Carbon-smart Urban Green Handbook

CO-CARBON

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Co-Carbon researchers in Nordhavn, Copenhagen. At the foot of Thomas Danbo's sculpture. PHOTO: CLAUS BEIER

Preface

This is Carbon-smart Urban Green Handbook. It is intended for experts, decision-makers, and anyone interested in **how natural carbon sinks can be maintained and increased in urban areas**. Achieving carbon neutrality targets in cities requires reducing emissions, but it also requires increasing carbon sinks. One essential means is to increase natural carbon sinks in urban green, i.e., urban forests, built parks, street plantings, and courtyards. Investing in sinks also has other benefits: it mitigates heat waves and urban flooding and increases well-being and biodiversity. It is therefore worthwhile to maintain and build carbon sinks.

So why do we need a handbook for carbon-smartness? We believe that the potential of urban green as a carbon sink and a cost-effective, multi-beneficial climate solution must be utilised more effectively than has been done so far. In the multi-year CO-CARBON project, we have studied the climate benefits of urban green and proposed **carbon-smartness** as a solution. Carbon-smartness refers to ways to improve the carbon sequestration of green structure, secure carbon sinks in urban development, and develop low-emission construction and maintenance methods – while also providing other vital ecosystem services. We have summarised our key recommendations and core messages that we want to convey in this handbook.

The handbook is divided into five chapters, each highlighting a distinct perspective on carbon-smart urban green. The first chapter forms the starting point for carbon sinks, which are influenced by both natural processes and human activity. The second chapter summarises the key principles of carbon-smartness. The third chapter presents various carbon-smart urban green solutions. The fourth chapter highlights methods that can be used to study carbon-smartness. The fifth chapter delves into how carbon-smartness can be put into practice through education and training.

The main message of the handbook is to bring urban green more strongly into climate goals and their implementation. It shows that carbon-smartness arises equally from large strategic policies and small everyday actions. Carbon-smartness can be achieved in your own backyard as well as at the table of political decision-makers. The handbook emphasises that carbon-smartness is achieved through cooperation among many actors. We invite everyone to join us in contributing to carbon-smart urban green!

CO-CARBON is a multidisciplinary research project that has quantified and modelled the carbon sequestration capacity of urban green and developed solutions for implementing carbon-smart urban green. The project has combined atmospheric and soil sciences, social sciences, and landscape architecture. Participants included University of Helsinki, Aalto University, Finnish Meteorological Institute, Häme University of Applied Sciences, and University of Copenhagen, and a wide range of partners: cities, companies, expert organisations, and residents – a warm thank you to all of you! The project (2020–2026) has been funded by the Strategic Research Council (SRC) operating in connection with the Research Council of Finland and its Climate Change and Humans research programme (CLIMATE).

PHOTO: RANJA HAUTAMÄKI

1 Basis

Urban green spaces are important multi-functional carbon sinks

The carbon cycle describes the flow of carbon in ecosystems, where plants absorb atmospheric carbon dioxide (CO_2) through photosynthesis, store it in their biomass, and release it back into the atmosphere through cell respiration and soil processes. Some of the carbon is released back quickly, but some is stored long-term in plant parts and soil. If photosynthesis and carbon sequestration exceed the amount of carbon released, a carbon sink is formed.

Urban green is a diverse carbon sink that can sequester part of the CO_2 emitted from cities. It has been estimated that urban nature can sequester 2–7% of cities' fossil fuel emissions, but the amount depends on total anthropogenic emissions and the quantity and quality of vegetation (Hardiman et al. 2017, Havu et al. 2024). **In addition to forests, other types of urban vegetation, such as built parks, gardens, and street plantings, are also important.** Urban carbon sinks have typically been thought to be in urban forests, but our recent research findings also highlight the importance of other green spaces as carbon sinks (Havu et al. 2024). Urban forests may have larger carbon sinks per unit area than other types of vegetation, but their area within cities is often quite small. In Helsinki, for example, it is estimated that about half of the carbon sinks are located in built-up areas and half in forests and other natural green areas.

The carbon sink potential of urban green is particularly influenced by the number of trees and the quality of the soil. Trees have higher biomass than other types of vegetation and can store carbon in their wood. Preserving and planting trees are, therefore, key means of supporting carbon sinks. In addition to vegetation, soil is also a significant carbon store (Järvi et al. 2024). However, the quality of the soil has a significant impact on its carbon storage capacity. Carbon-rich growing medium, i.e., medium containing easily decomposable organic matter, quickly releases carbon dioxide into the atmosphere (Havu et al. 2022), which may take years for vegetation to absorb back. This highlights the importance of preserving existing soil and using low-emission growing media in green construction.

The carbon sinks of urban green have multiple benefits. In addition to carbon sequestration, vegetation mitigates heat and urban flooding, supports human well-being, and provides habitats for many other species. Areas with significant carbon stocks are often also important for biodiversity. A good example of this is Helsinki's green fingers – radial green zones that, according to our research, particularly support both carbon sequestration and biodiversity (Raymond et al. 2023). There are also numerous ways to support multiple benefits in the built environment. In addition to climate benefits and biodiversity, social values associated with urban green play an essential role (Lampinen et al. 2024).

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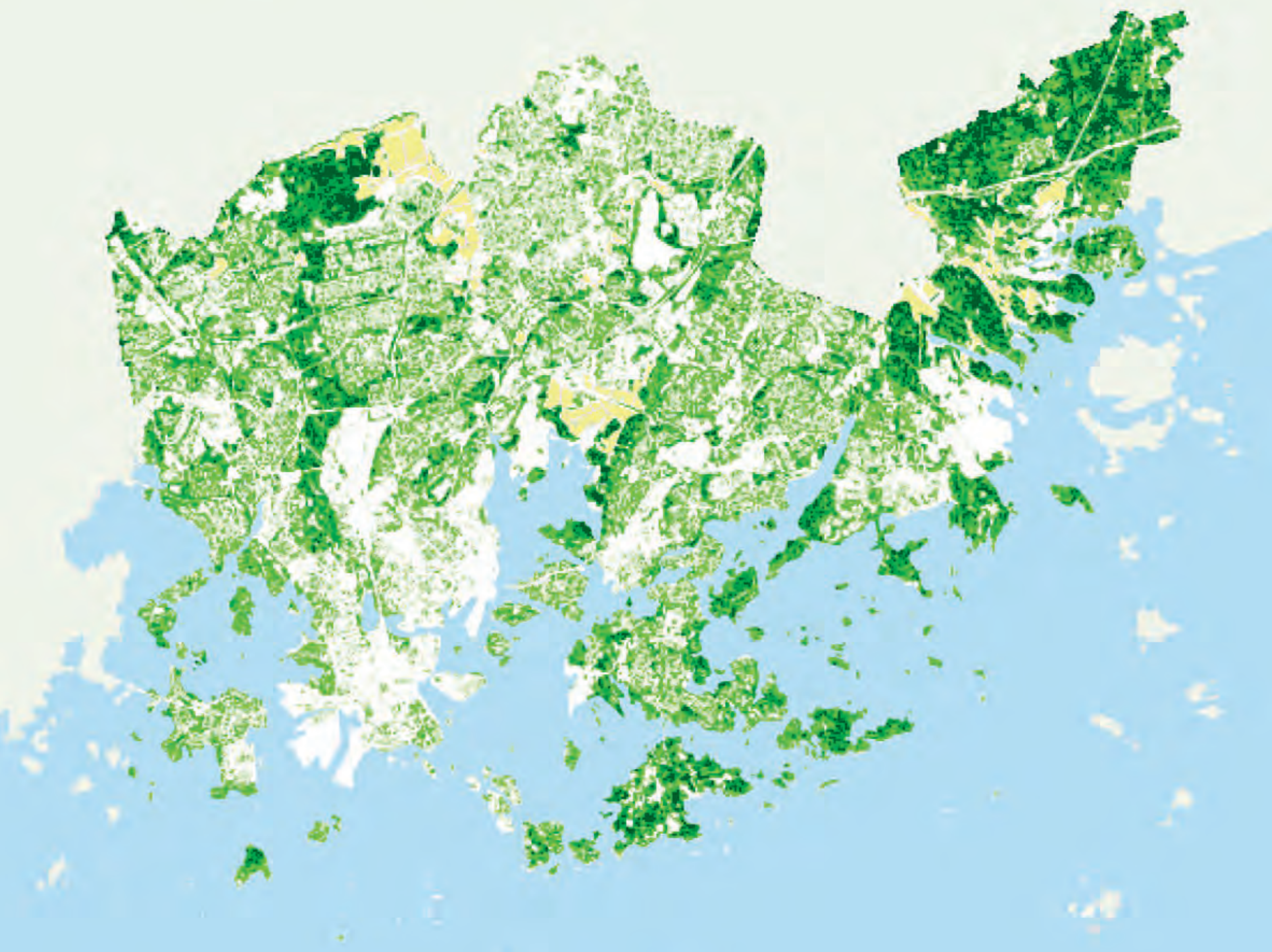
▸ Annual variation of carbon sinks in Helsinki. The darker the green, the larger the sink. The map clearly shows Helsinki's green fingers and sparsely built-up areas, such as Östersundom.
(FIGURE: VEERA VASENKARI AND LEIF BACKMAN)



Key messages:

- Built green spaces can act as effective carbon sinks alongside forests. The carbon sink potential is particularly influenced by the amount of tree cover and soil quality.
- Urban nature is a multi-beneficial carbon sink that also provides other ecosystem services and supports biodiversity.
- The social justice perspective on urban green emphasises that everyone should have equal access to the benefits provided by green spaces.

Carbon–smartness can be promoted at many levels of decision–making

The built environment offers significant opportunities to enhance carbon cycling and storage in vegetation. Carbon sequestration begins in the stomata of leaves, where plants absorb carbon dioxide for photosynthesis and regulate water evaporation. Thus, the carbon cycle links directly to water management decisions and the choices made during the construction and maintenance phases. In the urban context, human action ensures the effective performance of these processes across the lifespan of plants. When growing sites are carefully planned, and sufficient space is reserved for both above-ground canopy and underground root systems, vegetation thrives and sequesters carbon effectively. The key objective is to support plant growth and longevity by optimising soil quality and preventing biotic stress, creating conditions for continuous carbon sequestration.

Carbon-smartness can be promoted at multiple decision-making levels and by various actors, from urban planning and design to commissioning, supervision, construction, and maintenance. Decision-makers and practitioners involved in urban landscape management operate within municipal organisations and companies of various sizes. Many of us also contribute on a personal level, implementing carbon-smart urban green in our own gardens or in the shared yards of housing companies.

Carbon-smart urban green is the result of human choices in planning, construction, and maintenance. The planning stage determines how much space is allocated to green and how much of the existing vegetation is preserved. Construction defines growing conditions through soil quality and water management. Maintenance influences plant growth and the effectiveness of carbon sequestration over decades.

