Eco_Dry_Deposition_Model_Descriptions_V1.5.pdf [Last Access: 20/03/2023]

Holling, C. 1973. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4, 1-23. 10.1146/annurev.es.04.110173.000245

Huang, J., Lu, X. X., & Sellers, J. M. 2007. A global comparative analysis of urban form: Applying spatial metrics and remote sensing. Landscape and urban planning, 82(4), 184-197.

Iungman, T., Cirach, M., Marando, F., Barboza, E. P., Khomenko, S., Masselot, P., ... & Nieuwenhuijsen, M. 2023. Cooling cities through urban green infrastructure: a health impact assessment of European cities. The Lancet, 401(10376), 577-589.

Karr, J.R. 1993. Defining and assessing ecological integrity: Beyond water quality. *Environmental Toxicology and Chemistry*, 12, 1521-1531. https://doi.org/10.1002/etc.5620120902

Keith, H., Czúcz, B., Jackson, B., Driver, A., Nicholson, E., & Maes, J., 2020. A conceptual framework and practical structure for implementing ecosystem condition accounts. One Ecosystem, 5, e58216.

Keith, H., Vardon, M., Stein, J. A., Stein, J. L., & Lindenmayer, D., 2017. Ecosystem accounts define explicit and spatial trade-offs for managing natural resources. Nature Ecology & Evolution, 1(11), 1683-1692.

Konijnendijk, Cecil C. 2022. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *Journal of Forestry Research*, 1-10.

Kremer, P., Larondelle, N., Zhang, Y., Pasles, E., & Haase, D. 2018. Within-class and neighborhood effects on the relationship between composite urban classes and surface temperature. Sustainability, 10(3), 645.

La Notte, A., Maes, J., Dalmazzone, S., Crossman, N. D., Grizzetti, B., & Bidoglio, G., 2017. Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention. Ecosystem services, 23, 18-29.

La Notte, A. 2018. Accounting for the ecosystem services generated by Nature-based Solutions to measure urban resilience : a methodological proposal, in [Economics and Policy of Energy and Environment : 2, 2018][Milano : Franco Angeli, 2018.] - Permalink: http://digital.casalini.it/10.3280/EFE2018-002003

La Notte, A., & Dalmazzone, S. 2018. Sustainability assessment and causality nexus through ecosystem service accounting: The case of water purification in Europe. Journal of Environmental Management, 223, 964-974.

La Notte, A., Vallecillo, S., & Maes, J. 2019. Capacity as "virtual stock" in ecosystem services accounting. Ecological indicators, 98, 158-163.

La Notte, A., Vallecillo, S., Marques, A., & Maes, J., 2019a. Beyond the economic boundaries to account for ecosystem services. Ecosystem Services, 35, 116-129.

La Notte, A., & Rhodes, C., 2020. The theoretical frameworks behind integrated environmental, ecosystem, and economic accounting systems and their classifications. Environmental Impact Assessment Review, 80, 106317.

La Notte, A., & Zulian, G., 2021. An Ecosystem Services-Based Approach to Frame NBS in Urban Context. In Nature-Based Solutions for More Sustainable Cities–A Framework Approach for Planning and Evaluation. Emerald Publishing Limited.

La Notte, A., Czúcz, B., Vallecillo, S., Polce, C., & Maes, J., 2022. Ecosystem condition underpins the generation of ecosystem services: an accounting perspective. One Ecosystem, 7, e81487.

La Notte, A., Grammatikopoulou, I., Zurbaran Nucci, M., Marques, A., Ferrini, S., Cerilli, S. and Tamborra, M. 2022a. LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging (LISBETH) Part II, EUR 31185 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-55832-3, doi:10.2760/010621, JRC130438

Lai, T. Y., Salminen, J., Jäppinen, J. P., Koljonen, S., Mononen, L., Nieminen, E., ... & Oinonen, S., 2018. Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland. Ecological modelling, 377, 51-65.

Lankia, T., Neuvonen, M., Pouta, E., Sievänen, T., & Torvelainen, J., 2020. Outdoor recreation in ecosystem service accounting: pilot accounts from Finland. Scandinavian Journal of Forest Research, 35(3-4), 186-197.

Larondelle, N., Hamstead, Z. A., Kremer, P., Haase, D., & McPhearson, T. 2014. Applying a novel urban structure classification to compare the relationships of urban structure and surface temperature in Berlin and New York City. Applied Geography, 53, 427-437.

Lauwers, L., Barton, D.N., Blumentrath, S. & Often, A. 2017. Accounting for urban trees. Updating the VAT03 compensation value model. NINA Report 1453. Norwegian Institute for Nature Research.

Lehner, A., & Blaschke, T. 2019. A generic classification scheme for urban structure types. Remote Sensing, 11(2), 173.

Lemoine-Rodríguez, R., Inostroza, L., & Zepp, H. 2020. The global homogenization of urban form. An assessment of 194 cities across time. Landscape and Urban Planning, 204, 103949.

Maes, J., Driver, A., Czúcz, B., Keith, H., Jackson, B., Nicholson, E., & Dasoo, M. 2020. A review of ecosystem condition accounts: Lessons learned and options for further development. One Ecosystem 5: e53485.

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J.I., … et al. 2020a. *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment, EUR 30161 EN*. Publications Office of the European Union, Ispra. https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

Manes, F., Marando, F., Capotorti, G., Blasi, C., Salvatori, E., Fusaro, L., ... & Munafò, M. 2016. Regulating ecosystem services of forests in ten Italian metropolitan cities: air quality improvement by PM10 and O3 removal. Ecological indicators, 67, 425-440.

Marando, F., Salvatori, E., Fusaro, L., & Manes, F. 2016. Removal of PM10 by forests as a nature-based solution for air quality improvement in the Metropolitan city of Rome. Forests, 7(7), 150.

Marando, F., Heris, M.P., Zulian, G., Udías, A., Mentaschi, L., Chrysoulakis, N., … Maes, J. 2022. Urban heat island mitigation by green infrastructure in European Functional Urban Areas. *Sustainable Cities and Society*, 77, 103564. https://doi.org/10.1016/j.scs.2021.103564

McMahon, J. M., Hasan, S., Brooks, A., Curwen, G., Dyke, J., Saint Ange, C., & Smart, J. C., 2022. Challenges in modelling the sediment retention ecosystem service to inform an ecosystem account–Examples from the Mitchell catchment in northern Australia. Journal of Environmental Management, 314, 115102.

McPhearson, T., Pickett, STA., Grimm N.B, Niemelä J., Alberti M., Elmqvist, T., Weber, C., Haase, D., Breuste, J., and Qureshi, S. 2016. Advancing urban ecology toward a science of cities. *BioScience* 66, no. 3: 198-212.

Meerow, S., Newell, J.P., Stults, M. 2016. Defining urban resilience: A review. *Landscape and urban planning* 147: 38-49.

Methorst, J., Bonn, A., Marselle, M., Böhning-Gaese, K. and Rehdanz, K. 2021. Species richness is positively related to mental health – A study for Germany. Landscape and Urban Planning, 211, 104084. https://doi.org/10.1016/j.landurbplan.2021.104084

Mitz, E., Kremer, P., Larondelle, N., & Stewart, J. D. 2021. Structure of Urban landscape and surface temperature: a case study in Philadelphia, PA. Frontiers in Environmental Science, 9, 592716.

Morelli, F., Reif, J., Díaz, M., Tryjanowski, P., Ibáñez-Álamo, J.D., Suhonen, J., … Benedetti, Y. 2021. Top ten birds indicators of high environmental quality in European cities. Ecological Indicators, 133, 108397. https://doi.org/10.1016/j.ecolind.2021.108397

Mubareka, S., Koomen, E., Estreguil, C., & Lavalle, C. 2011. Development of a composite index of urban compactness for land use modelling applications. Landscape and Urban Planning, 103(3-4), 303-317.

Nedkov, S., Campagne, S., Borisova, B., Krpec, P., Prodanova, H., Kokkoris, I. P., ... & Dimopoulos, P., 2022. Modeling water regulation ecosystem services: A review in the context of ecosystem accounting. Ecosystem Services, 56, 101458.

Nel, J.L.; Driver, A. 2015. National River Ecosystem Accounts for South Africa. Discussion Document for Advancing SEEA Experimental Ecosystem Accounting Project; Pretoria

Newport, J., Shorthouse, D.J. and Manning, A.D. 2014. The effects of light and noise from urban development on biodiversity: Implications for protected areas in Australia. *Ecological Management & Restoration*, 15, 204-214. https://doi.org/10.1111/emr.12120

Normyle, A., Doran, B., Vardon, M., Mathews, D., Melbourne, J., & Althor, G., 2022. An Indigenous perspective on ecosystem accounting: Challenges and opportunities revealed by an Australian case study. Ambio, 1-13.

Obst, C., Hein, L. & Edens, B., 2016. National Accounting and the Valuation of Ecosystem Assets and Their Services. Environ Resource Econ 64, 1–23 https://doi.org/10.1007/s10640-015-9921-1

Ogilvy, S., Burritt, R., Walsh, D., Obst, C., Meadows, P., Muradzikwa P., Eigenraam, M., 2018. Accounting for liabilities related to ecosystem degradation, Ecosystem Health and Sustainability, 4:11, 261-27

Office for National Statistics, 2019. UK Natural Capital: Urban Accounts. UK

Office for National Statistics, 2022. Habitat extent and condition, natural capital,

Parastatidis, D., Mitraka, Z., Chrysoulakis, N., & Abrams, M. 2017. Online global land surface temperature estimation from Landsat. *Remote sensing*, *9*(12), 1208.

Petersen, J. E., Mancosu, E., & King, S., 2022. Ecosystem extent accounts for Europe. Ecosystem Services, 57, 101457.

Pickett, S. T., Cadenasso, M. L., Baker, M. E., Band, L. E., Boone, C. G., Buckley, G. L., ... & Szlavecz, K. 2020. Theoretical perspectives of the baltimore ecosystem study: Conceptual evolution in a social–ecological research project. BioScience, 70(4), 297-314.

Pickett, STA, Cadenasso, M.L., Childers, D.L., McDonnell, M.J., Zhou. W. 2016. Evolution and future of urban ecological science: ecology in, of, and for the city. *Ecosystem health and Sustainability* 2, no. 7: e01229.

Pimentel, D., Westra, L. and Noss, R.F. 2000. *Ecological Integrity: Integrating Environment, Conservation and Health.* , Island Press, Washington, DC

Pourpeikari Heris, M., Bagstad, K. J., Troy, A. R., & O'Neil-Dunne, J. P., 2022. Assessing the Accuracy and Potential for Improvement of the National Land Cover Database's Tree Canopy Cover Dataset in Urban Areas of the Conterminous United States. Remote Sensing, 14(5), 1219.

Pyšek, P., Hulme, P.E., Simberloff, D., Bacher, S., Blackburn, T.M., Carlton, J.T., ... Richardson, D.M. 2020. Scientists' warning on invasive alien species. Biological Reviews, 95, 1511-1534. https://doi.org/10.1111/brv.12627

Qureshi, S., Haase, D., & Coles, R. 2014. The theorized urban gradient (TUG) method—a conceptual framework for socio-ecological sampling in complex urban agglomerations. Ecological indicators, 36, 100-110.

