co-carbon

Carbon Factor

Carbon calculator for the Green Factor tool

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CO-CARBON
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CO-CARBON is an interdisciplinary research project aiming to determine the carbon stocks of urban green areas at different scales using new measurements and process-based models. The project brings together atmospheric scientists, soil scientists, and social scientists in collaboration with landscape architects and urban planners. It develops new solutions and knowledge to support the design, implementation, and maintenance of climate-smart urban green infrastructure. This is carried out in cooperation with project partners, citizens, companies, and urban planners.

The project is carried out by a consortium consisting of the University of Helsinki, Aalto University, the Finnish Meteorological Institute, Häme University of Applied Sciences (HAMK), and the University of Copenhagen. The CO-CARBON project is funded by the Strategic Research Council established within the Academy of Finland.

Carbon calculator for the Green Factor tool

The green factor carbon calculator estimates the carbon sink potential of vegetation and soil on a plot or block over a 50-year period, based on the amount and types of vegetation. The calculator has been developed as part of the green factor tool, and it automatically calculates the carbon sink of a plot based on the surface area data entered into the green factor. In addition to the green factor value, the calculator also provides the plot's "carbon factor," indicating the amount of carbon sink potential relative to the plot area.

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

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

What does carbon sink potential mean?

Plants capture carbon from the atmosphere and store it in their stems, leaves, and roots. When plant parts die, some of the carbon is transferred into the soil, while some is released back into the atmosphere. In built environments, the organic matter in the growing medium also decomposes rapidly in the initial stages, causing emissions (Havu et al., 2022; Riikonen et al., 2017). If more organic matter accumulates in the soil than is released back into the atmosphere through decomposition, carbon accumulates in the soil, forming soil organic carbon (SOC).

Vegetation functions as a carbon sink when plants absorb more carbon than is released back into the atmosphere through plant and soil respiration as well as emissions from maintenance. In this case, carbon remains stored and does not increase the concentration of carbon dioxide in the atmosphere.

Carbon sink potential refers to an estimate of the future carbon sink capacity of a plot's vegetation and soil. The estimate is based on the classification of vegetation types used in the green factor and is calculated over a 50-year life cycle, which corresponds to the standard time frame used in life cycle assessment (LCA). The estimate is indicative and includes uncertainties, but it reflects the order of magnitude of the potential carbon sink based on research data.

Assessment of the carbon sink potential of vegetation types

In assessing the carbon sink potential of vegetation types, a life-cycle approach was applied, examining the establishment and use phases of vegetation over a 50-year period. Two methods were used to estimate the carbon sink potential:

1. **Literature review:** Current knowledge on the carbon sequestration potential of urban vegetation was examined based on previous studies.
2. **Modeling:** Simulations were used to complement the findings of the literature review and to provide a more detailed assessment of the carbon sink potential of specific urban vegetation types. The LPJ-GUESS and JSBACH models were used in the simulations.

By combining data obtained from the literature review and simulations, an overall assessment of the carbon sink potential of different types of urban vegetation over a 50-year life cycle was produced. This integrated approach enabled a more accurate and comprehensive evaluation of the carbon sequestration capacity of urban vegetation, as neither method alone covered all the vegetation types examined.

For each vegetation type, the following were estimated:

- The amount of soil organic carbon (SOC) at the time of establishment, based on recommended and standardized growing medium thickness and type (kg CO_2/m^2) (VYL 2022)
- The accumulation of soil organic carbon over 50 years (kg CO_2/m^2)
- Carbon storage in woody vegetation 50 years after establishment (kg CO_2/tree)
- The average SOC stock in a stabilized state (kg CO_2/m^2)
- Emissions from construction and maintenance over 50 years (kg CO_2/m^2 or per tree)

Based on these estimates, the total carbon sequestration was calculated, including carbon accumulation in the soil and carbon stored in woody biomass, as well as total emissions from the growing medium and maintenance. The carbon sink over a 50-year period was determined by combining sequestration and emissions. It was assumed that vegetation and soil layers would not require renewal during this period. Simulated values were based on a single growing medium type that follows the recommended guidelines of the Finnish Association of Landscape Industries (VYL 2022). Alternative growing medium solutions were not examined. It should be noted that the chosen growing medium solution can significantly affect the calculated emissions, and thus the carbon sink potential.

Estimates for different vegetation types can be found in the “Carbon Calculations” sheet of the Carbon Factor tool (Excel).