Although vegetation and soil carbon sinks are minor compared to construction-related emissions, they are the only natural carbon sinks that can be actively maintained and created through planning and construction. This opportunity can be utilised more effectively than is currently the case (Hautamäki et al. 2025). The aim is not to offset construction emissions through carbon sinks created by landscape construction, but rather to preserve the existing carbon stocks and sinks as far as possible, create new carbon sinks whenever possible and minimise emissions from landscape construction itself. Strengthening carbon sequestration also has other benefits, such as promoting climate adaptation and biodiversity (Ariluoma et al. 2024, Leppänen et al. 2024).

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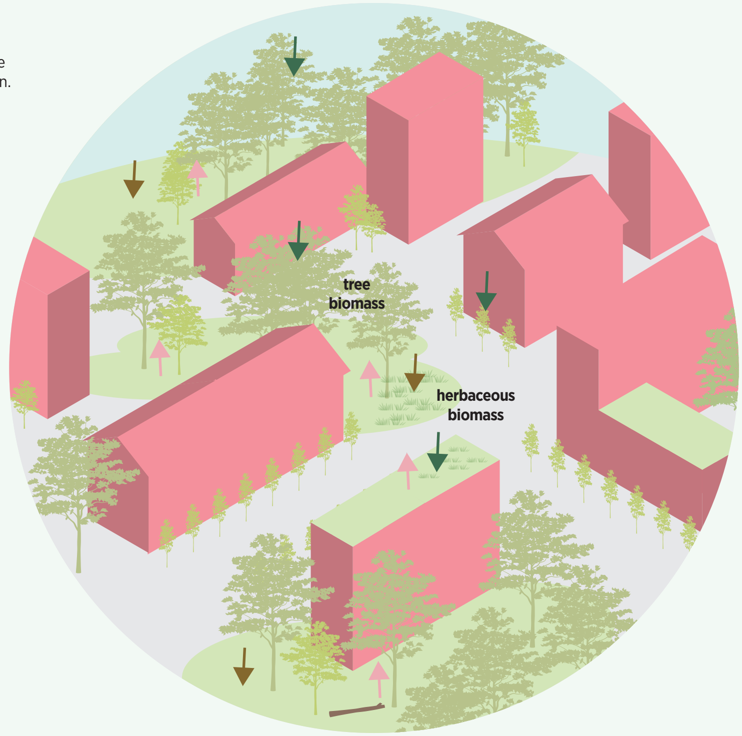
Key messages

- The success of vegetation and the carbon cycle can be influenced at many levels, from ensuring good growing conditions and water balance in home gardens to strategic urban land-use planning.
- Carbon-smart planning creates conditions for thriving urban green, preserves existing vegetation, and allocates sufficient space for new plantings.
- Landscape construction lays the foundation for carbon-smart vegetation by selecting a low-carbon growing medium that supports plant growth, and by ensuring adequate water supply at the growing site.
- During the maintenance phase, carbon-smart practices involve providing long-term support for plant growth and enhancing carbon storage in both biomass and soil.

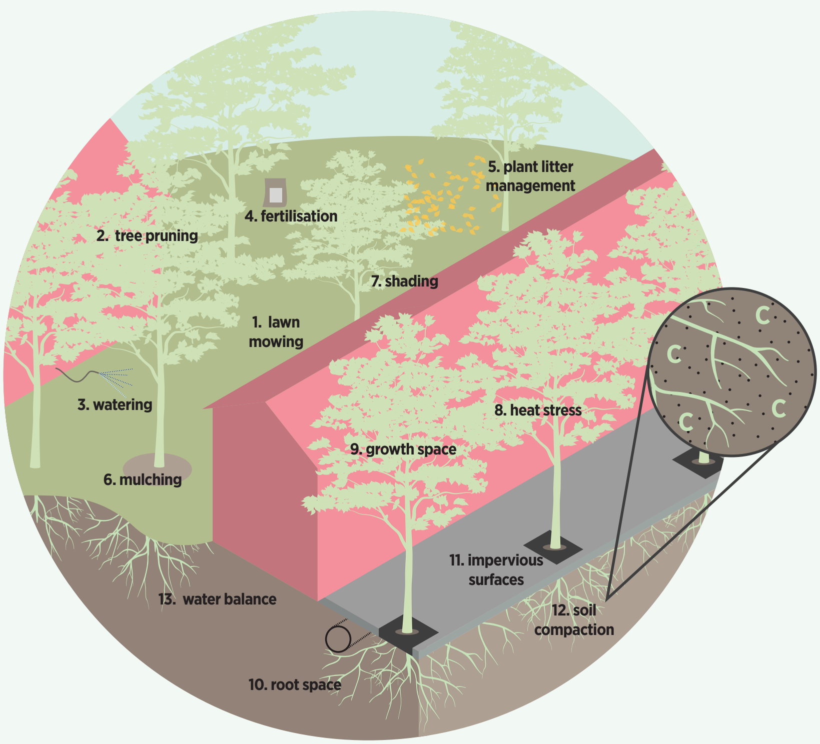
Carbon sequestration
Vegetation absorbs atmospheric carbon dioxide through photosynthesis, forming organic carbon. The higher the growth, the more carbon is sequestered.

Carbon accumulation in soil
As roots, leaves, and other organic litter decompose, part of them end up in the soil. Decomposers and microbes convert the litter into humus and organic carbon compounds, which gradually build up the soil's carbon stock.

Respiration is a process through which vegetation and soil organisms breathe and release carbon dioxide back into the atmosphere.



The carbon cycle in the built environment is influenced by both the characteristics of the construction site and the design, construction, and maintenance of urban green. (FIGURE: MARI ARILUOMA AND LOTTA LIPSANEN)



MAINTENANCE

1. Lawn moving
causes emissions, but on the other hand, also stimulates root growth and thus accumulation of soil carbon.

2. Tree pruning
removes tree trunk carbon, but also promotes healthy tree growth.

3. Watering
improves growth and biomass production but may also cause emissions.

4. Fertilization
can boost biomass production, but the production and transport of fertilizers cause emissions.

5. Plant litter management
The management of plant litter, such as leaves, is crucial for the carbon cycle and the accumulation of soil carbon.

6. Mulching
can improve growing conditions, but thick layers of mulch release carbon into the atmosphere.

GROWING CONDITIONS

7. Shading
Heavy shading caused by buildings reduces photosynthesis and carbon sequestration, as well as microbial activity in the soil.

8. Heat stress
The heat causes water shortages and heat stress in vegetation. On the other hand, the growing season may be extended.

9. Growth space
Lack of space is often a significant factor limiting the growth of large trees in particular.

10. Root space
The root system competes for space with various structures and infrastructure.

11. Impervious surfaces
hinder the natural carbon cycle in the soil and impair growing conditions.

12. Soil compaction
caused by factors such as vehicle traffic impairs root growth and reduces soil aeration and microbial activity.

13. Water balance
There is often either too little or too much water, both of which affect growth and carbon sequestration.

PHOTO: JOUNI MULTIMÄKI

2 Principles

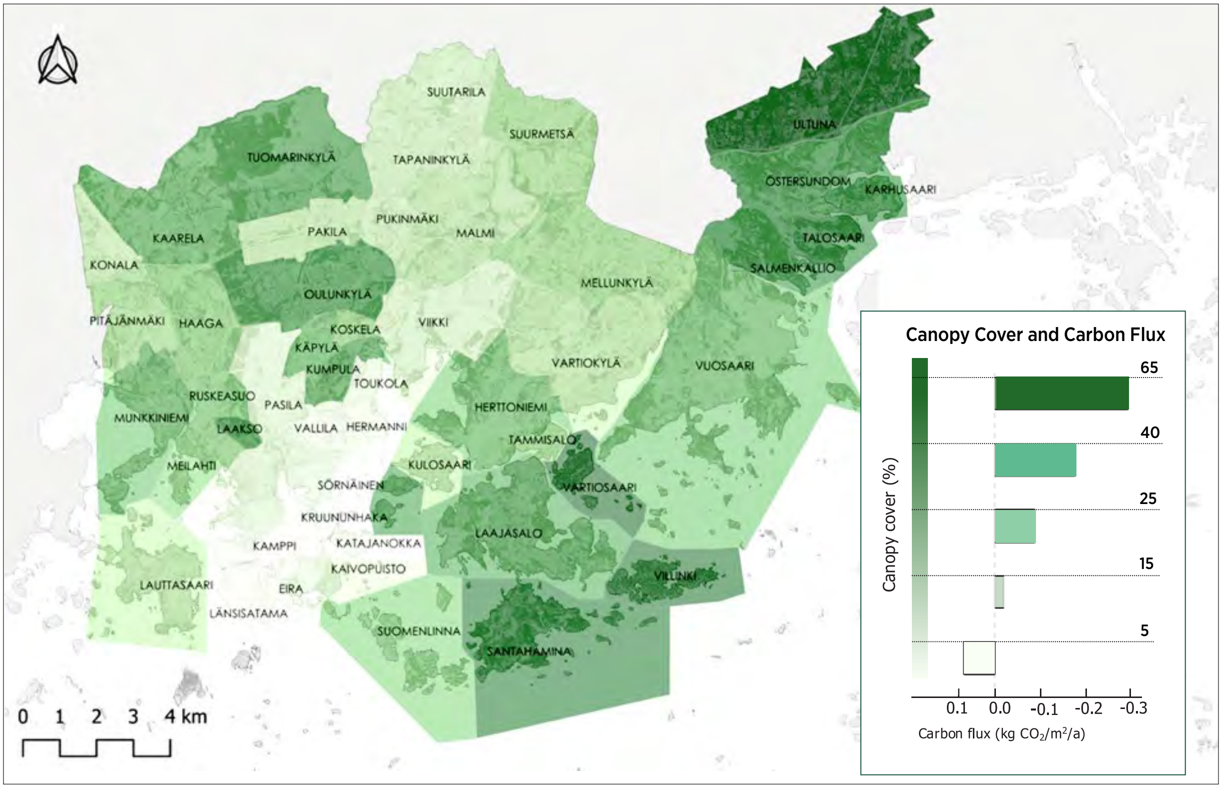
Preserve existing carbon stocks and sinks

Preserving existing vegetation and soil is the primary means of urban planning to secure carbon sinks and storage. Land use planning should preserve and strengthen existing green spaces, especially natural areas that are significant carbon storages and often have other benefits as well. Existing trees and soil should be preserved, for example, during the construction phase of plots or the renovation of streets. Existing urban green is always more valuable than new green, as it takes decades for new vegetation and soil to accumulate carbon stocks. (Hautamäki et al. 2023)

Protecting old street trees at construction sites extends their life cycle and preserves their carbon stores. (PHOTO: RANJA HAUTAMÄKI)

The ability of urban green to mitigate climate change and the problems it causes is directly dependent on the amount of vegetation cover and its ability to store carbon and mitigate heat waves and urban flooding. Although carbon sinks are mainly considered at the city level, other climate benefits, such as mitigating flooding and heat waves, are local. Well-being benefits and contact with nature, which is important for health, for example, through beneficial microbes in the soil, are also local (Tyrväinen et al. 2024). It is therefore important to ensure that there is sufficient urban green all over the city (Hautamäki & Laita 2023). However, our research shows that urban green is not evenly distributed – and therefore neither are the benefits it provides. For example, in the capital region, canopy cover, i.e., the percentage of vegetation taller than two meters, varies from around 4% to around 75% between different city districts (Kinnunen & Hautamäki 2025). As a point of comparison, the international recommendation for canopy cover in urban neighbourhoods is 30% (Konijnendijk 2023).