Redman, C., Grove, M. J. and Kuby, L. 2004. Integrating Social Science into the Long Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change. Ecosystems Vol.7(2), pp. 161-171.

Reis, J. P., Silva, E. A., & Pinho, P. 2016. Spatial metrics to study urban patterns in growing and shrinking cities. Urban Geography, 37(2), 246-271.

Remme, R. P., Edens, B., Schröter, M., & Hein, L., 2015. Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics, 112, 116-128.

Remme, R. P., Schröter, M., & Hein, L. 2014. Developing spatial biophysical accounting for multiple ecosystem services. Ecosystem Services, 10, 6-18.

Rendon, P., Erhard, M., Maes, J., & Burkhard, B., 2019. Analysis of trends in mapping and assessment of ecosystem condition in Europe. Ecosystems and People, 15(1), 156-172.

Rendon, P., Steinhoff-Knopp, B., Saggau, P., Burkhard, B., 2020. Assessment of the relationships between agroecosystem condition and the ecosystem service soil erosion regulation in Northern Germany. PLoS ONE 15(12): e0234288.

Roche, P. K., & Campagne, C. S., 2017. From ecosystem integrity to ecosystem condition: a continuity of concepts supporting different aspects of ecosystem sustainability. Current opinion in environmental sustainability, 29, 63-68.

Ryder RA. 1990. Ecosystem health, a human perception: definition, detection and the dichotomous key. J Great Lakes Res 16(4):619–24.

Salvati, L., & Sabbi, A. 2014. Identifying urban diffusion in compact cities through a comparative multivariate procedure. The Annals of Regional Science, 53, 557-575.

Schröter, M., Remme, R. P., Sumarga, E., Barton, D. N., & Hein, L. 2015. Lessons learned for spatial modelling of ecosystem services in support of ecosystem accounting. Ecosystem Services, 13, 64-69.

Schwarz, N. 2010. Urban form revisited—Selecting indicators for characterising European cities. Landscape and urban planning, 96(1), 29-47.

Schwarz, N., & Manceur, A. M. 2015. Analyzing the influence of urban forms on surface urban heat islands in Europe. Journal of Urban Planning and Development, 141(3), A4014003.

Silva, C.P., García, C.E., Estay, S.A. and Barbosa, O. 2015. Bird Richness and Abundance in Response to Urban Form in a Latin American City: Valdivia, Chile as a Case Study. PLOS ONE, 10, e0138120. 10.1371/journal.pone.0138120

Silva, C.P., García, C.E., Estay, S.A. and Barbosa, O. 2015. Bird Richness and Abundance in Response to Urban Form in a Latin American City: Valdivia, Chile as a Case Study. PLOS ONE, 10, e0138120. 10.1371/journal.pone.0138120

Stewart, J. D., Kremer, P., Shakya, K. M., Conway, M., & Saad, A. 2021. Outdoor atmospheric microbial diversity is associated with urban landscape structure and differs from indoor-transit systems as revealed by mobile monitoring and three-dimensional spatial analysis. Frontiers in Ecology and Evolution, 9.

Stewart ID, Oke TR. Conference notebook 2009. – A new classification system for urban climate sites. Bulletin of the American Meteorological Society; 90: 922–923.

Stokes, E. C., & Seto, K. C. 2019. Characterizing and measuring urban landscapes for sustainability. Environmental Research Letters, 14(4), 045002.

Su, M., Fath, B. D., & Yang, Z. 2010. Urban ecosystem health assessment: A review. *Science of the Total Environment*, *408*(12), 2425-2434.

Sylla, M., Harmáčková, Z. V., Grammatikopoulou, I., Whitham, C., Pártl, A., & Vačkářová, D., 2021. Methodological and empirical challenges of SEEA EEA in developing contexts: towards ecosystem service accounts in the Kyrgyz Republic. Ecosystem Services, 50, 101333.

Tanács, E., Bede-Fazekas, Á., Csecserits, A., Kisné Fodor, L., Pásztor, L., Somodi, I., ... & Vári, Á., 2022. Assessing ecosystem condition at the national level in Hungary-indicators, approaches, challenges. One Ecosystem, 7.

Taubenböck, H., Debray, H., Qiu, C., Schmitt, M., Wang, Y., & Zhu, X. X. 2020. Seven city types representing morphologic configurations of cities across the globe. Cities, 105, 102814.

Torres López, S., de los Angeles Barrionuevo, M., & Rodriguez-Labajos, B., 2019. Water accounts in decision-making processes of urban water management: Benefits, limitations and implications in a real implementation. Sustainable cities and society, 50, 101676.

Tilman, D. 1997. Biodiversity and ecosystem functioning In G.C. Daily (Eds.), Nature's services: societal dependence on natural ecosystems, Island, Washington, pp 93–112

UNDP. 2016. Sustainable Urbanization Strategy UNDP's Support to Sustainable, Inclusive and Resilient Cities in the Developing World.

United Nations. 2023. United Nations Population Division. World Urbanization Prospects: 2018 Revision. Available at: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=EU [Last Access: 20/03/2023].

United Nations. 2021. System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA). White Cover Publication, Pre-Edited Text Subject to Official Editing

UNEP-WCMC. 2022. Urban Ecosystem Accounting: Concepts and implementation. Available at: https://resources.unep-wcmc.org/products/WCMC_PR023 [Last Access: 20/12/2022]

Vačkářů, D., & Grammatikopoulou, I., 2019. Toward development of ecosystem asset accounts at the national level. Ecosystem health and sustainability, 5(1), 36-46.

Vallecillo S., La Notte, A., Kakoulaki, G., Kamberaj, J., Robert, N., Dottori, F., Feyen, L., Rega, C. and Maes, J., 2019. Ecosystem services accounting - Part II Pilot accounts for crop and timber provision, global climate regulation and flood control, EUR 29731 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-02905-2, doi:10.2760/631588, JRC116334.

Vallecillo, S., La Notte, A., Ferrini, S., & Maes, J., 2019a. How ecosystem services are changing: an accounting application at the EU level. Ecosystem Services, 40, 101044.

Vallecillo, S., La Notte, A., Zulian, G., Ferrini, S., & Maes, J., 2019b. Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. Ecological Modelling, 392, 196-211.

Vallecillo, S; Maes, J; Teller, A; Babí Almenar J; Barredo, J.I; Trombetti, M; Abdul Malak, D.; Paracchini ML; Carré A; Addamo AM; Czúcz, B; Zulian, G; Marando F; Erhard, M; Liquete, C; Romao, C; Polce, C; Pardo Valle, A; Jones, A; Zurbaran-Nucci, M; Nocita, M; Vysna, V; Cardoso AC; Gervasini, E; Magliozzi, C; Baritz, R; Barbero, M; Andre V; Kokkoris, I.P; Dimopoulos, P; Kovacevic, V; Gumbert, A. 2022. EU-wide methodology to map and assess ecosystem condition: Towards a common approach consistent with a global statistical standard. Publications Office of the European Union, Luxembourg, doi:10.2760/13048, JRC130782

Vanderhaegen, S., & Canters, F. 2017. Mapping urban form and function at city block level using spatial metrics. Landscape and Urban Planning, 167, 399-409.

Vardon, M., Burnett, P., & Dovers, S., 2016. The accounting push and the policy pull: balancing environment and economic decisions. Ecological Economics, 124, 145-152.

Vardon, M., Castaneda, J. P., Nagy, M., & Schenau, S., 2018. How the System of Environmental-Economic Accounting can improve environmental information systems and data quality for decision making. Environmental science & policy, 89, 83-92.

Vardon, M., Keith, H., & Lindenmayer, D., 2019. Accounting and valuing the ecosystem services related to water supply in the Central Highlands of Victoria, Australia. Ecosystem Services, 39, 101004.

Vardon, M., May, S., Keith, H., Burnett, P., & Lindenmayer, D. 2019. Accounting for ecosystem services–Lessons from Australia for its application and use in Oceania to achieve sustainable development. Ecosystem Services, 39, 100986.

Venter, Z. S., Brousse, O., Esau, I., & Meier, F., 2020. Hyperlocal mapping of urban air temperature using remote sensing and crowdsourced weather data. Remote Sensing of Environment, 242, 111791.

Venter, Z. S., Krog, N. H., & Barton, D. N., 2020a. Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. Science of the total environment, 709, 136193.

Virto, L. R., Weber, J. L., & Jeantil, M., 2018. Natural capital accounts and public policy decisions: findings from a survey. Ecological Economics, 144, 244-259.

Virtual Expert Forum SEEA EEA. 2020a. Consolidated breakout notes of Day 1 in Session 1: Ecosystem Extent & Condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020b. Compilation of ecosystem extent account and testing the IUCN GET Crosswalk - Estonia. Session 1: Ecosystem Extent & Condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020c. Mosaic landscapes. Session 1: Ecosystem Extent & Condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020d. SEEA EEA Revision: Status of work on Accounting for Ecosystem extent and Condition - Introduction to draft Chapters 3, 4 and 5. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020e. Consolidated key takeaway messages from breakout discussions on thematic accounts. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020f. David N. Barton. Ecosystem accounting for urban areas: challenges and opportunities for municipal land use planning and policy. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020g. Colin Smith and Rocky Harris (Defra, UK). Ecosystem Accounts for UK urban areas. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020h. Jennie Wang and François Soulard (Statistics Canada). Urban Ecosystem Accounts. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020i. Adam Dutton (Office for National Statistics UK). Ecosystem accounts UK experience with valuation. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020j. Testing the SEEA-EEA Ecosystem Condition Framework - Breakout Group #8: Norway. Session 1: Ecoystem Extent & Condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020k. Rocky Harris (Defra, UK). SEEA EEA Revision: Ecosystem asset Valuation and Accounting Entries. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020l. Consolidated breakout notes of Day 2 in Session 1: Ecosystem Extent & Condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020m. SEEA EEA Revision: Outstanding issues in Accounting for Ecosystem extent and condition. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020n. Jane Turpie. Towards a method for accounting for ecosystem services and asset value: Pilot accounts for KwaZulu-Natal, South Africa, 2005-2011. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Virtual Expert Forum SEEA EEA. 2020o. Alessandra La Notte. ESTIMAP for ecosystem services accounting. Available at: https://seea.un.org/events/virtual-expert-forum-seea-experimental-ecosystem-accounting-2020. [Last Access: 20/03/2023]

Vysna, V., Maes, J., Petersen, J.E., La Notte, A., Vallecillo, S., Aizpurua, N., Ivits, E., Teller, A. 2021. Accounting for ecosystems and their services in the European Union (INCA). Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU. Statistical report. Publications office of the European Union, Luxembourg.

Vogt, P., Riitters, K., Rambaud, P., Lindquist, E. and Pekkarinen, A. 2022. Software note 1–7. https://doi.org/10.1111/ecog.05864

Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. 2016. Heat waves and urban heat islands in Europe: A review of relevant drivers. *Science of the Total Environment*, *569*, 527-539.