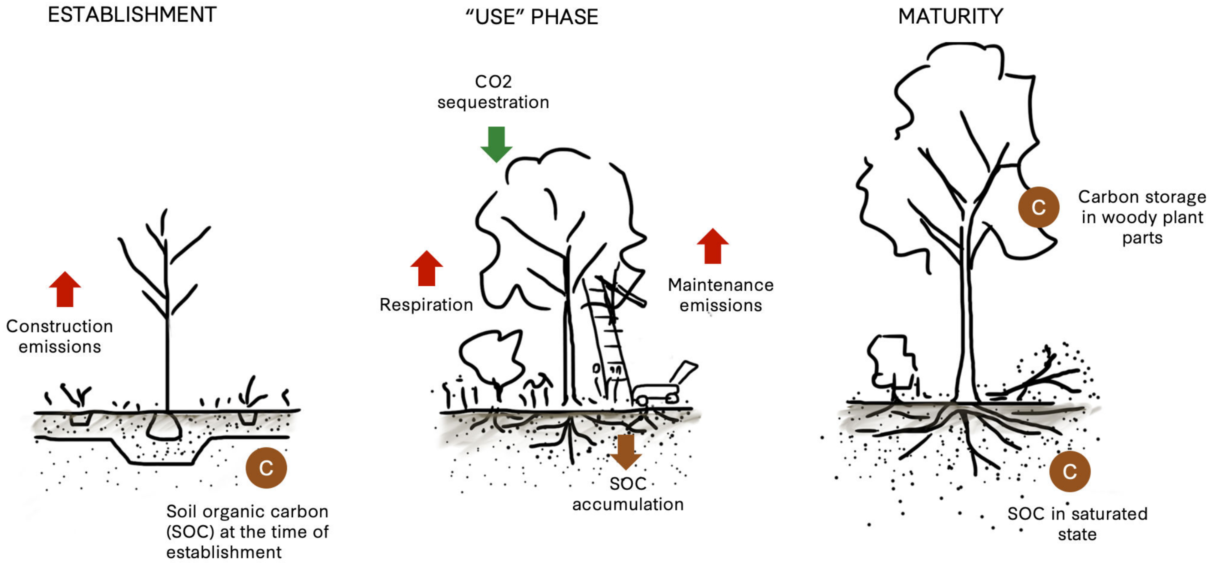

Figure 1: The calculation considered carbon sequestration, carbon stocks, and emissions of urban vegetation in accordance with adapted life cycle assessment phases. **The establishment phase** generates emissions from construction, and constructed growing media may contain high levels of organic carbon. **The use phase** refers to the carbon cycle during the lifecycle of the vegetation. During **the phase of active growth and development**, the amount of carbon released from the soil is initially high but later stabilizes to a level consistent with natural respiration. As vegetation matures, soil respiration may increase again due to the greater amount of decomposable plant material. At the same time, carbon sequestration becomes more efficient over time as leaf area increases. As a result, the carbon stocks of **mature vegetation and soil** are assumed to stabilize at a certain level.

Carbon factor target levels

Similarly to how the green factor expresses the amount of green infrastructure on a plot relative to its area, the carbon factor indicates the carbon sink potential of the plot's vegetation and soil relative to the plot area. Since carbon sequestration and the formation of carbon sinks are slow processes, the carbon sink potential is assessed over a 50-year period. A high green factor value does not automatically mean a high carbon factor, as the green factor calculation also emphasizes many other aspects. However, for example, large trees effectively increase both the green factor and carbon sinks.

Unlike the green factor, the carbon factor can also have a negative value. A positive carbon factor means that the plot's vegetation and soil act as a carbon sink over a 50-year period. A negative carbon factor means that emissions over 50 years exceed the amount of carbon that is sequestered. The largest emissions in the calculation arise from the initial emissions of the growing medium.

A target level can be set for the carbon factor in the same way as for the green factor. Based on test calculations produced in the CO-CARBON project, **a carbon factor exceeding approximately 5.0 can be considered a recommended level**. This corresponds to a carbon sink of 5 kg CO_2/m^2 for the plot. In the test cases, carbon factor values showed considerable variation between sites (see Ariluoma, M., webinar presentation, November 7, 2024).

Based on preliminary test cases, the following indicative target levels can be defined:

> 9.0 Strong carbon sink

5.0–9.0 Moderate carbon sink

0–5.0 Low carbon sink

If the carbon factor is negative, it is recommended to revise the design solution and reduce emissions, for example by favoring recycled growing media.

Example

In this example, the carbon factor has been tested in five city blocks that represent a relatively dense urban structure based on perimeter blocks. The example blocks and their yard designs are based on preliminary concept design phase plans prepared for the Hiedanranta area in Tampere, along with the green factor calculations developed for them (Figure 2). The green factors and carbon factors of the sites are presented in Table 1.