Our research results also show that the amount of vegetation has decreased on residential plots since the late 1970s, which reduces their climate benefits (Leppänen et al. 2024). Therefore, as the urban structure becomes denser, sufficient urban green cover must be ensured.



Canopy cover of Helsinki, i.e., the percentage of trees over two meters tall by city district. Canopy cover is unevenly distributed, which also affects the sinks shown on the right side of the map. (FIGURE: ANTTI KINNUNEN)

The life cycle of urban green, and especially the longevity of trees, is essential for long-term carbon storage. The longer trees are allowed to grow, the greater the amount of carbon stored in their biomass and soil. This also compensates for the initial spike in emissions caused by the decomposition of organic matter in the growing medium (Havu et al. 2022). Over time, carbon is returned to the soil and plant parts, but it may take up to a decade before the plantation begins to function as a carbon sink when the emissions of the growing medium are also taken into account. Therefore, efforts should be made to preserve especially the old trees in urban environments. (Hautamäki 2025)

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Recommendations:

- Set binding targets for carbon sinks in climate plans.
- Ensure that the vegetation and canopy cover do not decrease.
- Take into account the most valuable carbon sinks and avoid the destruction of forests and natural areas.
- Consider the climate benefits of urban green when assessing the climate impacts of land use planning. Assess the loss of carbon sinks as part of the climate impacts of construction.
- Preserve existing trees, soil on new plots, and protect trees from root and trunk damage on construction sites.

Construct new multi–beneficial and low–emission carbon sinks

When building new urban areas, sufficient space must be reserved for urban green, especially for large trees. Favourable growing conditions must be ensured for vegetation, including sufficient space for the canopy and roots, as well as suitable moisture and light conditions. This ensures the well-being of vegetation and, at the same time, secures the benefits of effective carbon sequestration and climate adaptation. This is particularly important in dense urban structures, where the effects of urban flooding and heat waves are greatest. (Hautamäki et al. 2023)

When designing new urban green, attention must be paid to multi-beneficial urban green, which, in addition to carbon sequestration, also improves biodiversity and enables residents to connect with nature. Multiple benefits can be supported by favouring native plant species, multi-species, and multi-layered vegetation and by advocating a new kind of urban wildness that produces climate, biodiversity, and health benefits (Ariluoma 2025). The shift towards multi-beneficial urban green also requires a change in attitudes and challenging the traditional ideal of a ”neat park” (Lampinen et al. 2023).

In the construction of new urban green spaces, low-emission materials should be used, especially growing media, which currently account for a considerable proportion of emissions from green construction. According to our research, peat-based growing media account for 35% of emissions from the manufacturing of materials, construction, and maintenance of parks (Moinel et al. 2024). Therefore, particular attention should be paid to preserving existing soil and using recycled growing media or utilising biochar or compost instead of peat. The key question is where the organic material used in the growing medium comes from: if compost made from waste is used, emissions into the atmosphere would occur anyway, and thus these seemingly negative emissions into the atmosphere are ultimately neutral (Orttenvuori et al. 2023). Low-emission maintenance should also be supported, as well as green spaces that do not require intensive care. Understanding the emissions from green construction—and the potential for carbon sequestration—supports a comprehensive understanding of a climate-smart city. (Hautamäki et al. 2025)

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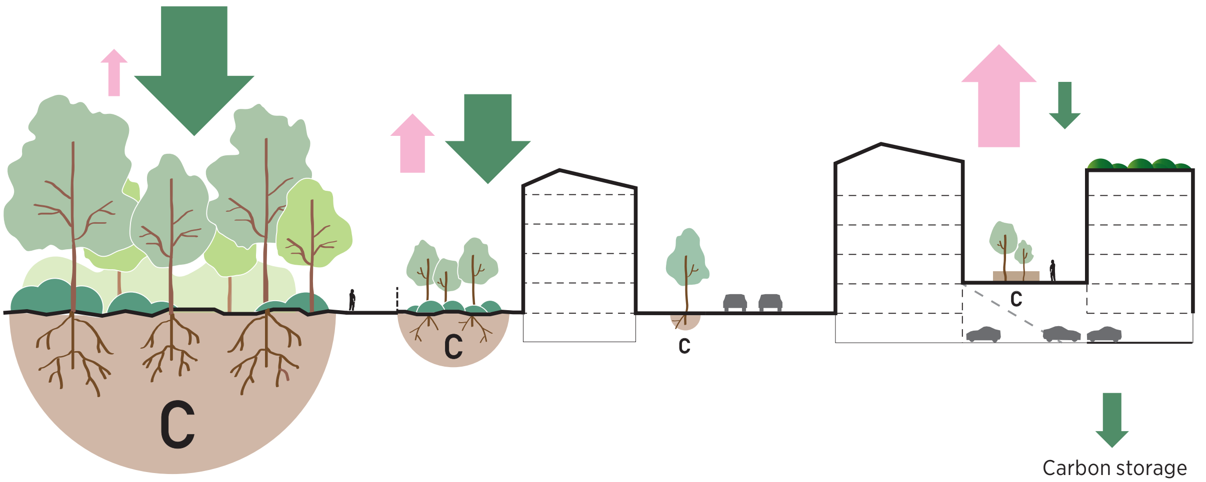

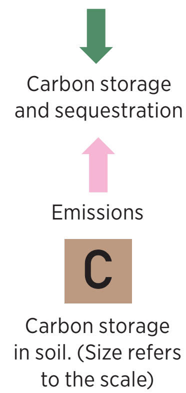

Carbon sinks, storages, and emissions vary in different types of green spaces. Green arrows indicate carbon sequestration and pink arrows indicate emissions. Carbon storage is marked in brown (C). Left: A forest with high sink and storage potential and low emissions. Middle: At-grade yard has moderate sequestration potential but also high emissions due to emissions from the growing medium. Right: A podium yard, where emissions exceed carbon sequestration. However, carbon sequestration can be enhanced in all green areas. (FIGURE: HAUTAMÄKI ET AL. 2025)

RECOMMENDATIONS

- Reserve sufficient space for vegetation, especially large and long-lived trees, and ensure good growing conditions for them even in dense urban structure.
- Utilise multi-species and multi-layered vegetation, which is a better carbon sink than single-species planting and supports biodiversity and stormwater management.
- Favour at-grade yards with direct contact to native soil over podium yards to minimise construction emissions and ensure diverse ecosystem services.
- Consider carbon-smartness early in the design phase and compare different options in terms of carbon sequestration and emissions.
- Pay attention to the quality of the growing medium, as growing media are a significant source of emissions. Utilise existing soil, recycled growing media, and low-carbon growing media.
- Utilise low-emission maintenance methods and green spaces that do not require intensive care.

Carbon–smartness requires social acceptance

Carbon-smart decisions must be socially acceptable. Green spaces cannot be planned solely from the perspective of carbon sequestration; various values associated with urban green must also be taken into account: outdoor recreation, biodiversity, and urban sustainability goals. For this reason, lawns, which are particularly important for recreation and exercise, should not be completely converted into meadows, even if the change would promote biodiversity and low emissions. Our research shows that preserving outdoor recreation opportunities and the aesthetic qualities of a site are key prerequisites for the social acceptability of restoration measures. (García-Antúnez et al. 2026)

Decisions concerning green spaces must promote social justice. This applies, for example, to the accessibility of local green spaces, i.e. how close they are to people's homes and how easy they are to use. Care must be taken to ensure that there is sufficient canopy cover in different neighbourhoods so that everyone can enjoy the benefits of urban green. Ensuring fairness also means taking different views into account in planning, and particularly the participation of vulnerable groups.

Our research shows that expectations for carbon-smartness varied according to the age, gender, and income level of city residents, but also according to the extent to which residents felt they were able to participate in and influence the maintenance of their local green spaces (Lampinen et al. 2022). City residents' attitudes toward increasing the carbon sequestration potential of green spaces were mainly positive, but variations in attitudes were again explained by residents' age and income level, as well as diverse ways of valuing green spaces (Lampinen et al. 2023).

Areas important for biodiversity (blue), areas supporting carbon sequestration (yellow), and areas with high social value (pink) in Helsinki. The dark areas represent meeting points for the three, including Central Park and other green fingers in Helsinki.
(FIGURE: LAMPINEN ET AL. 2024)

As public acceptance grows, people will be more willing to implement carbon-smart solutions in private yards, which account for a substantial proportion of urban green infrastructure. It is therefore important to identify ways to promote carbon-smart yards and the factors that hinder their implementation. Our research shows that wild nature with uncut lawns and dead trees can cause resistance despite its biodiversity and carbon benefits (Garcia-Antúnez et al. 2023). The decisions of yard owners are influenced by personal motives and social norms: their own lifestyle may support pro-environmental gardening, but the expectations of the neighbourhood may favour another kind of gardening. Promoting carbon-smartness, therefore, also requires consideration of social factors.

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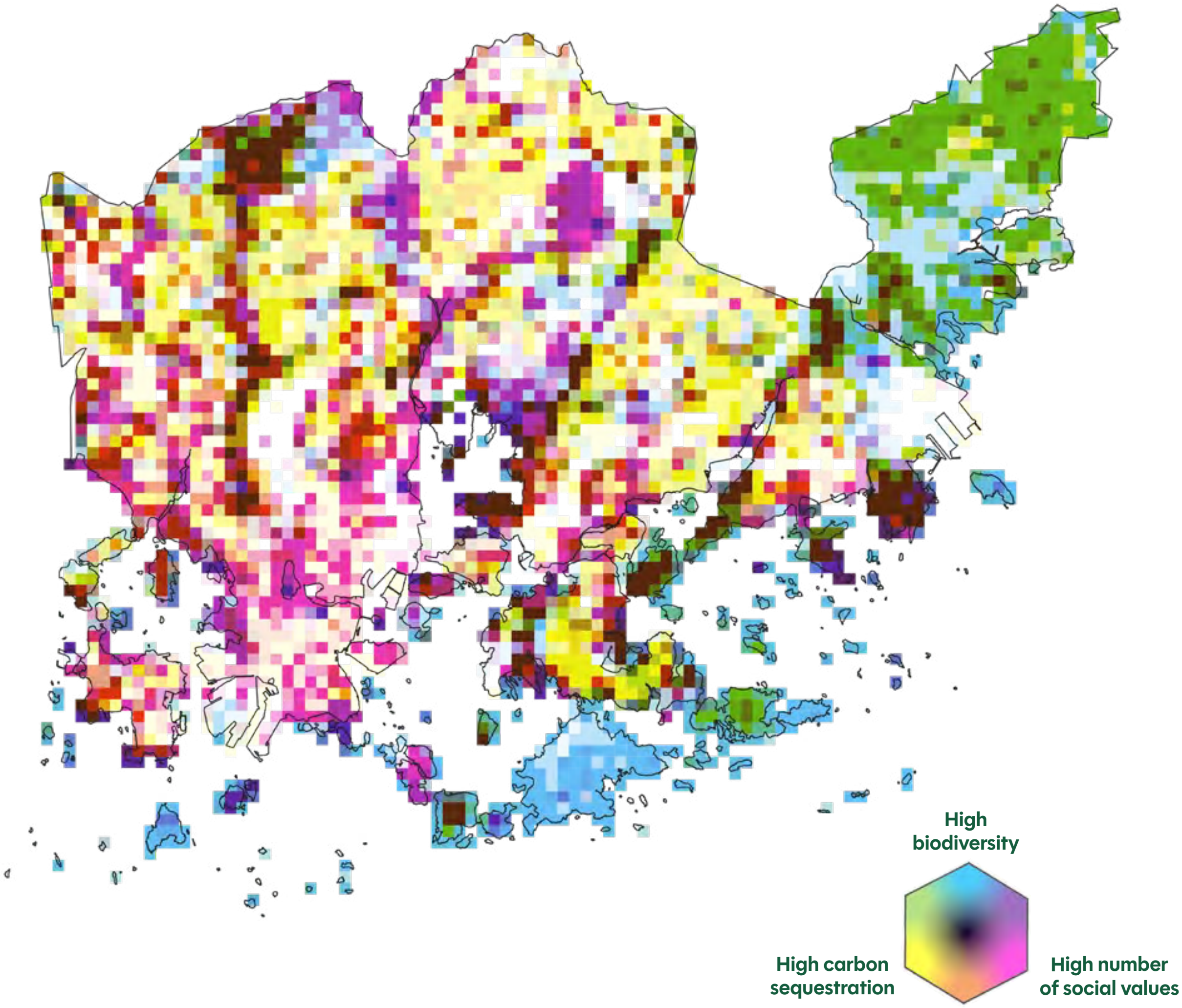