Warnell, K. J., Russell, M., Rhodes, C., Bagstad, K. J., Olander, L. P., Nowak, D. J., ... & Villa, F., 2020. Testing ecosystem accounting in the United States: A case study for the Southeast. Ecosystem services, 43, 101099.

WHO. 2021. Global air quality guidelines. Particulate matter (PM 2.5 and PM 10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO

Wolfram, M., & Frantzeskaki, N. 2016. Cities and Systemic Change for Sustainability: Prevailing Epistemologies and an Emerging Research Agenda. Sustainability, 8(2), 144. https://doi.org/10.3390/su8020144

Xing, H., & Meng, Y. 2020. Measuring urban landscapes for urban function classification using spatial metrics. Ecological Indicators, 108, 105722.

Yang, Y., Jia, Y., Ling, S., & Yao, C., 2021. Urban natural resource accounting based on the system of environmental economic accounting in Northwest China: A case study of Xi'an. Ecosystem Services, 47, 101233.

Zhao, C., & Sander, H. A., 2018. Assessing the sensitivity of urban ecosystem service maps to input spatial data resolution and method choice. Landscape and urban planning, 175, 11-22.

Zhang, Y., Kong, D., Gan, R., Chiew, F.H.S., McVicar, T.R., Zhang, Q. and Yang, Y. 2019. Coupled estimation of 500 m and 8-day resolution global evapotranspiration and gross primary production in 2002–2017. Remote Sensing of Environment, 222, 165-182. https://doi.org/10.1016/j.rse.2018.12.031

Zhou, W., Cadenasso, M. L., Schwarz, K., & Pickett, S. T. 2014. Quantifying spatial heterogeneity in urban landscapes: integrating visual interpretation and object-based classification. Remote Sensing, 6(4), 3369-3386.

Zulian, G., Marando, F., Mentaschi, L., Alzetta, C., Wilk, B. and Maes, J. 2022a. Green balance in urban areas as an indicator for policy support: a multi-level application. One Ecosystem, 7. 10.3897/oneeco.7.e72685

Zulian, G., Marando, G., Vogt, P., Barbero Vignola, G., Babí Almenar, J., Zurbarán-Nucci, M. and Princé, K. 2022b. BiodiverCities: A roadmap to enhance the biodiversity and green infrastructure of European cities by 2030, EUR31224 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-57023-3, doi:10.2760/21172, JRC129888.

List of abbreviations

AT	Austria
BB	Backbone
BE	Belgium
BG	Bulgaria
C	Cities below 50,000 inhabitants
CC	Cities above 50,000 inhabitants
CH	Switzerland
CLC	Corine Land Cover
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EC	European Commission
EE	Estonia
EFTA	European Free Trade Association
EL	Greece
ES	Spain
EU	European Union
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IS	Iceland
INCA	Integrated Natural Capital Accounting
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	International Panel of Climate Change
IT	Italy
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
LAI	Leaf Area Index
LAU	Local Administrative Unit
LI	Liechtenstein
LST	Land Surface Temperature
LT	Lithuania
LU	Luxembourg
LV	Latvia
MAES	Mapping and Assessment of Ecosystem Services

MS	Member States
MT	Malta
NBS	Nature based-solutions
NL	Netherlands
NO	Norway
NUTS	Nomenclature of Territorial Units for Statistics
PL	Poland
PM	Particulate Matter
PT	Portugal
RO	Romania
SE	Sweden
SEEA EA	System of Environmental Economic Accounting – Ecosystem Accounting
SI	Slovenia
SK	Slovakia
T	Towns and Suburbs
UN	United Nations

Glossary

Anthropogenic ecosystems: ecosystems predominantly influenced by human activities where a natural ecological state is unobtainable and future socio-economic interventions are required to maintain their state.

Ecosystem: is 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit' (Convention on Biological Diversity, article 2, entitled 'Use of terms').

Ecosystem accounting area: is the geographical territory for which an ecosystem account is compiled.

Ecosystem assets: are contiguous spaces of a specific ecosystem type characterised by a distinct set of biotic and abiotic components and their interactions.

Ecosystem condition: is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics.

Ecosystem condition indicator: are rescaled versions of ecosystem condition variables using the upper and lower reference levels.

Ecosystem condition variable: are quantitative metrics describing individual characteristics of an ecosystem asset.

Ecosystem condition index (and sub-indices): composite indicator aggregated from the combination of individual ecosystem condition indicators.

Ecosystem type: from Chapter 3 onwards, ecosystem type is used to refer to the types of the EU Ecosystem Typology Level 1 developed by EUROSTAT.

Ecosystem sub-type: from Chapter 3 onwards, ecosystem sub-type is used to refer to a further disaggregation of EU Ecosystem Types Level 1 (EUROSTAT) into more detailed types.

Ecosystem integrity: in natural ecosystems implies an unimpaired condition of being complete or undivided (Karr, 1993). Ecosystem integrity making use of a traditional rationale is defined as the ecosystem's capacity to maintain its characteristic composition, structure, functioning and self-organisation over time within a natural range of variability (Pimentel et al., 2000; United Nations, 2021). Ecosystems with high integrity or condition are typically more resilient – able to recover from disturbances or to adapt to environmental changes (Holling, 1973).

Good ecosystem condition: ecosystem is in good physical, chemical and biological condition or of a good physical, chemical and biological quality with self-reproduction or self-restoration capability, in which species composition, ecosystem structure and ecological functions are not impaired.

Natural ecosystems: ecosystems predominantly influenced by natural ecological processes characterised by an ecological state maintaining ecosystem integrity; ecosystem condition ranges within its natural variability.

Reference condition: is the condition against which past, present and future ecosystem condition is compared to in order to measure relative change over time.

Reference level: is the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable.

Semi-natural ecosystems: an ecosystem with most of its processes and biodiversity intact, though altered by human activity in strength or abundance relative to the natural state.

Socio-ecological-technological systems: 'A dynamic coherent system of biophysical, social and technological factors that regularly interact and might be formed by several spatial, temporal and organisational levels hierarchically linked (Adapted from Redman et al. (2004).

Urban local administrative units: local administrative units classified as "cities" or "towns and suburbs" according to the Degree of Urbanisations (Regulation (EU) 2017/2391; EUROSTAT, 2018).

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Annexes

Annex I. Supplementary Material of Chapter 2

Table I.1. List of grey documents and peer-review papers retrieved from the systematic literature review

Item	Title	Type of Document	Reference
1	A study to scope and develop urban natural capital accounts for the UK - Final Report.	Report (Grey Literature)	EFTEC, 2017.
2	UK Natural Capital: Urban Accounts	Report (Grey Literature)	ONS, 2019.
3	Habitat extent and condition, natural capital, UK: 2022	Report (Grey Literature)	ONS, 2022.
4	A harmonised definition of cities and rural areas: the new degree of urbanisation	Report (Grey Literature)	Dijkstra and Poelman, 2014.
5	Applying the degree of urbanisation: a new international manual for defining cities, towns and rural areas : 2021 edition.	Report (Grey Literature)	European Commission, 2021.
6	Ecosystem Accounting Limburg Province, the Netherlands. Part I: Physical supply and condition accounts	Report (Grey Literature)	De Jong et al., 2016.
7	Accounting for urban trees. Updating the VAT03 compensation value model	Report (Grey Literature)	Lauwers et al., 2017..
8	Urban green. Integrating ecosystem extent and condition data in urban ecosystem accounts. Examples from the Oslo region.	Report (Grey Literature)	Garnåsjordet et al., 2020.
9	Mapping urban tree canopy cover using airborne laser scanning – applications to urban ecosystem accounting for Oslo	Report (Grey Literature)	Hanssen et al., 2019.
10	The potential of geospatial analysis and Bayesian networks to enable i-Tree Eco assessment of existing tree inventories.	Peer-review Paper	Cimburova & Barton, 2020.
11	Location matters. A systematic review of spatial contextual factors mediating ecosystem services of urban trees.	Peer-review Paper	Cimburova, & Pont, 2021.
12	Utilizing LiDAR data to map tree canopy for urban ecosystem extent and condition accounts in Oslo	Peer-review Paper	Hanssen et al., 2021.
13	Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway	Peer-review Paper	Venter, Krog, & Barton, 2020.
14	Hyperlocal mapping of urban air temperature using remote sensing and crowdsourced weather data.	Peer-review Paper	Venter et al., 2020a.
15	The use of combined Landsat and Radarsat data for urban ecosystem accounting in Canada	Peer-review Paper	Grenier et al., 2020.

Item	Title	Type of Document	Reference
16	Ecosystem accounts define explicit and spatial trade-offs for managing natural resources.	Peer-review Paper	Keith et al., 2017.
17	Beyond the economic boundaries to account for ecosystem services	Peer-review Paper	La Notte et al., 2019.
18	A review of ecosystem condition accounts: Lessons learned and options for further development.	Peer-review Paper	Maes et al., 2020.
19	Analysis of trends in mapping and assessment of ecosystem condition in Europe.	Peer-review Paper	Rendon et al., 2019.
20	From ecosystem integrity to ecosystem condition: a continuity of concepts supporting different aspects of ecosystem sustainability.	Peer-review Paper	Roche & Campagne, 2017.
21	Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people.	Peer-review Paper	Vallecillo et al., 2019a.
22	Methodological and empirical challenges of SEEA EEA in developing contexts: towards ecosystem service accounts in the Kyrgyz Republic	Peer-review Paper	Sylla et al., 2021.
23	An Ecosystem Services-Based Approach to Frame NBS in Urban Context.	Book Chapter	La Notte, & Zulian, 2021.
24	Accounting for the ecosystem services generated by Nature-based Solutions to measure urban resilience. A methodological proposal	Peer-review Paper	La Notte 2018.
25	Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands.	Peer-review Paper	Remme et al., 2015.
26	Integrating physical and economic data into experimental water accounts for the United States: Lessons and opportunities.	Peer-review Paper	Bagstad et al., 2020.
27	How ecosystem services are changing: an accounting application at the EU level.	Peer-review Paper	Vallecillo et al., 2019b.
28	Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention	Peer-review Paper	La Notte et al., 2017.
29	Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland.	Peer-review Paper	Lai et al., 2018.
30	Sustainability assessment and causality nexus through ecosystem service accounting: The case of water purification in Europe	Peer-review Paper	La Notte & Dalmazzone. 2018.
31	Capacity as “virtual stock” in ecosystem services accounting.	Peer-review Paper	La Notte, Vallecillo, Maes. 2019.
32	Selection criteria for ecosystem	Peer-	Czúcz et al., 2021.