The total carbon sequestration of the courtyards ranges from 19 to 41 tonnes of CO_2, corresponding to 5.3–7.8 kg CO_2 per square meter over a 50-year period (Figure 3). When emissions from growing media, construction, and maintenance are included, the net carbon sink decreases significantly to 0.7–1.9 tonnes of CO_2 (Table 1). Courtyard B4 produces more carbon emissions than it sequesters, resulting in a negative carbon factor. If emissions from growing media were excluded from the calculation, all courtyards would function as net carbon sinks, sequestering 6–22 tonnes of CO_2. This outcome could be achieved by using lower-emission growing media.

In courtyards B1–B3, carbon sequestration is mainly based on large trees, while other vegetation types have only a minor influence. In contrast, in courtyards B4 and B5, vegetation types are more varied, and carbon sequestration is primarily driven by small trees and lawn areas, while large trees play a smaller role. The emissions of these courtyards are mainly caused by perennials and shrubs, particularly due to emissions from their growing media. Courtyards with extensive shrub plantings in particular generate high emissions, as shrubs require (according to VYL recommendations) relatively large volumes of growing medium compared to their carbon sequestration capacity. In addition, large green roof areas, especially the rooftop garden in courtyard B4, contribute to higher emissions. Emissions could be reduced by switching to a lighter green roof type.

Although the blocks are broadly similar, there are significant differences between the sites. For example, the largest courtyard, B4, produces the lowest carbon sequestration per square meter because it has little tree cover and the rooftop garden increases emissions. In contrast, B3, which has the densest tree cover, achieves the highest level of carbon sequestration, as the large number of planted trees offsets the emissions from other vegetation types. By applying different vegetation solutions, it would be possible to significantly increase the carbon factor of all sites.

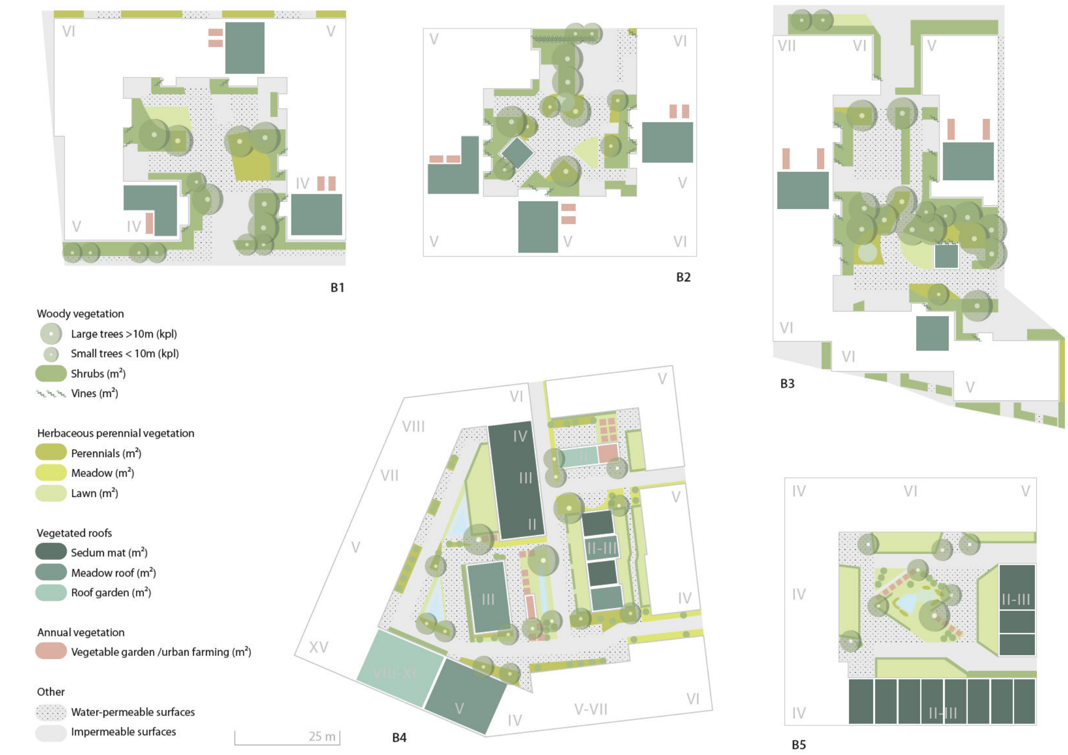

Figure 2. Blocks B1–B5 and their vegetation types used in the example calculations, based on preliminary concept design plans and green factor calculations.