Recommendations:

- Ensure social justice: allow different actors to express their views and strive to guarantee everyone equal access to the benefits provided by green spaces.
- Recognise the different values of green spaces, coordinate them, and prioritise them. In addition to climate considerations, green areas are also important for well-being and biodiversity.
- Consider the accessibility and attractiveness of green spaces when implementing carbon-smart measures.
- Involve residents in the planning and maintenance of green spaces to ensure that climate measures are socially acceptable.
- Monitor the social impacts of planning and promote environmental justice.

Carbon–smart urban green is an essential part of strong sustainability

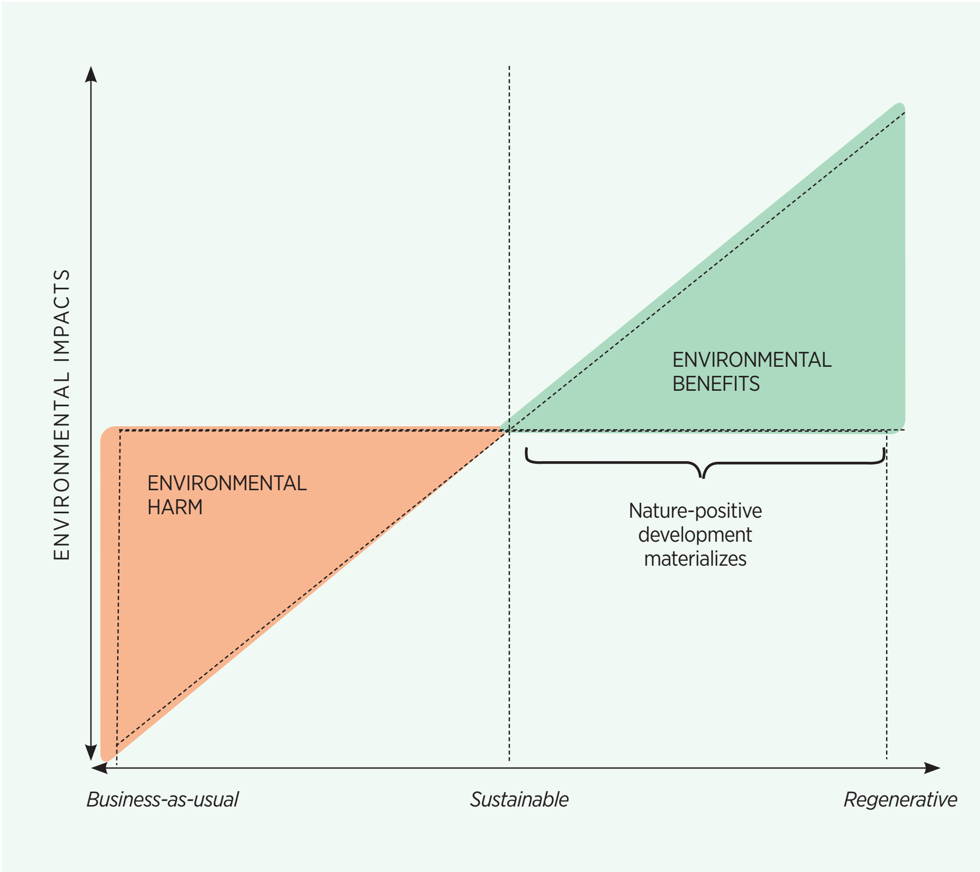
Dense urban development alone does not guarantee a comprehensively sustainable urban environment. Densification has become an established key strategy in Finnish urban policy for promoting sustainable urban development. However, recent research shows that compacting urban structures has reduced the amount of urban green in residential environments, thereby weakening local ecosystem services (Leppänen et al. 2024, Berghauser Pont et al. 2021, Hautamäki et al. 2024). This development pattern is problematic from a strong sustainability point of view, as the reduction of urban green negatively impacts both health and the quality of living environments. However, international research shows that greening can also have undesirable consequences, such as exacerbating regional segregation (Anguelovski et al. 2022). For this reason, when planning new urban green infrastructure interventions, it is important to consider potential future risks and ensure that equity issues are integrated into the planning process at an early stage.

While mitigating climate change requires the use of existing infrastructure and reducing emissions, attention must also be paid to carbon sinks and the local environmental benefits provided by urban green spaces. Although the annual carbon sequestration of urban green is relatively small compared to the annual greenhouse gas emissions of a city, its importance is growing year by year as the surrounding society decarbonises. Carbon sinks currently account for less than 10% of total emissions in the city of Helsinki, but the more emissions from transport and energy production are reduced, the greater the role carbon sinks will play in the city's carbon balance. Therefore, their role should not be undermined.

Urban green provides local well-being and health benefits while supporting climate adaptation. This is emphasised, for example, by the 3-30-300 principle, according to which every apartment should have a view of at least three trees, the canopy cover of the neighbourhood should be at least 30 %, and the nearest green area should be no more than 300 meters away (Konijnendijk 2023). Furthermore, urban green is unrivalled as a cost-effective solution for cities to adapt to future climate-related impacts, such as mitigating the urban heat island effect, stormwater management, and ensuring equal recreational opportunities (Hautamäki et al. 2023, Suomi et al. 2025).

Urban green is closely intertwined with ecological, social, and economic sustainability and systemic sustainability transformation. Urban green should not be seen merely as a separate or quantitative element, but as part of strategic urban development and critical infrastructure for society. Urban green affects people's well-being, the attractiveness of cities, social justice, climate adaptation, and the carbon neutrality goals to which municipalities are committed in their land use policies. Recognising the importance of urban green as an essential part of strong sustainability requires systemic change. Regenerative urban planning emphasises strengthening ecosystem services and restoring natural processes to the built environment—giving back to nature more than is taken from it (Kinnunen 2024, Pedersen Zari 2018).

AUTHOR: ILMARI TALVITIE



The shift in sustainability thinking is moving the focus from prevailing practices that minimise damage to development that regenerates the environment (so-called nature-positive visions of the future, in which human activity improves the environment). (FIGURE: KINNUNEN 2024)

Key messages:

- Urban green infrastructure should be considered critical infrastructure of today's cities to both strengthen strong sustainability outcomes and improve urban liveability.
- Climate impacts must be assessed holistically, considering not only emissions but also carbon sinks and the benefits of urban green in adapting to climate change.
- The city of the future must adopt a planning model in which the built environment not only seeks to minimise the loss of natural assets, but also actively strengthens and restores them.

PHOTO: MIKKO RASKINEN

3 Solutions

Carbon–smart yard

In a carbon-smart yard, permeable and vegetation-covered surfaces should be favoured. Lawns, meadows, and ground cover vegetation are better than asphalt, as they absorb carbon and water and support microorganisms. Layered, multi-species plantings with trees, shrubs, and ground cover can further enhance carbon sequestration (Ariluoma et al. 2024).

A carbon-smart yard takes local growing conditions and maintenance into account. Selecting species suited to local conditions and providing sufficient soil are essential. Where possible, roots should grow directly into the soil rather than in contained planting areas or root boxes, and stormwater should be used as the primary irrigation source.

Recycling organic matter and fostering the living soil maintain soil biota and strengthen its carbon storage. Methods range from composting garden waste in small yards to shredding autumn leaves on site (Tahvonen 2023), but the principle is the same across private yards and public parks: keep carbon in place. Leaves can be shredded on the lawns or plantings, twigs and branches can be used for compost, or for mulching.

However, not all urban green is automatically a good carbon sink. Maintenance based on continuous soil cultivation can even act as a source of carbon emissions, as has been observed in allotment gardens (Ke et al. 2025). For this reason, it is important to strengthen vegetation and soil carbon while reducing work-related emissions by shortening transport, choosing equipment carefully, and reducing peat-based growing media (Suomalainen et al. 2022).

▸ **The amount of vegetation, especially large trees, has decreased significantly in residential areas of Helsinki since the late 1970s. This weakens carbon sequestration and may raise summer temperatures.**
(FIGURE: LEPPÄNEN ET AL. 2024)

From the perspective of carbon-smartness, it is problematic that the carbon storage of trees accumulates slowly if growth is poor, and is lost completely if the tree is felled prematurely.

Carbon-smart yards are promoted through choices in the use and maintenance, both in private and semi-public yards (Ryymin & Tahvonen 2025). Detached house owners can make decisions quickly and easily, whereas housing association yards require the involvement of multiple actors, including the housing association, property managers, and maintenance companies. A carbon-smart yard is worthwhile: in addition to carbon sequestration, it offers other benefits, such as habitats for other species and contact with nature that promotes the health of residents. Although the solutions implemented in a single yard may seem small, yards as a whole account for a considerable proportion of urban green infrastructure, around 40% in Europe (Haase et al. 2019). **When many yards promote carbon-smartness, a significant impact can be achieved in residential areas.**

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Recommendations:

- Minimise paved areas and maximise the amount of vegetation and permeable surface materials to allow carbon storage, water absorption, and microbial habitat.
- Recycle organic matter in your yard: compost garden waste, leave autumn leaves on the ground or shred them on the lawns or planting areas.
- Avoid unnecessary tilling, as it releases carbon.

Meadows and lawns

Meadows are more resilient than lawns during dry periods (Trémeau et al. 2024), **which may be a significant advantage in the future climate.** This is probably due to species diversity and low mowing frequency, which allows meadow plants to develop deep root systems. However, **when looking at the carbon balance throughout the year in the current climate, meadows and lawns are quite similar:** although meadows have higher biomass in midsummer, lawns sequester carbon more efficiently than average meadows in spring and autumn (Trémeau et al. 2024). However, emissions from lawn maintenance and mowing are higher than those from meadow management (Ariluoma 2025).