Item	Title	Type of Document	Reference
	condition indicators	review Paper	
33	Ecosystem accounting in the Netherlands	Peer-review Paper	Hein et al., 2020.
34	Assessment of the relationships between agroecosystem condition and the ecosystem service soil erosion regulation in Northern Germany	Peer-review Paper	Rendon et al., 2020.
35	Assessing the sensitivity of urban ecosystem service maps to input spatial data resolution and method choice.	Peer-review Paper	Zhao & Sander, 2018.
36	The theoretical frameworks behind integrated environmental, ecosystem, and economic accounting systems and their classifications.	Peer-review Paper	La Notte & Rhodes, 2020.
37	Progress in natural capital accounting for ecosystems.	Peer-review Paper	Hein et al., 2020.
38	Accounting for liabilities related to ecosystem degradation	Peer-review Paper	Ogilvy et al., 2018.
39	Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters	Peer-review Paper	Grizzetti et al, 2019.
40	Lessons learned from development of natural capital accounts in the United States and European Union.	Peer-review Paper	Bagstad et al., 2021.
41	Accounting for ecosystem services–Lessons from Australia for its application and use in Oceania to achieve sustainable developmen	Peer-review Paper	Vardon et al.,2019
42	Outdoor recreation in ecosystem service accounting: pilot accounts from Finland	Peer-review Paper	Lankia et al., 2020.
43	National Accounting and the Valuation of Ecosystem Assets and Their Services.	Peer-review Paper	Obst, Hein, & Edens., 2016.
44	Developing spatial biophysical accounting for multiple ecosystem services.	Peer-review Paper	Remme, Schröter, Hein. 2014.
45	Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital	Peer-review Paper	Hein et al., 2015.
46	Lessons learned for spatial modelling of ecosystem services in support of ecosystem accounting.	Peer-review Paper	Schröter et al., 2015.
47	Testing ecosystem accounting in the United States: A case study for the Southeast.	Peer-review Paper	Warnell, et al., 2020.
48	Piloting urban ecosystem accounting for the United States	Peer-review	Heris et al., 2021.

Item	Title	Type of Document	Reference
		Paper	
49	Towards ecosystem accounts for Rwanda: Tracking 25 years of change in flows and potential supply of ecosystem service	Peer-review Paper	Bagstad et al., 2020.
50	Biophysical and economic assessment of four ecosystem services for natural capital accounting in Italy.	Peer-review Paper	Capriolo et al., 2020.
51	Assessing the Accuracy and Potential for Improvement of the National Land Cover Database's Tree Canopy Cover Dataset in Urban Areas of the Conterminous United States	Peer-review Paper	Pourpeikari et al., 2022.
52	A conceptual framework and practical structure for implementing ecosystem condition accounts	Peer-review Paper	Keith et al., 2020.
53	Applying the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) framework at catchment scale to develop ecosystem extent and condition accounts	Peer-review Paper	Farrell et al., 2021.
54	A critical review of ecosystem accounting and services frameworks.	Peer-review Paper	Bordt, Saner, 2018.
55	Establishing the SEEA Ecosystem Accounting as a global standard	Peer-review Paper	Edens et al., 2022.
56	Accounting and valuing the ecosystem services related to water supply in the Central Highlands of Victoria, Australia	Peer-review Paper	Vardon, Keith, & Lindenmayer, 2019.
57	How the System of Environmental-Economic Accounting can improve environmental information systems and data quality for decision making.	Peer-review Paper	Vardon, Castaneda, Nagy, Schenau, 2018.
58	The accounting push and the policy pull: balancing environment and economic decisions	Peer-review Paper	Vardon, Burnett, Dovers, 2016.
59	Measuring natural capital: towards accounts for the UK and a basis for improved decision-making	Peer-review Paper	Bright, Connors, Grice, 2019.
60	Hierarchical classification system of Germany's ecosystems as basis for an ecosystem accounting-methods and first result	Peer-review Paper	Grunewald, Schweppe-Kraft, Syrbe, Meier, Krüger, Schorcht, Walz, 2020.
61	Discourses in ecosystem accounting: a survey of the expert community.	Peer-review Paper	Bordt, 2018.
62	Natural capital accounts and public policy decisions: findings from a survey.	Peer-review Paper	Virto, Weber, & Jeantil, 2018.
63	ater accounts in decision-making processes of urban water management: Benefits, limitations	Peer-review Paper	Torres López, de los Angeles Barrionuevo, Rodriguez-Labajos, 2019.

Item	Title	Type of Document	Reference
	and implications in a real implementation.		
64	Experimental ecosystem accounting for coastal and marine areas: a pilot application of the SEEA-EEA in Long Island coastal bays	Peer-review Paper	Dvarskas, 2019.
65	Modeling water regulation ecosystem services: A review in the context of ecosystem accounting	Peer-review Paper	Nedkov et al., 2022.
66	Challenges in modelling the sediment retention ecosystem service to inform an ecosystem account-Examples from the Mitchell catchment in northern Australia	Peer-review Paper	McMahon et al., 2022.
67	An Indigenous perspective on ecosystem accounting: Challenges and opportunities revealed by an Australian case study	Peer-review Paper	Normyle et al., 2022.
68	How the ecosystem extent is changing: A national-level accounting approach and application	Peer-review Paper	Bruzón et al., 2022..
69	Ecosystem accounting to support the Common Agricultural Policy	Peer-review Paper	Grondard et al., 2021.
70	The system of environmental and economic accounting and the valuation problem: a review of the literature	Peer-review Paper	Cavalletti, Corsi, 2022.
71	TEEB-Russia: Towards National Ecosystem Accounting	Peer-review Paper	Bukvareva et al., 2021.
72	Urban natural resource accounting based on the system of environmental economic accounting in Northwest China: A case study of Xi 'an	Peer-review Paper	Yang et al., 2021.
73	Ecosystem accounting's potential to support coastal and marine governance	Peer-review Paper	Chen et al., 2020.
74	Toward development of ecosystem asset accounts at the national level	Peer-review Paper	Vačkářů, Grammatikopoulou, 2019.
75	Ecosystem extent accounts for Europe	Peer-review Paper	Petersen, Mancosu, & King, 2022
76	Using Ocean Accounting towards an integrated assessment of ecosystem services and benefits within a coastal lake	Peer-review Paper	Gacutan et al., 2022.
77	Ecosystem condition underpins the generation of ecosystem services: An accounting perspective	Peer-review Paper	La Notte et al., 2022.
78	Assessing ecosystem condition at the national level in Hungary - indicators, approaches, challenges	Peer-review Paper	Tanács et al., 2022.
79	Developing ecosystem accounts for	Peer-	Grilli et al., 2021.

Item	Title	Type of Document	Reference
	the marine and coastal environment: Limitations, opportunities and lessons learned from the United Kingdom experience	review Paper	

Table I.2. List of papers retrieved from the synthetic literature review

Item	Title	Type of Document	Reference
80	A global comparative analysis of urban form: Applying spatial metrics and remote sensing	Peer-review Paper	Huang et al., 2007
81	Urban form revisited—Selecting indicators for characterising European cities	Peer-review Paper	Schwarz 2010
82	Development of a composite index of urban compactness for land use modelling applications	Peer-review Paper	Mubareka et al., 2011
83	Regional Variations in Urban Fragmentation Among U.S. Metropolitan and Megapolitan Areas	Peer-review Paper	Bereitschaft & Debbage 2014
84	Spatial metrics to study urban patterns in growing and shrinking cities	Peer-review Paper	Reis et al., 2016
85	Towards sustainability? Analyzing changing urban form patterns in the United States, Europe, and China	Peer-review Paper	Dong et al., 2019
86	The global homogenization of urban form. An assessment of 194 cities across time	Peer-review Paper	Lemoine-Rodriguez et al 2020
87	Seven city types representing morphologic configurations of cities across the globe	Peer-review Paper	Taubenbock et al., 2020
88	Analyzing the Influence of Urban Forms on Surface Urban Heat Islands in Europe	Peer-review Paper	Schwarz and Manceur 2015
89	How many metrics are required to identify the effects of thelandscape pattern on land surface temperature?	Peer-review Paper	Chen et al., 2014
90	Ecological Heterogeneity in Urban Ecosystems: Reconceptualized Land Cover Models as a Bridge to Urban Design	Peer-review Paper	Cadenasso et al., 2013
91	Quantifying Spatial Heterogeneity in Urban Landscapes: Integrating Visual Interpretation and Object-Based Classification	Peer-review Paper	Zhou et al., 2014
92	Theoretical Perspectives of the Baltimore Ecosystem Study: Conceptual Evolution in a Social–Ecological Research Project	Peer-review Paper	Picket et al., 2020

93	Characterizing and measuring urban landscapes for sustainability	Peer-review Paper	Stokes and Seto 2019
94	Identifying urban diffusion in compact cities through a comparative multivariate procedure	Peer-review Paper	Salvati & Sabbi 2014
95	The Theorized Urban Gradient (TUG) method—A conceptualframework for socio-ecological sampling in complex urbanagglomerations	Peer-review Paper	Qureshi et al., 2014
96	Applying a novel urban structure classification to compare the relationships of urban structure and surface temperature in Berlin and New York City	Peer-review Paper	Larondelle et al., 2014
97	Classification of the heterogeneous structure of urban landscapes (STURLA) as an indicator of landscape function applied to surface temperature in New York City	Peer-review Paper	Hamstead et al., 2016
98	Within-Class and Neighborhood Effects on the Relationship between Composite Urban Classes and Surface Temperature	Peer-review Paper	Kremer et al., 2018
99	Mapping urban form and function at city block level using spatial metrics	Peer-review Paper	Vanderhaegen & Canters 2017
100	Measuring urban landscapes for urban function classification using spatialmetrics	Peer-review Paper	Xing & Meng 2020
101	How urban densification influences ecosystem services—a comparison between a temperate and a tropical city	Peer-review Paper	Gret-Regamey et al., 2020
102	Structure of Urban Landscape and Surface Temperature: A Case Study in Philadelphia, PA	Peer-review Paper	Mitz et al., 2021
103	Outdoor Atmospheric Microbial Diversity Is Associated With Urban Landscape Structure and Differs From Indoor-Transit Systems as Revealed by Mobile Monitoring and Three-Dimensional Spatial Analysis	Peer-review Paper	Stewart et al., 2021
104	A Generic Classification Scheme for Urban Structure Types	Peer-review Paper	Lehner & Blaschke 2019
105	Thermal Summer Diurnal Hot-Spot Analysis: The Role of Local Urban Features Layers	Peer-review Paper	Guerri et al., 2020

Table I.3. Key lessons extracted from the literature

Type of Study	Lessons	Source
Urban Ecosystem Accounts – United Kingdom	- Urban ecosystems should include in their accounting areas blue and green spaces beyond gardens. - Internal division of an urban ecosystem in ecosystem sub-types should allow reconciliation with broader accounts (e.g. comprehensive national ecosystem accounts) to avoid double counting issues. - Buffers around built-up areas might avoid leaving out from accounting areas periurban green spaces.	EFTEC, 2017; ONS, 2019
Urban Ecosystem Account – Oslo	- Ownership of land (e.g. green open spaces) as an (auxiliary) attribute could be valuable in the development of extent or condition accounts	Garnåsjordet et al., 2020
Urban Ecosystem Account – Canada (input data analysis)	- Urban ecosystems (and their accounts) are composed by a mix of natural and artificial features. - Local Climate Zone classification (Stewart and Oke, 2009) can be valuable for internal division of an urban ecosystem in sub-types. - The use of Earth Observation Technology as valuable input data for enhancing the development of accounts such as urban extent accounts.	Grenier et al., 2020
Accounting for the ecosystem services delivered by nature-based solutions - Methodological development	- Nature-based solutions classifications can help in the internal split of urban ecosystems in sub-types. - Their use would help to pre-identify in ecosystem services accounts which ecosystem services are supplied by each ecosystem subtype (presence/absence). - Their use would help to pre-identify the socio-environmental issues that each ecosystem sub-type could address.	La Notte, 2018
Urban Ecosystem Accounts – United States	- Municipal boundaries with a constraint on population number as an approach for defining urban ecosystem accounting areas. - Land cover classes as a simple way for splitting an urban ecosystem in sub-types.	Heris et al., 2021
Ecosystem Extent Accounts - Europe	- Aggregation of CORINE land cover classes as a simple way for defining broad ecosystem types	Petersen et al., 2022
Practical Guidance Notes on Urban Ecosystem Accouts - Australia	- Thematic urban ecosystem accounts as an opportunity to inform public policy related to urban planning, management and investment decisions. - Thematic urban ecosystem accounts might incorporate auxiliary data such as expenditure (related to management and restoration of urban ecosystem assets), disservices, dependencies, socio-economic distribution of benefits derived from services. - Strict classification of the IUCN Ecosystem Typology might lead to entire urban areas classified as “Urban and Industrial Ecosystems” which would not be valuable for analytical purposes. Instead, using IUCN Typology classes to split the urban landscape mosaic into narrow ecosystem types compatible with broader ecosystem accounts (e.g. national) might be more desirable.	Cryle et al., 2021

Type of Study	Lessons	Source
	- Several urban ecosystem accounting areas and reporting units are possible, each of them have pros and cons and the selection of a specific alternative depends on the policy purposes. Four are specifically proposed in Australia: OECD functional urban areas, city statistical areas, urban growth boundary, and metropolitan region.	
Synthetic review – urban characterisation	- Characterisation/clustering of urban ecosystems based on five dimensions: compactness, centrality, complexity, porosity, and population density. - Use of auxiliary socio-economic variables (purchasing power parity, telephone lines per person, vehicles per person) for characterisation.	Huang et al., 2007
Synthetic review – urban characterisation	- Characterisation/clustering of urban ecosystems based on metrics of composition and configuration of the physical structure (landscape metrics) and socio-economic variables such as population number and population density	Schwarz 2010; Lemoine-Rodriguez et al., 2020
Synthetic review – urban characterisation	- Review on metrics of urban characterisation. Categorisation of them in three groups: landscape metrics, geospatial metrics and spatial statistics.	Reis et al., 2016
Synthetic review – urban characterisation	- Split of single urban ecosystems in sub-types (core area, inner urban, suburban) based on the urban gradient approach. - Cluster urban ecosystems in groups based on their physical compactness and population density	Dong et al., 2019; Salvati and Sabbi, 2014; Qureshi et al., 2014
Synthetic review – urban characterisation	- Split of single urban ecosystems in sub-types according to the combination of three types of biophysical elements: buildings, surface materials, vegetation. - Development of a new urban land cover classification (HERCULES) based on this approach.	Cadenasso et al., 2013; Zhou et al., 2014; Picket et al., 2020;
Synthetic review – urban characterisation	- Split of single urban ecosystems in sub-types according to the combination of six biophysical characteristics: tree canopy, low-height plants, soils, water, paved surfaces, building height. - Development of a new urban land cover classification (STURLA) based on this approach.	Larondelle et al., 2014; Hamstead et al 2016, Kremer et al., 2018; Mitz et al. 2021
Synthetic review – urban characterisation	- Split of single urban ecosystems in sub-types according to the combination of nine biophysical characteristics: water area, tree area, shrub area, grass area, bare soil area, buildings area, built surface, building height, vegetation height.	Gret-Regamey et al, 2020
Synthetic review – urban ecosystem condition	- Proposed urban ecosystem health as an underpinning concept for urban ecosystem condition. - Urban ecosystem health should include the human dimension and therefore human health. - Proposal to find reference condition based on a comparative assessment of existing urban ecosystem assets and/or feasible scenarios for them.	Guo et al., 2002, Guo 2003

Annex II. Supplementary Material of Chapter 3

Table II.1. Correspondence of CORINE land cover classes Level 3 to UE Ecosystem Types Level 1 (Task force on Ecosystem Accounting)

EU ecosystem types - Level 1	CORINE Land Cover - Level 3
01. Settlements and other artificial areas	Continuous urban fabric
	Discontinuous urban fabric
	Industrial or commercial units
	Road and rail networks and associated land
	Port areas
	Airports
	Mineral extraction sites
	Dump sites
	Construction sites
	Green urban areas
	Sport and leisure facilities
02. Cropland	Non-irrigated arable land
	Permanently irrigated land
	Rice fields
	Vineyards
	Fruit trees and berry plantations
	Olive groves
	Annual crops associated with permanent crops
	Complex cultivation patterns
	Land principally occupied by agriculture, with significant areas of natural vegetation
	Agro-forestry areas
03. Grassland	Pastures
	Natural grasslands
04. Forest and woodland	Broad-leaved forest
	Coniferous forest
	Mixed forest
	Transitional woodland-shrub
05. Heathland and shrubland	Moors and heathland
	Sclerophyllous vegetation
06. Sparsely vegetated ecosystems*	Beaches, dunes, sands
	Bare rocks
	Sparsely vegetated areas
	Burnt areas
	Glaciers and perpetual snow
07. Inland wetlands	Inland marshes
	Peat bogs
08. Marine inlets and transitional waters*	Intertidal flats
	Estuaries
09. Rivers and canals	Water courses
10. Lakes and reservoirs	Water bodies
11. Coastal beaches, dunes and wetlands*	Beaches, dunes, sands
	Bare rocks
	Salt marshes
	Salines
	Coastal lagoons
12. Marine ecosystems	Sea and ocean

*The land cover classes “bare rocks” and “beaches, dunes, sands” does not have a univocal correspondence, since those classes can correspond to “06. Sparsely vegetated ecosystems” and “11. Coastal beaches, dunes and wetlands” depending on contextual factors. The additional allocation rules applied to those CORINE land cover classes are described below.

Additional allocation rules **for assigning "bare rocks" and "beaches, dunes and sand" to "06. Sparsely vegetated ecosystems" or "11. Coastal beaches, dunes and wetlands"** in this technical report.

Both CORINE land cover classes are allocated to "11. Coastal beaches, dunes and Wetlands" when certain conditions regarding distance from "Sea and Ocean" CORINE land cover classes are fulfilled. Those conditions are explained below per each land cover class.

Bare rocks

When "bare rocks" are in a distance from "Sea and Ocean" CORINE land cover classes below or equal to 200 meters, they are allocated to the ecosystem type "Coastal Beaches, Dunes and Wetlands".

Beaches, dunes and sand

When a contiguous area of "beaches dunes and sand" is in a distance from "Sea and Ocean" CORINE land cover classes below or equal to 200 meters, partially or completely, they are allocated to the ecosystem type "Coastal Beaches, Dunes and Wetlands". In this case, the allocation rule is made for an entire contiguous area of cells and not individual cells. This because coastal dune systems in many cases extend beyond 200 meters. Therefore, it is enough that part of the cells forming a contiguous area of "beaches dunes and sand" are inside the 200 meter threshold.

As indicated in Section 3.1., the allocation rules described above are a specific output of this report and are not representative of final allocation rules endorsed by the Task force on ecosystem accounting, since they were still in discussion during the development of the research activity associated with this technical report.

Rules applied to refine Local Administrative Units (LAU) classified as DEGURBA Class 1 (cities) and 2 (towns and suburbs)

1) LAU below 1000 inhabitants were removed.

They were not representing towns, sometimes were classified as "towns and suburbs" because were adjacent to LAU classified as towns and the last raster cell classified as a town at raster level was partially in this LAU. Other times it was not clear why they were classified as "towns and suburbs", since there was not even a real settlement on some of them. Above values of 1000 inhabitants, LAU were in many cases correctly classified, they were just very small. It was not possible to move beyond this threshold without removing LAU that were correctly classified as towns.

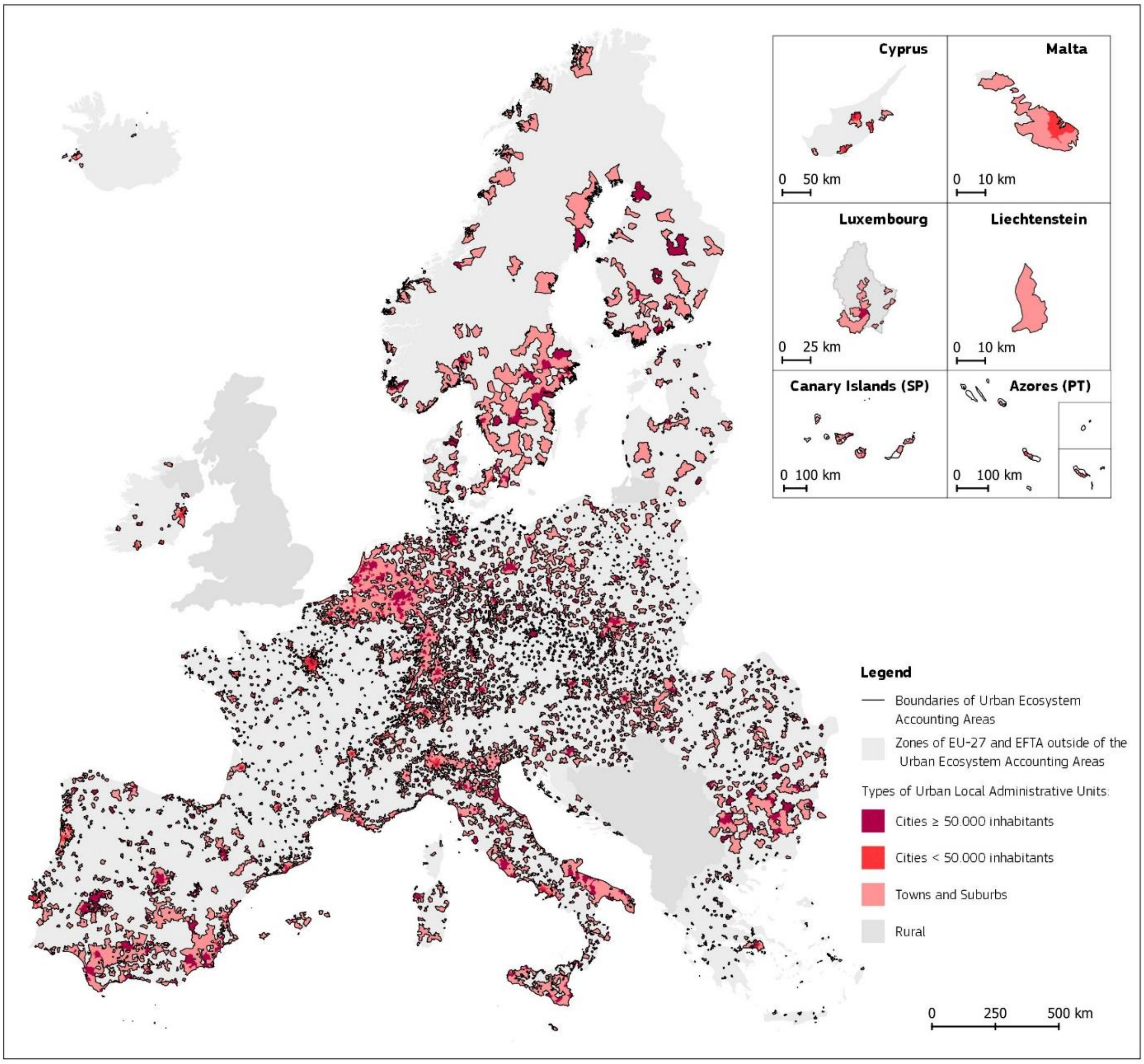
2) LAUs with a Population Density below 10 inhabitants/km2 were removed

Some LAU are very large, especially in the north of Europe (e.g., Sweden) and few parts of Southern Europe (e.g., Spain). In Sweden, they contain clearly small settlements that in practice are towns (10.000-20.000 inhabitants), but in zones that occupy less than 10% of an entire LAU. Then, those LAU might appear to policy makers and other stakeholders to be classified as "cities or "towns and suburbs" by mistake due to inherent constraints of the original method. Consequently, tests showed that adding a threshold of 10 inhabitants/km2 permits to remove those LAU.