Lawn is an effective carbon sink, but carbon released from the soil has a critical impact on the carbon balance. If a lawn is planted on an organic-matter-rich growing medium, the amount of carbon dioxide released into the atmosphere by microbial activity may exceed the amount of carbon sequestered by photosynthesis. In this case, the lawn acts as a source of atmospheric carbon. On the other hand, in mature lawns or on low-carbon growing media, carbon sequestration may exceed decomposition, in which case the area acts as a carbon sink. This supports the key message of preserving existing green spaces and minimising their change. When establishing new lawns, it is also important to consider the origin of the growing medium. The use of existing soil or waste-based materials causes fewer additional emissions, as they would decompose anyway. On the other hand, the use of virgin natural resources such as peat as a growing medium is clearly more harmful to the climate.

Irrigation of lawns increases carbon sequestration in summer, when lawns dry out easily, but irrigation can also increase soil emissions. According to our study conducted in Helsinki, irrigation improves plant viability, photosynthesis, and growth, but at the same time, accelerates the decomposition of organic matter in the soil (Thölix et al. 2025). Thus, the impact of irrigation on the carbon balance depends largely on soil properties and how quickly organic matter decomposes in moist conditions. According to model simulations, irrigation increases decomposition more than photosynthesis, resulting in a negative climatic impact in a warmer climate in the future (Koiso-Kanttila et al. 2026). Organising irrigation and purchasing equipment also causes emissions.

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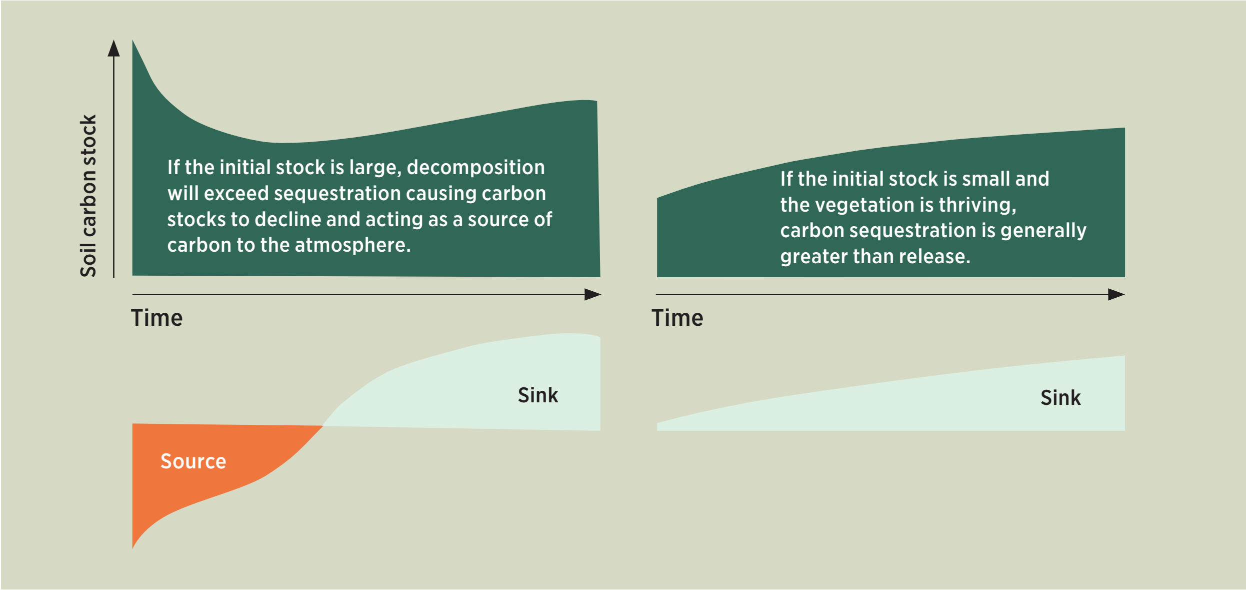
Key messages:

- Meadows are drought-resistant and require less maintenance than lawns, which causes less emissions. At the same time, meadows support biodiversity.
- Lawns can act as effective carbon sinks when the soil contains little carbon, and the lawn is maintained without unnecessary soil preparation. This allows carbon to gradually accumulate in the soil.
- A newly established lawn on a carbon-rich growing medium can act as a source of atmospheric carbon, since the emissions from the soil exceed the amount of carbon fixed through photosynthesisThe irrigation of a drought-affected lawn increases its photosynthesis but can also increase emissions.
- The irrigation of drought-affected lawn increases its photosynthesis but can also increase emissions.

Researchers collecting vegetation samples from different types of meadows.
PHOTO: OUTI TAHVONEN



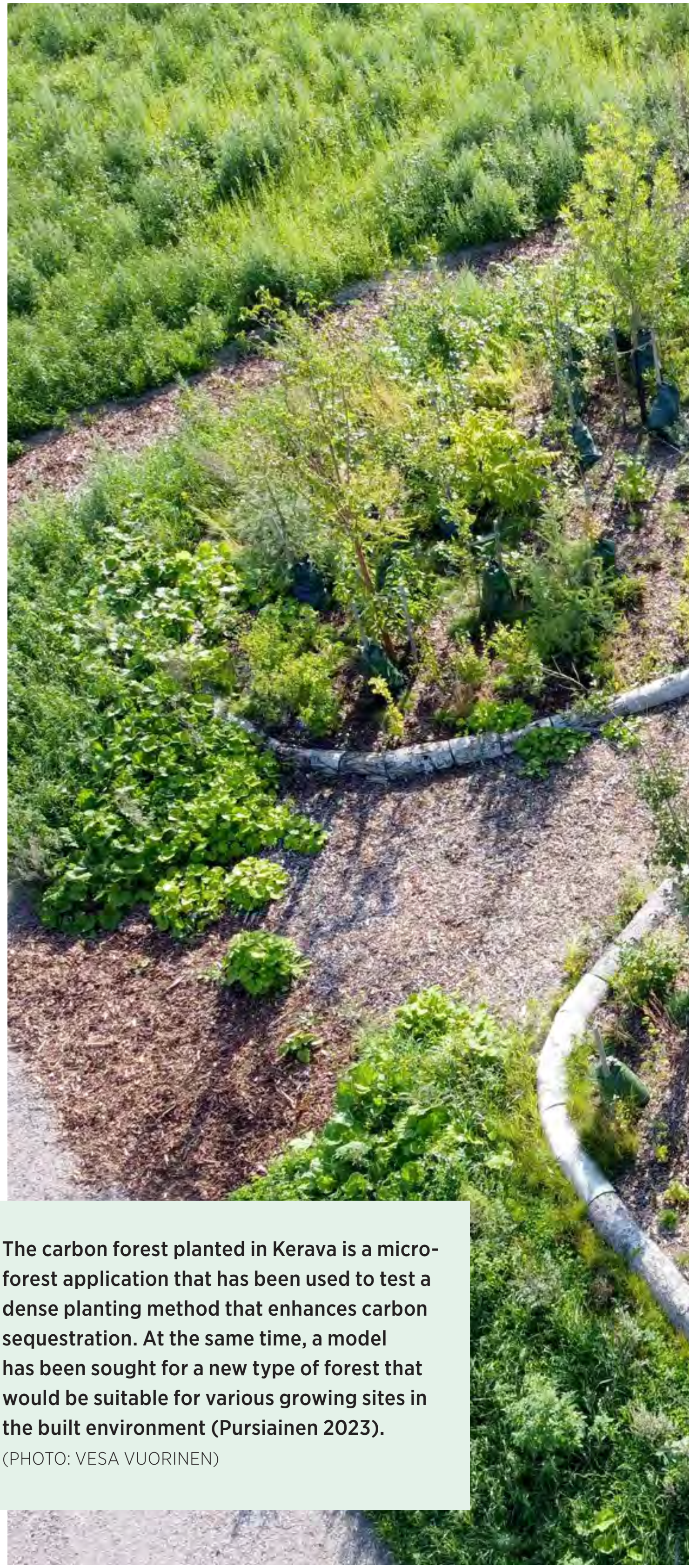
The ability of lawns and meadows to act as carbon sinks depends, among other things, on the size of the soil carbon store. A large carbon store decomposes more quickly, making it more difficult for vegetation to sequester more carbon from the atmosphere than is released from the soil. Especially at the time of planting, a lot of organic matter is often added to the growing medium, which decomposes quickly into the atmosphere and causes emissions (FIGURE: LIISA KULMALA 2025).

Microforests

A microforest refers to dense, multi-species, and multi-layered tree and shrub vegetation whose characteristics promote growth, carbon sequestration, and support biodiversity. Vegetation created using the microforest principle quickly creates protective and shading green where it is needed. The idea of microforests was originally developed by Japanese professor **Akira Miyawaki**, who created a method for restoring forests. The aim was to grow forests based on local species in challenging growing areas where, for example, erosion and drought occur. Usually, microforest cultivation begins by planting small seedlings densely. After the initial phase, the multi-species forest is allowed to develop naturally, and the most successful species take over the area. The microforest method has also found other applications around the world. (Lewis, H. 2022)

Microforests can vary in size and be located in many different environments, including densely built-up areas. Nowadays, microforests are mainly established in cities, where growing conditions are often harsh. The idea behind microforests is that the vegetation will naturally develop in a way that is most suitable for the location. This is an effective way to increase carbon sinks and biodiversity. Microforests are suitable for many types of locations, such as roadsides, noise barriers, squares, and spaces between buildings, where vegetation is otherwise scarce. Microforests can also be established in parks and home gardens. Their establishment and maintenance can also involve community engagement, for example, in the form of a forest planted together with pupils in a schoolyard. In this way, microforests can also have social and educational significance.

AUTHOR: MARI ARILUOMA



The carbon forest planted in Kerava is a microforest application that has been used to test a dense planting method that enhances carbon sequestration. At the same time, a model has been sought for a new type of forest that would be suitable for various growing sites in the built environment (Pursiainen 2023).
(PHOTO: VESA VUORINEN)

Key messages:

- A microforest can be established almost anywhere where there is at least the space of a single parking spot.
- Seedlings of various sizes can be used for planting, such as small forest seedlings and bare-root shrubs, as well as some seeds.
- The species to be planted should be selected based on the type of soil at the site and the species that grow naturally in the environment. The principle is to modify the soil as little as possible.
- The planting density depends on the size of the seedlings. As a rule of thumb, you can use 3-4 seedlings per square meter when using, for example, small tree seedlings that are 20-40 cm tall.
- In the initial stages, it is advisable to monitor the need for watering and remove any weeds that are spreading too vigorously, so that the seedlings get off to a good start.
- Later, when the vegetation is well rooted, it can be left to develop freely.