3) DEGURBA classes were recalculated to spot mistakes: every LAU that did not appear as Class 1 (cities) or 2 (towns and suburbs) were removed

Making use of GEOSTAT 2018 population dataset at 1 km resolution, the Degree of Urbanisation classes at raster level and then its classification of LAU at vector level were recalculated. This refinement intended to remove LAU still misclassified after steps 1 and 2. The intention was to remove all the LAUs that appear as Class 3 (rural). This recalculation, identified LAU classified as "towns and suburbs" that were in fact "rural".

Figure II.1. Urban Ecosystem Accounting Area for EU-27 and EFTA MS differentiated by type of urban LAU (cities above 50.000 inhabitants, cities below 50.000 inhabitants, towns and suburbs)



Source: JRC analysis

Annex III. Supplementary Material of Chapter 4

Table III.1. Brief description and justification of the selection of condition variables for urban ecosystem accounts.

Condition Variable	Description and justification
Imperviousness per inhabitant:	Imperviousness is a well-known variable of ecosystem degradation, since it seals the soil and limits functions such as the infiltration of water. It has also been widely demonstrated its direct relationship with an increase of land surface temperature, and consequently, intensification of urban heat island effect, especially during warm months (Marando et al., 2022). Imperviousness is a consequence of the expansion of built-up areas, which are needed to provide houses and infrastructure to people. For this reason, the suggested variable measures the level of imperviousness in relation to the population size (impervious area per capita). Imperviousness data is derived from reliable and accurate remote sensing imagery (High Resolution Layers of Copernicus product), covering the whole EU with comparable time series. Population

Condition Variable	Description and justification
	data used to estimate imperviousness per capita is derived from the GEOSTAT 1x1 km population grid provided by Eurostat, providing also spatially accurate and reliable data to be used consistently at EU level.
Waste generated per inhabitant	Waste generation is related to the rate of urbanization, the population density, the types, and patterns of consumption, household revenue, size, and lifestyles (Maes et al., 2020a). Monitoring or estimating changes in material consumption would provide a better understanding of the amount of resources demanded by inhabitants in urban ecosystems, and therefore the environmental pressure generated by them on the condition of ecosystems on which they are dependent. The indicator is measured per inhabitant to better acknowledge unit of demand (citizen), to ensure a fair comparison among urban ecosystems of different sizes (population) and facilitate definition of reference levels broadly applicable to urban ecosystems independently of their size. Calculation of this variable disaggregated by category of waste, material or waste treatment, disaggregation available at country level, might provide relevant additional details. Currently, data at EU level are only available per country, which is a too coarse spatial resolution for a detailed urban assessment. Data disaggregated by local administrative unit (LAU) would be required instead.
Normalised Difference Moisture Index	Vegetation functional status can be influenced by natural factors (e.g. drought), or human activities (e.g. urban green management or air pollution). Functional status of vegetation is strongly linked to water availability. A higher water availability is usually related to a higher ecosystem function, and to an enhanced capability to provide ecosystem services. Remote sensing indices that estimate the water content in tree canopies, such as NDMI (Normalised Difference Moisture Index), or other plant/soil water content indices, are widely used and can detect early or ongoing water stress in vegetation, therefore indicating a worsening or an improvement of the functional status of vegetation. NDMI is derived from Near Infra-Red and Short-Wave Infra-Red satellite bands and can be easily calculated from Landsat images at no cost.
Noise pollution exposure	Noise pollution negatively influences human activities (e.g. learning) and human health. It also negatively influences fauna physiology, behaviour, and reproduction, including those species already present in urban or peri-urban areas (Newport et al., 2014). In the case, of urban ecosystems both aspects are relevant, since humans are the species for excellence inhabiting this ecosystem and fauna is already highly pressured in urban ecosystems and surrounding ecosystems (which could be also impacted by noise from urban areas). In this sense, monitoring noise pollution provides valuable data to understand urban ecosystem condition, including the one of humans inhabiting this ecosystem. However, there is not consistent available noise monitoring data and yet the possibility to model it in a consistent way for the entire EU (with the aim to inform policy making). The only available dataset updated every five years is the large-scale assessment data reported at agglomeration level as a response to the Environmental Noise Directive. This variable cannot be disaggregated by ecosystem asset (ecosystem subtypes) within urban ecosystems.
Air pollutants concentration (NO_2, PM_{10}, $PM_{2.5}$, O_3, SO_2, CO)	To maintain urban ecosystem health, it is essential to keep air pollution levels as low as possible. The five pollutants used in the European Air Quality Index are here proposed. Carbon monoxide (CO) is also added to these five pollutants since it is considered in other air quality indexes (e.g. air quality index developed by the United Stated Environmental Protection Agency), and therefore its monitoring is also recommended. High levels of air pollution are still a main cause of premature human death and chronic illness negatively influencing human quality of life. High levels of air pollution also contribute to damage the health of terrestrial plants, which is observable as an increased defoliation, poorer crown condition (in woody plants), higher probability of insect damage. Air pollution also causes the reduction

Condition Variable	Description and justification
	of terrestrial plant species richness, including lichens and mosses, since those resistant to high levels of air pollution are more advantaged (Bignal et al., 2007). Data on air pollutant concentration can be derived from EMEP and CAMS products at 0.1°, which could be later downscaled to 1x1 km resolution using ground-monitoring station data provided in the annual air quality statistics repository of the European Environment Agency. The air quality database contains validated air quality monitoring information for more than 30 participating countries throughout Europe. Every year countries report air quality measurements for a set of pollutants at a representative selection. Data are validated, sources are reputable and provide reliable data continuously updated over time. The monitoring of air pollution at 1 km resolution provides spatially accurate data to be used consistently at EU level.
Soil organic carbon stock	Soil organic carbon, among other processes, influences soil structure and availability of energy and matter for soil microorganisms and macroinvertebrates, as well as organic bound nutrients in the soil (Billings et al., 2021). It indirectly influences net productivity of land plants since they are dependent on the presence of nutrients, macroinvertebrates and soil microorganisms that through a cascade of processes make nutrients bioavailable for plants and mobilise those along the soil profile. In addition, soils with higher levels of organic carbon provide increased resilience to extremes of weather (i.e. droughts, floods). Consequently, soil organic carbon has a relevant role in the functioning of terrestrial ecosystems, including urban ecosystems, and the derived ecosystem services. In this context, it is well understood that soils with low organic carbon stocks struggle to provide a balance of ecosystem services. Currently, in the case of urban ecosystems there is a gap regarding soil data, since monitoring schemes are not systematically developed, while remote sensing products do not have the necessary spatial resolution or spectral characteristics to capture soil condition. Moreover, biogeochemical models on soil organic flows (e.g. RothC) are being developed to inform the dynamics of other ecosystems but are difficult to be used for policy purposes since results are difficult to be validated due to the use of theoretical carbon pools instead of real monitorable pools. Finally, soil carbon stocks are expressed for a reference depth of soil. IPCC Guidelines measure carbon stocks to a default depth of 30 cm.
Heavy metals in soils (As, Cd, Cr, Cu, Hg, Pb, Mn, Sb, Co, Ni, Zn)	While low levels of heavy metals are required in the form of micro-nutrients for good ecosystem functioning, high levels are of concern. Heavy metals cannot be easily degraded and are sometimes difficult to be stabilised or to be modified to reduce the associated risks. Moreover, heavy metals tend to bio-accumulate in many trophic chains, with a long-term risk for the local biota and humans (Briffa et al., 2020). In the case of urban ecosystems, heavy metals are of special concern because they are a consequence of past and present commercial and industrial activities and transport. Currently, as explained in soil organic carbon for urban ecosystems there is a gap regarding soil data.
Autochthonous woody vegetation species (or functional trait) richness:	It represents the amount of native tree or shrub species (or their functional traits) present in an area. Species (or trait) richness is positively correlated to ecosystem health and function (Tilman, 1997). Higher levels of species richness are linked to higher ecosystem stability and resilience. EU-Forest Dataset (JRC) and local urban tree inventories are suitable sources of information on the amount and distribution of native tree species. It is necessary to carefully evaluate the spatial resolution of the analysis, as the relation between richness and ecosystem function is scale dependent.
Urban bird species richness	Presence of specific species of birds and their richness has already been used as a variable informing about good ecological condition of urban areas (Morelli et al., 2021). In this sense, a condition variable measuring urban bird species richness among a predefined set in European urban areas might be useful to inform on

Condition Variable	Description and justification
	ecological condition for animal biodiversity in a broad sense. Additionally, there are already pilot studies relating species richness in urban areas to positive effects on human mental health (Methorst et al., 2021). Beyond species richness, other indicators are currently being tested in pilot studies for urban areas to provide biodiversity indicators more robustly related to the condition of ecosystems (Zulian et al., 2022b).
Pressure by invasive alien species on urban ecosystems	The pressure by IAS on ecosystems has a potential negative effect on their condition due to the increased threat (Pyšek et al., 2020). Pressure by IAS can be measured as the cumulative pressure exerted by IAS based on the sum of their occurrence in an area, weighted by the extent of the ecosystem(s) potentially affected. This cumulative pressure indicator was developed for the EU ecosystem assessment (Maes et al., 2020a) using species records from the baseline distribution of IAS of Union concern available on the European Invasive Species Information Network (https://easin.jrc.ec.europa.eu/easin/Documentation/Baseline). It will be possible to infer trends in relation to the baseline of IAS when the EU MS second reporting under the IAS Regulation becomes available in 2025.
Greenness - annual max NDVI	Greenness is defined as the amount of vegetation present in urbanised areas. This variable has been used to identify urban green spaces and changes in vegetation cover (Zulian et al., 2022a). Specifically, change in vegetation cover is used as 'structural ecosystem attribute' to analyse urban ecosystem condition. Gradual and abrupt changes in greenness are used as a proxy of an improvement or worsening of the amount of vegetation cover in urban areas. In particular, based on the direction and intensity of the change, it is possible to discriminate between gradual changes, likely due to vegetation growth, land degradation, or drought as well as other factors, and abrupt changes, usually induced by land use change or shifts in urban green space management, as well as extreme events such as fires or climatic conditions. Greenness is estimated calculating the highest value of NDVI of the year, therefore is always indicative of the maximum vegetation growth (influenced by intra-annual phenological variations).
Tree canopy cover	'Urban tree canopy cover' means the total area of trees in an urban area, calculated based on the Tree Cover Density data, as provided for by the Copernicus Land Monitoring Service, representing the 'vertical projection of tree crowns to a horizontal earth's surface. Trees and other woody plants along streets and in public squares and car parks as well as private gardens contribute to biodiversity and provide habitat for wildlife and supporting pollination. The link between the abundance of tree canopy cover and several ecosystem services (such as air temperature mitigation, runoff prevention and air quality regulation) is well established in literature. An increase in tree canopy cover is indicative of an improvement of ecosystem condition, whereas a decrease can be indicative of ecosystem degradation (for natural or anthropogenic causes). High quality Copernicus satellite data is already available going back to 2000 and will be available every three years at high-resolution scale at 10m² level of detail. This data can very easily be set over urban areas and it is available online.
Green spaces per total urban area and/or green spaces per inhabitant (Modified with respect to the EU-	'Urban green space' is the proportion of existing green infrastructure in an urban area. Specifically, Urban green spaces correspond to any piece of urban land covered with mosses and lichens, herbs, shrubs, or trees, which do not correspond to commercial arable land. Urban green spaces can be of public, semi-private, or private ownership and be present in land of different built-up character (e.g. ground open space, building rooftop, building façade). Urban green spaces can generate a substantial range of social, environmental and economic benefits for urban citizens, whilst also providing protection against the effects of climate change. As urban green spaces are the basic building blocks of urban ecosystems, measuring and

Condition Variable	Description and justification
wide Methodology)	monitoring variations in % of the total urban area represents the fundamental variable of urban ecosystem condition.
Semi-natural and natural riparian land cover	Riparian zones are transitional environments (ecotones) that provide a wide range of services and functions, such as air and water filtration, flood control and habitat maintenance. Riparian zones are key components of the green-blue infrastructure, and exert an essential role in sustaining biodiversity and ecosystem integrity, as well as in minimizing pressures (Clerici et al., 2014). Nevertheless, riparian zones are also highly vulnerable and susceptible to anthropic pressure and are easily degraded, involving alterations in the hydrologic regimes and species composition. Due to the multitude of benefits that semi-natural and natural riparian land covers deliver to humans and the urban ecosystem as a whole, and their linkage with overall ecosystem health, their presence can be considered as directly correlated with urban ecosystem condition.
Plant evapotranspiration	It is the amount of water evaporated from the soil and vegetation in a given amount of time. It is a proxy of water status and reflects vegetation physiological status. In case of vegetation stress, the rate of gas exchange between the plant and the atmosphere usually decreases as a result of a reduction of water availability or an impairment of photosynthetic rate, or as a change in climatic and environmental conditions (Fusaro et al., 2015). It can be derived from models such as the PML_V2 Penman Monteith Leuning model (Zhang et al., 2019), available at 500 m spatial resolution every 8 days. However, it is uncertain how often it will be updated in the upcoming years.
Integrity (coherence) of the green network	Integrity is defined as the degree of connectedness of all green spaces in a given space and time, and it can be regarded as an additional metric to measure ecosystem connectivity, whose relationship with condition is well established (Correa Ayram et al., 2016). It describes the status of a given network of green spacs. The increase in integrity is a measure of the success of a restoration scenario (i.e. increase in size, consistency, and number of green spaces patches). An increase in integrity is indicative of an increase in condition (higher coherence, connectivity), whereas a decrease will be indicative of a worse condition (fragmentation, deterioration). The quantitative variable values and their change (before/after) are also usually applied to serve compelling arguments to define and defend the most cost-efficient restoration scenarios. Moreover, it is critical to quantify temporal progress towards policy goals and the final overall success of a restoration project. Integrity is calculated using urban green spaces as input data.
Fragmentation of the green network at Fixed Observation Scale	Landscape fragmentation is usually defined as the splitting of a habitat or ecosystem asset into smaller pieces. In landscape ecology, it is commonly accepted that landscape fragmentation can be assimilated to the inverse of structural connectivity, i.e., the degree to which a landscape mosaic does or does not facilitate the movement of species among patches. In this case, it is also assumed that fragmentation represents the inverse of structural connectivity. With Frag-FOS the level of structural connectivity of the network of natural and semi-natural vegetation patches (e.g. linear features, small woody patches and large forested areas) in urban areas can be measured. Since fragmentation/connectivity depends on the scale- of observation, a suitable, fixed observation scale must be chosen to capture and quantify the degree of connectivity. Consequently, the analysis scheme FOS (Fragmentation at Fixed Observation Scale), measuring fragmentation in five categories from highly fragmented to little fragmented is proposed. Fragmentation values can be measured at the patch level. The methodology is based on geometric principles only; as such, it can be applied to any natural and semi-natural vegetation

Condition Variable	Description and justification
	raster maps, independent of spatial resolution. In contrast to many existing fragmentation schemes, the outlined methodology provides a normalised index quantifying fragmentation within the range of 0-100 %. This metric can be measured via the freeware Guidos Toolbox (Vogt et al., 2022).
Riparian fragmentation	As previously described for the 'semi-natural and natural riparian land cover' variable, riparian zones exert key function and provide essential services. However, not only their presence and abundance are indicative of good ecosystem condition, but also their connectivity. High levels of lateral and longitudinal semi-natural and natural riparian land covers regulate the changes in matter, energy and biota (Fernandes et al., 2016). Euclidean Nearest Neighbour of semi-natural and natural riparian land covers informs about the distance to the nearest patch of the same land cover class or group of them (Babí Almenar et al., 2019). This variable will help to monitor changes in the structural connectivity of the semi-natural and natural riparian land covers in a simple and cost-efficient form. In terms of input data, the same sources of the variable 'semi-natural and natural riparian land cover' can be used, from where distances between patches can be calculated.
Patch richness or Shannon Diversity Index (SHDI) of land cover types	Natural and semi-natural land cover richness (heterogeneity) and its proportion (amount) in the total extent of an ecosystem accounting area inform about the capacity of a system to contribute to species richness and their abundance (Silva et al., 2015). It is also expected that higher levels of natural and semi-natural land cover diversity would contribute to maintain a more diverse set of ecological processes and functions and therefore a more diverse set of derived ecosystem services. Moreover, high levels of land cover richness or diversity are associated with a general positive human (visual) perception of the surrounding landscape (independently of cultural legacy) and might contribute to the supply of cultural services such as outdoor recreation activities. The above attributes together with the easiness to measure diversity (SHDI) or richness of land cover and communicate it to policy makers made this variable suitable to monitor landscape characteristics contributing to urban ecosystem condition. In terms of resolution, there is available spatial data generated by reputable sources (Copernicus Land Project) at an adequate temporal (every 6 years) and spatial resolution (100 to 10 m) for the entire EU.

Source: Modified from EU-wide Methodology (Vallecillo et al., 2022)

Table III.2: Core land cover components present in any type of urban green space. These land cover components can be located in any ecosystem type present in an urban ecosystem.

Component	Definition	Urban Green Spaces in which can be present*
High-growing woody plants (trees)	Perennial woody plants with single or multiple self-supporting stems, smaller branches and shoots growing to a considerable height (usually above 5 meters). It can be evergreen or deciduous with needle leaf, broadleaf or palm leaf.	Forests, transitional woodlands/scrubland, parks, gardens (public or private), urban farm/horticultural land (sparsely), tree-lined streets, tree streets, urban meadows or grasslands (sparsely), sparsely vegetated areas, green roofs (intensive), raingardens (sparsely).
Low-growing woody plants (shrubs, bushes)	Perennial woody plants with multiple stems arising at or near the base, which usually grows to a height below 5 meters. It can be evergreen or deciduous with needle leaf, broadleaf or palm leaf.	Forests, transitional woodlands/scrubland, parks (independent of its size), gardens (public or private), urban farm/horticultural land (sparsely), urban hedges, urban meadows or grasslands (sparsely), sparsely vegetated areas, green roofs

		(intensive or semi-intensive), raingardens.
Permanent herbaceous	Non-woody vegetation cover persistent over the year (i.e., no bare soil occurs in any seasons). Its attributes might change over the year. It can have different types of management (e.g., unmanaged, intensively managed).	Forests, transitional woodlands/scrubland, parks (independent of its size), gardens (public or private), urban farm/horticultural land, urban hedges, urban meadows or grasslands, sparsely vegetated areas, green roofs (extensive, semi-intensive, intensive), green walls, raingardens, swales, constructed or natural wetlands.
Non-permanent (periodical) herbaceous	Non-woody vegetation cover that is not persistent over the year (i.e., bare soil occurs in one or more seasons). Its attributes might change over the year. It can have different types of management (e.g., unmanaged, intensively managed).	Forests, transitional woodlands/scrubland, parks (independent of its size), gardens (public or private), urban farm/horticultural land, urban hedges, seasonal meadows, wet grasslands, sparsely vegetated areas, green roofs (extensive, semi-intensive, intensive), green walls, raingardens, swales, retention ponds, constructed or natural wetlands.
Permanent non-vascular plants (mosses and lichens)	Persistent non-vascular vegetation cover over the year, i.e., composed of mosses and lichens). It is rarely present in urban ecosystems, but it might occur in LAUs in northern Europe and in artificial urban green spaces such as green roofs (moss roofs).	Forests, transitional woodlands/scrubland, parks (independent of its size), gardens (public or private), sparsely vegetated areas, green roofs (moss roofs), green walls.

* In some cases, components might appear in a sparse form (e.g., trees in grassland). Not always core land cover components are present in the types of urban greens spaces in which they can be present.

Source: JRC own elaboration

Table III.3: Descriptive list of common types of urban green space present in European urban ecosystems. The list is based on the urban green space classifications and descriptions included in Babí Almenar et al. (2021), Castellar et al. (2021) and FAO (2016). The urban green space types represented have been also identified in the H2020 projects Nature4Cities, UnaLab, UrbanGreenUp and ThinkNature.