PHOTO: MIKKO RASKINEN

4 Methods

Carbon sink assessment

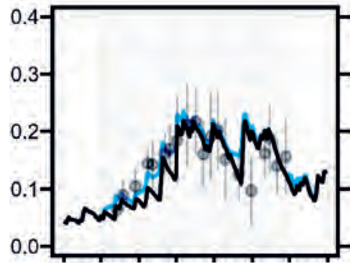
There are several methods for measuring carbon sinks, each with its own strengths and limitations. Carbon balance could be assessed based on changes in carbon stocks in vegetation and soil, but this method is rarely used because measurements are expensive and laborious due to the mosaic character and high local variation of urban nature. For this reason, **chamber measurements** are often used to assess the carbon dioxide exchange of a single branch or a small grassland or meadow area with the atmosphere and its response to various environmental factors such as light.

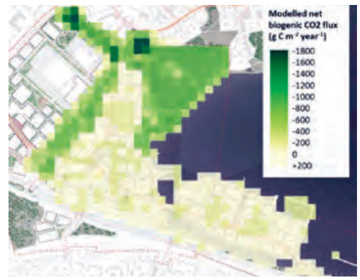
Carbon balance assessments often use models tested on different types of vegetation and developed using a variety of measurements. On the left are branch and soil chambers that measure leaf respiration and natural carbon dioxide emissions from the soil. (PHOTOS: LEFT: CO-CARBON; TOP RIGHT: KARVINEN ET AL. 2024; BOTTOM RIGHT: JÄRVI ET AL. 2024)

Similarly, micrometeorological **eddy covariance measurements** provide a regional carbon balance over a radius of several hundred meters. This is the most direct way to measure carbon dioxide exchange between the atmosphere and vegetation, but the challenge is to distinguish between the different components of the carbon balance. In addition, the observation is an average of several different growing sites, making it difficult to study individual vegetation types. However, the technique is a valuable tool, especially for testing models. **Satellites** can be used to observe changes in various indices describing vegetation abundance and activity. Satellite products are widely used in model development and testing but are difficult to use alone to assess changes in carbon stocks, especially in soil.

Assessing the carbon balance of a large area, such as a municipality, is easiest using **models that describe the functioning of different ecosystems**. Urban carbon sinks are commonly assessed using the i-Tree application developed in North America, which assesses tree carbon sinks and stores using measured tree growth equations. However, it is not able to comprehensively consider the diversity of urban nature, such as management practices, soil, and many types of grassy or shrubby vegetation. For this reason, process-based models have been developed for various Finnish and European urban vegetation types using local measurements (Havu et al. 2022, Karvinen et al. 2024, Trémeau et al. 2024, Stagakis et al. 2025, Thölix et al. 2025). Satellite and process-based models enable the examination of interannual variation in carbon sequestration, and the latter also enable carbon sequestration estimates for different management scenarios and future climates (Havu et al. 2024, Koiso-Kanttila et al. 2026). **These models can thus be used to estimate plant viability and their ability to sequester carbon in the future when making planning decisions.** Many scientific models are heavy and difficult to use, but they have already been simplified using machine learning methods for practice (Vasenkari et al., in peer-review).

AUTHORS: LIISA KULMALA AND LEENA JÄRVI





Key messages:

- Assessing urban carbon sinks requires combining several methods. Individual measurements are not sufficient to describe the mosaic-like character of urban environments and their considerable temporal and spatial variation.
- Urban carbon balances can be assessed using ecosystem models. Field and satellite measurements are useful for the development of those models. Process-based models take better into account the diversity of urban nature, management practices, and distinct types of vegetation than simpler tools that focus on trees.
- The models enable the examination of variations in carbon sequestration in different climate, construction, and management scenarios, as well as the evaluation of future planning solutions.

Life-cycle assessment of urban green

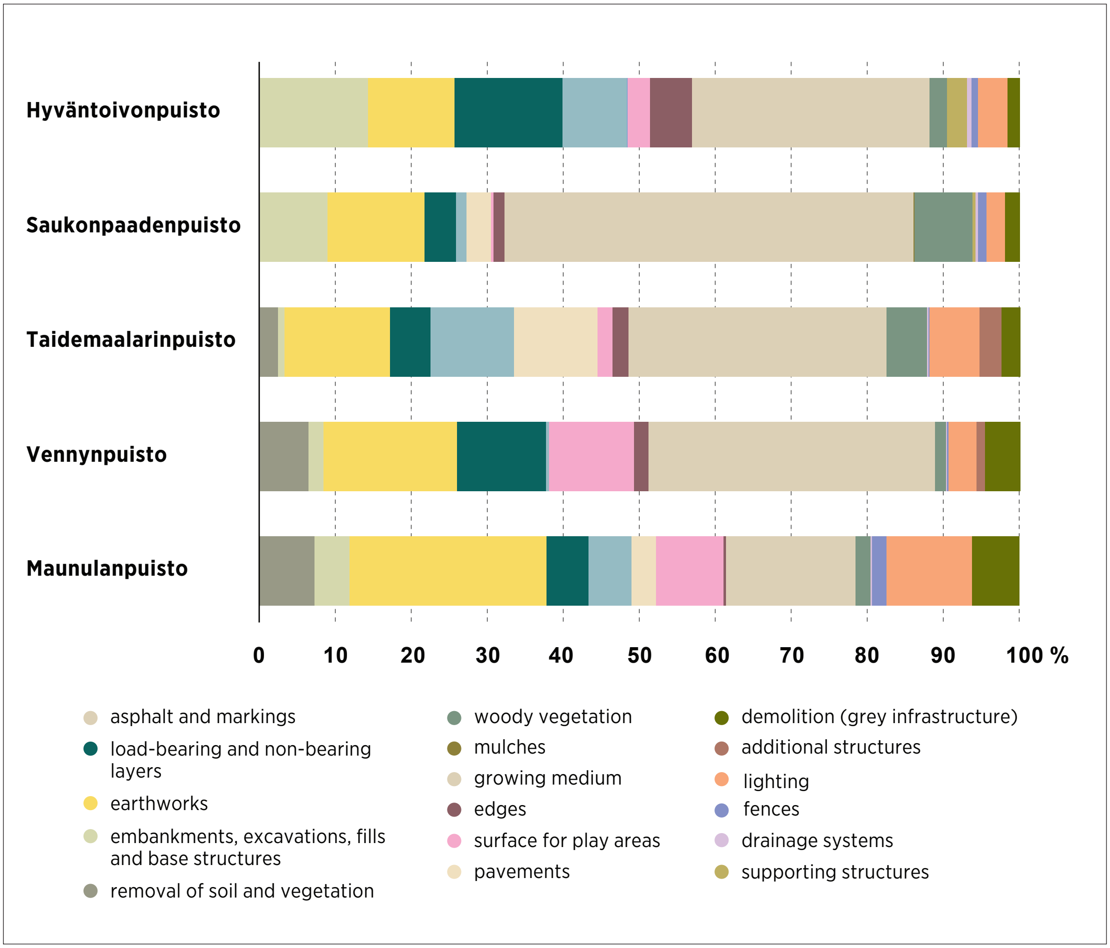
Carbon-smart urban green design entails life cycle assessment (LCA), which can be used to highlight the environmental impacts of a product, process, or service. The new Building Act requires a mandatory “climate declaration” based on life cycle assessment for new construction projects. Life cycle assessment is also becoming part of EU building regulations. In accordance with European standard EN 15978, the assessment includes everything that is within the site. This logically also means built greenery, including planted vegetation and soils (Moinel 2025).

Although life cycle assessment has become common in the building construction industry and aims to cover all environmental impacts of construction, urban green infrastructure is seldom included in the calculations. This is due to insufficient data on landscape construction products, such as ornamental plants or growing media, in the national emissions database. According to our research, the carbon footprint of vegetation, growing media, and maintenance requires further attention (Moinel et al. 2024). In addition, standardised calculation methods are lacking because the life cycle of living vegetation and soil differs significantly from that of construction products. Compilation of scenarios for the accumulation and release of organic carbon and its reporting at the end-of-life of urban green spaces needs to be methodologically harmonised.

The life cycle assessment of urban green spaces focuses on each stage of the life cycle of materials, vegetation, and soil. The assessment estimates greenhouse gas emissions and removals associated with urban green infrastructure products (manufacturing of materials and nursery production of ornamental plants), construction (machinery and transportation), use and establishment, and end-of-life of an urban green space. Life cycle assessment can be used to identify the main sources of emissions from materials and processes at the beginning of the design phase and during the detailed construction phase. This makes it possible to compare different options and make the necessary changes to reduce emissions. Our study of park projects in Helsinki revealed that growing media are one of the largest sources of emissions in green construction (Moinel et al. 2024). This highlights the importance of low-emission growing media and soil conservation in construction.

Life cycle assessment of green construction is an essential part of implementing carbon-smartness. However, further research is needed before it can become established. **Only then will it be possible to comprehensively assess the carbon footprint of the built environment.**

AUTHOR: CAROLINE MOINEL



Share of CO_2 emissions in different components of the park. Growing media containing peat-based compost accounts for an average of 35% of total emissions. (FIGURE: CAROLINE MOINEL)

Key messages:

- Life cycle assessment of urban green infrastructure estimates greenhouse gas emissions and removals from materials, vegetation, and soil during the production phase, construction phase, use phase, and end-of-life phase.
- Life cycle assessment can be used to identify the most significant sources of emissions and make the necessary changes early in the design phase.
- The widespread adoption of life cycle assessment in urban green infrastructure requires more comprehensive emission data on landscape construction products and the development of standardised calculation methods.

Carbon calculator as a tool for landscape design

The carbon factor is a calculator developed in connection with the Green Factor tool. It estimates the carbon sink potential of the vegetation and soil on a plot or block over a period of 50 years. Carbon sink potential refers to an estimate of how much carbon the vegetation and soil can sequester in the future. The calculation is based on the surface areas of the vegetation types on the plot and indicates the carbon factor, i.e., the amount of carbon sink in relation to the surface area of the plot (kg CO_2/m^2). The estimate is based on the vegetation classification of the green factor and a 50-year life cycle, which corresponds to the established time frame for life cycle assessment (LCA).

The result of the calculator describes the magnitude of the potential carbon sink based on research data. The calculation takes into account the carbon stored in the soil and woody vegetation as well as emissions from growing media, construction, and maintenance. The carbon sink is formed by the difference between carbon sequestration and emissions. The default assumption is that vegetation and soil layers will not be renewed for 50 years. The carbon factor can be **positive** (the site acts as a carbon sink) or **negative** (emissions exceed sequestration). A carbon factor exceeding approximately 5.0 can be considered a recommended level. This means that the carbon sink capacity of the site is **5 kg CO_2/m^2**. The carbon factor calculator can be used to set a target value for the carbon sink capacity of a site or block (Ariluoma et al. 2025).

The Green Factor carbon calculator helps designers compare different vegetation solutions and their effects on the carbon sinks of the site. The assessment can be carried out at the concept or implementation planning stage, provided that the area of the plot and the types of vegetation and their areas are known. The carbon factor encourages the selection of sustainable and carbon-smart landscape construction solutions and complements the Green Factor method.

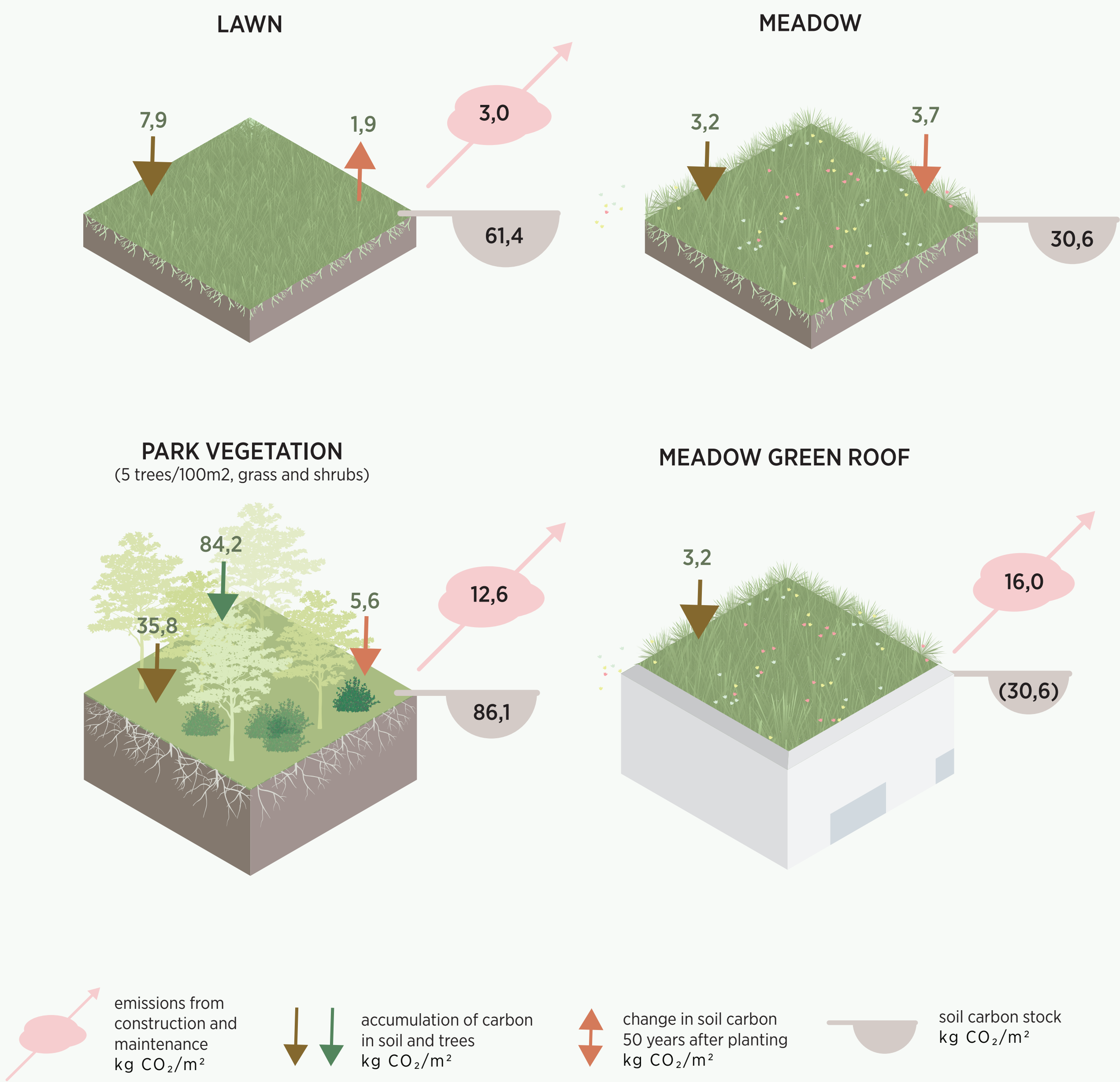
AUTHOR: MARI ARILUOMA

$$\text{Green factor} = \frac{\text{Total weighted green area}}{\text{Plot area}}$$

$$\text{Carbon factor} = \frac{\text{Total carbon sink (vegetation and soil)}}{\text{Plot area}}$$

Key messages:

- The carbon factor is a calculator developed as part of the Green Factor tool. It estimates the carbon sink potential of the vegetation and soil of a plot or block over a 50-year period.
- The result is a carbon factor value (kg CO_2/m^2) that indicates the size of the plot's carbon sink in relation to its surface area.
- The calculator takes into account both carbon sequestration and emissions (soil, woody vegetation, growing media, construction, and maintenance), and the resulting value can be positive or negative.
- The carbon factor calculator helps designers compare the effects of different vegetation solutions on carbon sinks.



The carbon factor can be used to calculate the sink and emission effects of different urban vegetation types and changes in carbon stocks. (FIGURE: ARILUOMA ET AL. 2025)

PHOTO: RANJA HAUTAMÄKI

5 Knowledge mobilisation

Carbon-smartness through Garden coaching

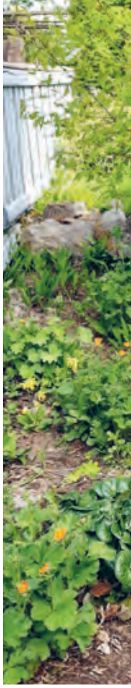
Garden coaching is a method designed to support the gardening practices and material choices of detached house residents (Rantanen & Tahvonen 2023a-c). It provides tailored guidance on carbon-smart options, which are based on understanding distinct types of vegetation, their carbon storage, and the factors that influence carbon emissions (Ariluoma et al. 2023). Much like a personal trainer at the gym, garden coaching involves regular meetings, monitoring progress toward specific goals, and offering encouragement and practical advice to help residents implement and maintain carbon-smart practices in their own gardens.

In garden coaching, participants walk through their yard to discuss how each area can better support plant growth, enhance living soil, reduce exposed soil, and make use of on-site green waste, including branches and twigs. The training often focuses on preserving trees, other vegetation, and soil at distinct stages of the yard's life cycle, ensuring good growing conditions, and identifying different options for the local processing of organic matter generated in the yard. Particular attention is paid to favouring permeable surfaces and ground-level vegetation, as this also allows the soil to be used as a carbon stock. The key topics of garden coaching have been compiled in the Home Yard Carbon Gardening Guidelines (Tahvonen 2023).

Increasing knowledge and expertise among residents and housing companies is essential: accurate and sufficient information builds motivation, enables participation, and facilitates practical changes in private or housing company yards. Implementation of carbon-smart practices varies: in detached house yards, change often starts with an individual resident, while in housing company yards, the process is multi-stage, involving residents, property managers, boards, yard committees, competitive bidding for contractors, or volunteer instructions.

Residential yards differ considerably due to location characteristics, such as soil, growing conditions, and microclimate, as well as residents' wishes, values, and needs. These factors determine which carbon-smart solutions are feasible. Garden coaching applies research-based knowledge to local conditions, while allowing residents to share their views on opportunities and obstacles. Trials in Hämeenlinna and Lauttasaari highlighted the need for better handling of organic matter on the plots.

AUTHOR: OUTI TAHVONEN

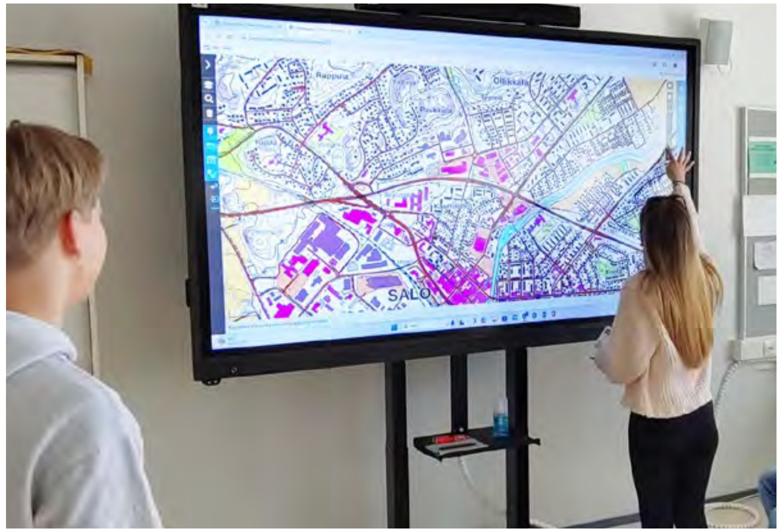


Garden coaching helps residents of detached houses apply carbon-smart solutions in everyday gardening and material choices. The method is based on sharing information, interaction, and taking into account local conditions, residents' goals, and existing yards. (PHOTOS: OUTI TAHVONEN).

Questions to consider in Garden coaching:

- How can you support good plant growth in distinct parts of your yard?
- How can you support soil vitality (microbial activity, addition of organic matter)?
- How could you cover open soil surfaces in your yard?
- Where do the twigs and branches from your yard end up? What about grass clippings and other yard waste?

Carbon–smartness in upper secondary education

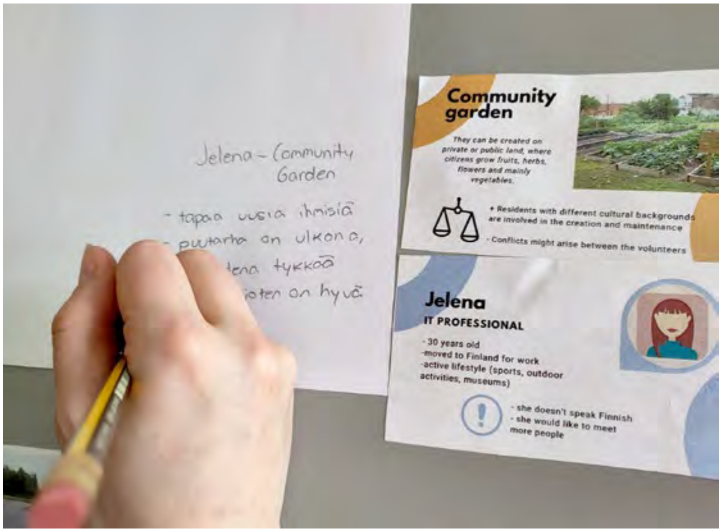


Climate education is not just about teachers sharing facts with students, but rather a multifaceted learning process that combines research, discussions about values, and concrete action. Carbon-smartness in upper secondary education means teaching practices and ways of thinking that support carbon sequestration and a sustainable lifestyle, and, above all, young people's ability to act as active citizens. According to our survey, teachers consider climate education important, and more than 60% incorporate multidisciplinary content combining climate change, biodiversity, and justice into their teaching (Castellazzi et al. 2025). Combining natural, social sciences, and art can support a comprehensive approach to climate education. An interdisciplinary climate education increases students' understanding of the social and ecological dimensions of climate change.

Instead of focusing on disaster scenarios, teaching should inspire hope, including spaces for emotional processing and local examples of carbon-smartness. Emphasising hope creates space for emotional processing and imagining different futures. Concrete examples close to the students' everyday lives increase understanding and relevance of the topic. Students should also be involved and given space to discuss, question, and influence their environment. This supports critical thinking and collaboration skills.