Types	Description	Alternative names
Green Roofs	A vegetated area that is implemented on the rooftop of buildings. They are usually classified as extensive, semi-intensive and intensive based on the depth of its substrate and weight. <u>Common land cover components per sub-type:</u> • Extensive: Mosses, permanent herbaceous and non-permanent herbaceous. • Semi-intensive: Permanent herbaceous, non-permanent herbaceous, low-growing woody plants (shrubs) • Intensive: Permanent herbaceous, non-permanent herbaceous, low-growing woody plants (shrubs), high-growing woody plants (trees)	Intensive/semi-intensive green roof; Roof garden; Roof park; Public Intensive Green Roof; Social Intensive Green Roof; Vegetated roof; Living roof; Smart roof; Biodiversity roof; Eco systemic roof; Constructed wet roof; Green covering shelters; living roof; vegetated roof; moss roof

Types	Description	Alternative names
Green facades & green walls	A vertical vegetated area composed of climbing plants growing along a wall (in building facade or other types of walls). The wall can be covered partially or completely with vegetation. The vegetation can be planted onto different structures (e.g., ground, containers, the wall itself) and depend on multiple types of supporting structures (e.g., vertical panels, trellis). <u>Common land cover components:</u> Mosses, permanent herbaceous and non-permanent herbaceous.	Climber green wall; Ground-based green-wall; Green climber wall; Green wall with ground-based greening; Climber plant wall; Ground-Based Green Facade with Climbing Plants; Soil-based green façade; Hydroponic green facade; Facade-bound greening; Facade bound green wall; Living wall; Continuous green wall; Plant wall system; Green façade with vertical panels; Greening vertical panel; Vertical greening panel; Wall-based green facade
Raingardens	A small-vegetated area placed in a shallow depression designed to collect, filter, store, and infiltrate urban stormwater runoff. The soil usually includes layers of sandy soil to facilitate infiltration and mulch to promote microbial activity. <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous, shrubs and (sparse) high-growing woody plants (trees)	Infiltration garden; Rainfall garden; Water control garden, Floodable garden, Bioretention filter, Bioretention area, Bioremediation wet retention. Bioretention facility
Swales	An open vegetated channel designed for treatment and conveyance of stormwater runoff. It might be lined or unlined and it usually has banks with a gentle slope. <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous	Grassed swale; Green drainage corridor; Vegetative filter; Vegetated Bioswale; Bioswale
Floating wetlands	Small artificial floating platforms vegetated with aquatic emergent plants, which are usually placed in urban river stretches or other waterbodies. The platforms can be aggregated forming larger structures. <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous	-
Wetlands-Constructed, natural and naturalized	A permanently or intermittently wet areas, shallow water, and land water margins that are vegetated which can be of natural, naturalized or constructed. Constructed wetlands are human-made wetlands used to depurate waste water and stormwater. Naturalized wetlands are human-made wetlands that mimic the structure and process of natural ones, whose main scope is not water depuration. <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous	Planted horizontal/vertical filter Helophyte filter; Root-zone Wastewater Treatment; Natural wastewater treatment; Treatment wetlands; Artificial Wetland; Subsurface constructed wetland; Planted sand/soil filters;
Community gardens & orchards	A permanent or seasonal public urban vegetated area dedicated to the cultivation of vegetables, fruits and flowers. It can be private, public or semi-public. <u>Common land cover components per sub-type:</u> • Orchards: High-growing woody plants (trees), low-growing woody plants (shrubs) • Gardens: Permanent herbaceous and non-	Community garden, allotment(s); community allotment(s); urban allotment; Urban garden/gardening; Urban agriculture; Urban farm; Multi cultivated gardens; Edible city solution; Semi- subsistence garden; Food growing area; Community Growing Spaces; Community orchard; Community urban orchard;

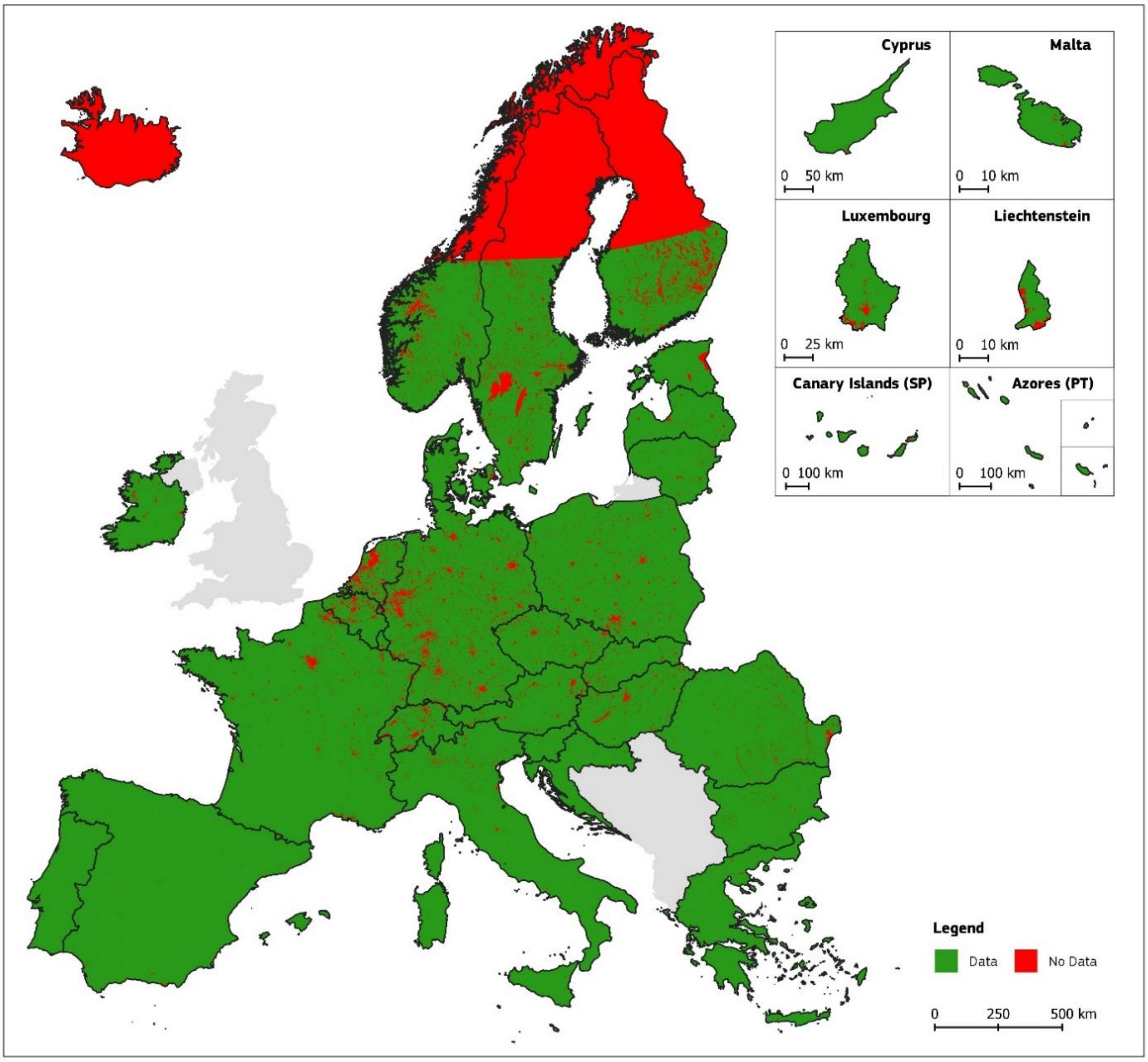
Types	Description	Alternative names
	permanent herbaceous	Allotment orchard; Food forest
Urban (peri-urban) forests and woodlands	Forests and woodlands in (and surrounding) towns and cities that can provide goods and services such as wood, fibre, fruit, other non-wood forest products, clean water, recreation and tourism <u>Common land cover components:</u> High-growing woody plants (trees), low-growing woody plants (shrubs). It can include as low-vegetation layer permanent herbaceous and non-permanent herbaceous.	Group of trees; Wood; Urban woodland; Arboreal areas around urban areas; Arboreal urban parks; Arboretum;
Transitional urban (peri-urban) woodlands	A vegetated area formed by herbaceous, scrublands and occasional scattered trees. It can represent a young forest development or form the edge of forested areas. <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs), (sparse) high-growing woody plants (trees).	-
Urban parks	Publicly accessible large vegetated areas (>0.5 ha) within a city with a variety of land cover and at least partly equipped with facilities for leisure and recreation (FAO 2016). <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs), high-growing woody plants (trees).	Large urban park; Urban park; Public park; Park; Green Park; Residential Park; Greened recreation areas/regional parks; Green resting areas; City park
Pocket parks	Publicly accessible small vegetated areas (<0.5 ha) within a city equipped and at least partly equipped with facilities for recreation/ leisure, (FAO 2016). <u>Common land cover components:</u> Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs), high-growing woody plants (trees).	Small Park; Neighbourhood park; Landscape park; Empowerment Park; Pocket parks (FAO, 2016)
Lined urban trees	A linear vegetated area where trees are the dominant land cover, which is usually placed in (or adjacent to) a public square, thoroughfare, street, road or similar. In some cases, they can form part of other urban spaces such as vacant lands, cemeteries, sport areas, biodiversity agricultural land. It can include other land cover components as understory. It can be single-lined (in one side of the street) or double-lined (both sides of the street. <u>Common land cover components:</u> High-growing woody plants (trees)	Tree-lined streets, boulevard, alleys.
Individual urban trees	Small vegetated area formed by an individual tree as dominant land cover, which is usually placed in (or adjacent to) a public square, thoroughfare, street, road or similar. In some cases, they can form part of other urban spaces such as vacant lands, cemeteries, sport areas, high biodiverse agricultural land. The tree is not close enough to others to form a group or a tree-lined street. <u>Common land cover components:</u> High-growing woody plants (trees)	Street trees

Types	Description	Alternative names
Urban and (peri-urban) Grassland & Meadow	An open and continuous vegetated area formed by herbaceous plants, in (and surrounding) towns and cities. It can be of different sizes and might be present inside other green spaces or informal urban spaces such as vacant lands or peri-urban agricultural areas. In some cases, it can be used as filter strips in the adjacency of waterbodies. Urban meadow usually suggest presence of wildflowers, more species diversity and non-intensive managements. Common land cover components: Permanent herbaceous and non-permanent herbaceous,	-
Wet Meadow	A shallow impound vegetated area that temporarily detains water, or it is below the phreatic level, remaining periodically or seasonally saturated with water. Common land cover components: Permanent herbaceous and non-permanent herbaceous	-
Urban (peri-urban) moors & Heathland	A vegetated area formed by low and closed cover dominated by bushes, shrubs, dwarfs shrubs and herbaceous plants. It can be of different sizes and might be present inside other green spaces or informal urban spaces such as vacant lands. Common land cover components: Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs),	-
Private gardens	A vegetated area of private ownership adjacent to private houses/buildings of residential or corporative character. The land can be privately owned or rented. The plants are cultivated mainly for ornamental purposes or personal food production. Common land cover components: permanent herbaceous, non-permanent herbaceous,	Residential garden; House garden
Public gardens	A vegetated area of public ownership adjacent to schools or other public buildings Common land cover components: Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs), and (sparse) high-growing woody plants (trees).	-
Heritage gardens	A vegetated area of historical character and importance that preserve outstanding social, cultural, aesthetic or scientific values. Common land cover components: Permanent herbaceous and non-permanent herbaceous, low-growing woody plants (shrubs), and (sparse) high-growing woody plants (trees).	Heritage park/garden; Historical park/garden
Other urban green spaces	Any vegetated area in (and surrounding) towns and cities, which does not fit any of the previous types of urban green spaces and it does not correspond to commercial arable land. It should be formed of at least one of the core land components described in Table 1.	-

Source: JRC own elaboration

Annex IV. Supplementary Material of Chapter 5

Figure IV.1. Visualisation of monthly LAI data gaps present in December 2018 to illustrate the two main types of LAI data gaps (winter and urban gaps) in EU-27 and EFTA countries. The LAI data gaps presented are those that remain after mosaicking data from MODIS (MCD15A3H Version 6.1) and Global Copernicus datasets.



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