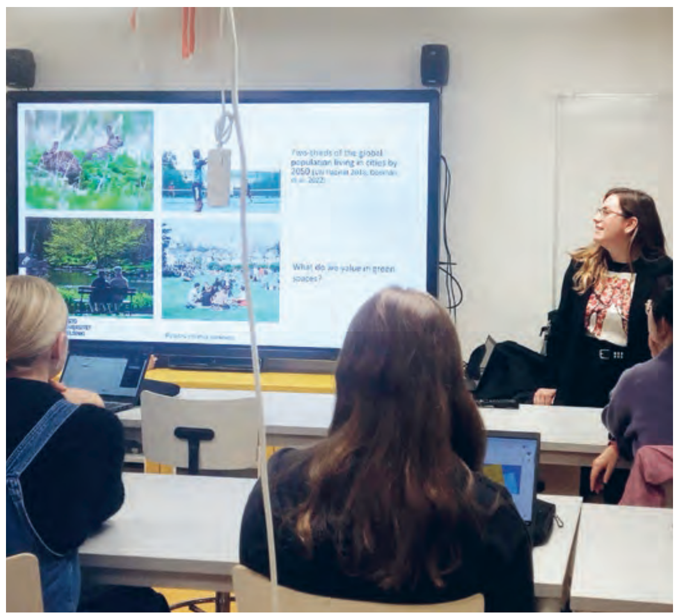
Although climate education in upper secondary schools is considered important, a lack of time and expertise prevents its implementation. More than 70% of the teachers who responded to our survey said they did not have time to collaborate with external stakeholders, and more than a third did not have time to include climate topics in their teaching. The curriculum is full, and climate issues sometimes feel superfluous and disconnected. Instead of isolated lessons, climate education should be a cross-curricular theme. In addition, 74% of teachers had not received any training on climate issues during their teacher training, and 63% reported that their employer did not offer any additional training. This often leaves teachers on their own to find materials and solutions, instead of having training tailored to different subjects. Many teachers also mentioned emotional strain: the conflict between ideals and prevailing practices in society.

AUTHOR: EUGENIA CASTELLAZZI



Recommendations for teachers:

- Promote interdisciplinarity by combining natural sciences, social studies, and art. For example, use project work in which students discuss ways to mitigate climate change in their neighbourhood or analyse the effects of climate change from different perspectives.
- Move from talking about disasters to solutions and use local examples. Emphasising hope and concrete examples increases relevance.
- Utilise collaboration with researchers by inviting them to visit your classes or participate in school projects.
- Use participatory methods, games, and drama, such as: **Role-play** (1 hour), in which students take on different roles (humans and animals) and consider nature-based solutions from the perspective of justice. (Castellazzi et al. 2024). **Forum play** (1.5 hours), in which groups write and perform scenes depicting conflicts related to nature-based solutions. In the second round, other students can interrupt and change the events.
- More information and materials (in Finnish): https://doi.org/10.5281/zenodo.19184146



In the role-play, students take on the roles of different people and animals and consider nature-based solutions from the perspective of fairness. The aim is to understand how different values and needs influence decisions.
(PHOTOS: PREVIOUS PAGE: LASSI SUOMINEN,
TOP: EUGENIA CASTELLAZZI, BOTTOM: KIRSI HAAPAMÄKI)

Research–based knowledge for teaching and urban green professional practices

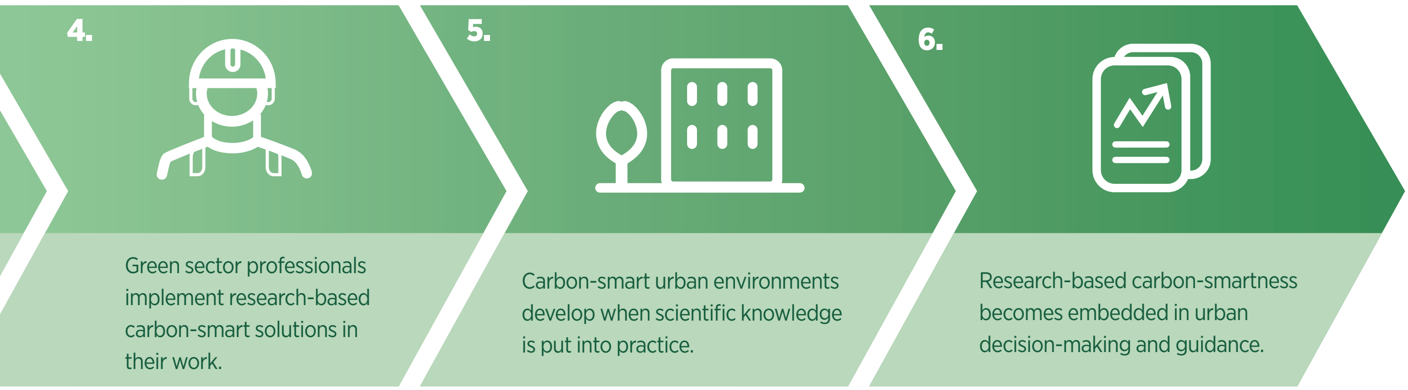
The path of research-based knowledge of carbon-smartness through education into the green infrastructure professional practices (FIGURE: RYYMIN ET AL. 2025).

Communicating research-based knowledge on carbon-smartness is key to promoting sustainable practices. Scientific knowledge alone does not change the world; it is effective only when simplified for teachers, applied in teaching, and practiced in green infrastructure. Communication between researchers and teachers who train professionals in the green infrastructure sector is therefore crucial for transferring new knowledge to teaching, learning, and professional practice.

Teaching reaches new professionals, allowing research findings to be widely disseminated throughout the professional sector (Ryymin & Tahvonen, 2025). Teaching about the carbon cycle is challenging, as many of the processes are invisible and the whole is complex: plant species, growing media, maintenance practices, climate, and urban structure all affect carbon sequestration. The subject is new in the sector, and there is not much ready-made teaching content available.

When a researcher shares findings with teachers, it is an exchange of knowledge between experts (interspecialist communication). Their knowledge and professional language may not always align. **Effective communication requires that the researcher understands the recipients' background and needs and presents the results in a clear and accessible way so they can be readily applied in everyday practice.** This is essential, as green infrastructure professionals from all educational levels design, build, and maintain environments where carbon-smart solutions are put into practice.

Teachers transform research-based knowledge into learning objectives and teaching that support the development of students' thinking and professional skills. Traditionally, curricula present established views from the profession's knowledge base, with only a fraction of scientific publications used as study material. In this era of acute sustainability crisis, transferring research into teaching is too slow. In the fields of green infrastructure, the rapid



transfer of research-based knowledge related to carbon-smart practices into teaching is essential.

The implementation of scientific knowledge does not end with education but continues in working life. Professionals who have entered working life act as practical mediators and developers of knowledge. They apply, test, and share the knowledge they have learned with their colleagues and organisations. In this way, science communication becomes a continuous cycle in which research, teaching, and practice support each other (Ryymin et al. 2026). This transfer of knowledge from researchers to teachers, students, and further on to professionals ensures that research results do not remain confined to the pages of publications but are transformed into concrete actions, carbon-smart solutions, and sustainable practices effectively.

AUTHORS: ESSI RYYMIN, VIIVI VIRTANEN, AND OUTI TAHVONEN

Key messages:

- Research-based knowledge on carbon-smartness only has an impact when it is communicated and applied in practice.
- Researchers should simplify complex knowledge for teachers, who then develop methods for all education levels to apply carbon-smart principles in practice.
- Research, teaching, and practical application form a continuous knowledge cycle of the carbon-smartness of urban green infrastructure.

Glossary

Carbon cycle

Carbon balance: The difference between carbon uptake and carbon emissions in a given area or system over a specific period. The carbon balance indicates whether the system is a sink or whether it releases more carbon than it sequesters. In terms of mitigating climate change, it is favourable if ecosystems sequester more carbon than they release.

Carbon cycle: The continuous circulation of carbon between the atmosphere, vegetation, soil, water bodies, and living organisms. It is driven by biological, chemical, and physical processes such as photosynthesis and decomposition.

Carbon decomposition: The process by which organic matter breaks down and releases carbon back into the atmosphere. Decomposition is a natural part of the carbon cycle.

Carbon flux: The rate at which carbon dioxide or other carbon compounds are transferred between one carbon storage and another, for example, from the atmosphere to the vegetation. The sign of the carbon flux (negative/positive) indicates the direction in which the carbon is flowing. In atmospheric sciences, it is often defined that negative denotes a direction toward the ecosystem and positive toward the atmosphere.

Carbon sink: A natural or artificial reservoir that absorbs more carbon dioxide from the atmosphere than it releases. In urban settings, vegetation, soils, and trees can function as carbon sinks.

Carbon stock / storage: The absolute quantity of carbon stored in a carbon pool (i.e., forests, soils, water) at a given time, measured in mass. Large and long-lasting carbon stocks support climate change mitigation.

Carbon-smartness

At-grade yard, podium yard: An at-grade residential yard is connected to the native subsoil, whereas podium courtyards are built on top of structures—typically parking facilities—where the potential for carbon sequestration is more limited than in at-grade yards.

Canopy cover: The percentage of total area covered by tree canopies. High canopy cover supports carbon sequestration, cools the city, and improves the quality of the living environment.

Carbon factor: A tool to estimate how much vegetation, soil or activity sequesters or releases carbon. The carbon factor complements the green factor tool.

Carbon-smartness: A design and operating approach that strengthens carbon sequestration as a part of a broader, more holistic approach to sustainability.

Climate education: Teaching, learning, and building understanding of the causes, impacts and responses to climate change, and its connections to other sustainability crises.

Garden coaching: Management of vegetation and soils in ways that enhance carbon sequestration and protect existing carbon stocks. It emphasizes long-lived vegetation and minimal soil disturbance.

Ground-based vegetation: In-ground vegetation is connected to the subsoil, which enables carbon to be stored in the soil.

Life cycle assessment (LCA): A method for evaluating environmental impacts across the entire life cycle of a product or activity. LCA includes production, use, and end-of-life stages.

Microforest: A small, dense, and species-rich forest-like planting in an urban environment. Microforests support carbon sequestration, biodiversity, and liveability.

Multifunctionality of urban green: The ability of green environments to deliver several benefits at the same time, such as carbon sequestration, biodiversity, and human well-being. A multi-functional approach supports holistic and cost-effective planning.

Pervious / impervious surface: A pervious surface allows water and carbon dioxide to pass into the soil, supporting vegetation, carbon sequestration, and health-promoting contact with nature. Impervious surfaces, such as asphalt, undermine these processes.

Regenerative urban planning: A systems approach where urban development not only reduces adverse impacts but improves the functioning and resilience of ecosystems and communities. The goal is a carbon-negative city that strengthens natural processes.

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This is a handbook for carbon-smart urban green that summarizes the key messages of the multidisciplinary CO-CARBON project. The handbook is intended for experts, decision-makers, and anyone interested in how natural carbon sinks can be maintained and expanded in urban areas. Achieving cities' carbon neutrality goals requires not only reducing emissions but also strengthening carbon sinks. One key approach is to increase natural carbon sinks in urban green spaces—such as urban forests, parks, street plantings, and yards. Investing in sinks also yields other benefits: it mitigates heat waves and urban flooding and enhances well-being and biodiversity. Carbon sinks are, therefore, worth preserving and expanding.