	Plot area, m²	Yard area, m²	Carbon sink potential in 50 years, kg CO_2	Green factor	Carbon factor
Hiedanranta B1	4229	1878	732	0.84	0.2
Hiedanranta B2	3527	1261	1946	0.86	0.6
Hiedanranta B3	5376	2815	1485	0.85	0.3
Hiedanranta B4	6547	2556	-9337	0.9	-1.4
Hiedanranta B5	3498	1401	1662	0.92	0.5

Table 1: Green factors and carbon factors of the example blocks. All sites meet the target level for the green factor. However, the carbon sink potential in all blocks is very low, and in one block (yellow cells), vegetation and soil appear to act as a source of emissions rather than a carbon sink.

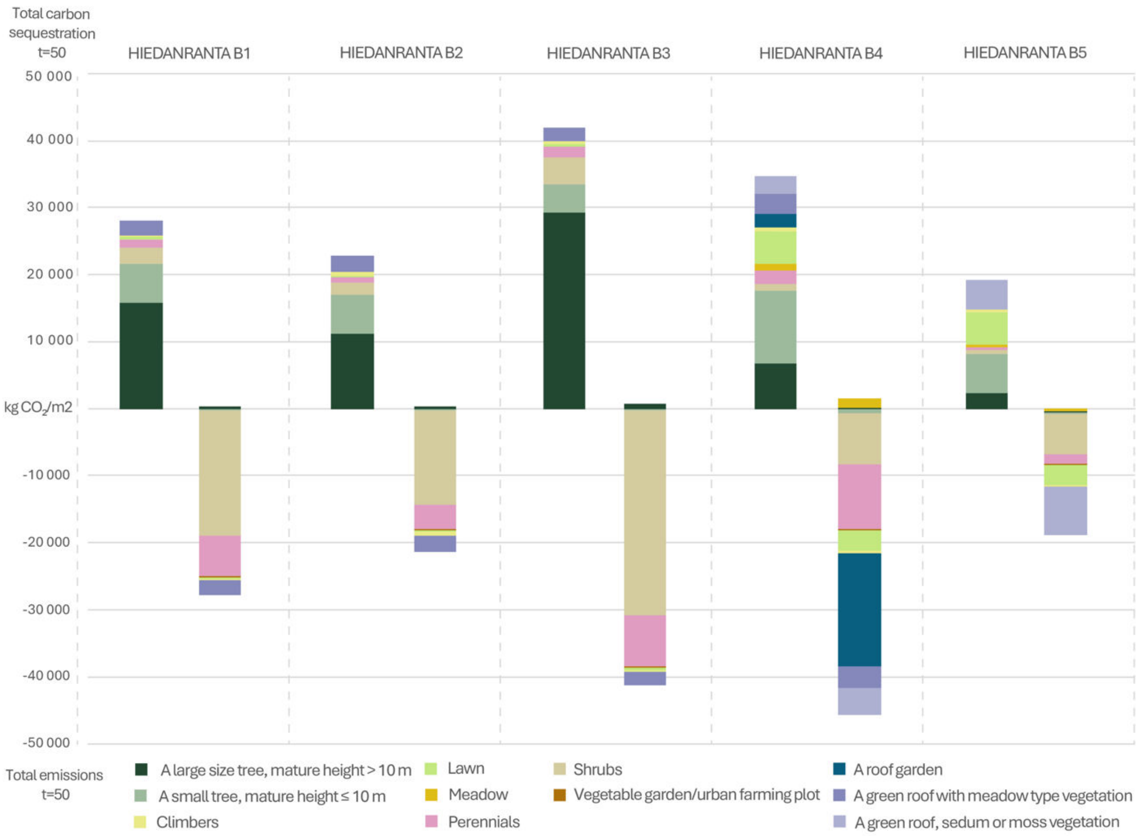

Figure 3: Carbon sequestration and emissions of vegetation and soil by vegetation type in the example blocks B1–B5. In the sites with extensive shrub plantings, emissions from shrub growing media are emphasized. Trees are the most effective in carbon sequestration, but other vegetation types also absorb carbon.

What are the benefits of the carbon factor?

With the green factor carbon calculator, designers can compare different vegetation solutions and their impacts on a plot's carbon sinks. The assessment can be carried out during the concept design or implementation design phase, as long as the plot area, vegetation types, and their areas are known. The carbon factor encourages the selection of sustainable and climate-smart green infrastructure solutions and complements the green factor method. In principle, the assessment can also be applied, for example, to park design projects, but in such cases the carbon factor target levels do not apply, as they have been defined based on residential blocks.

Although the carbon sinks of vegetation and soil are quantitatively small compared to emissions from construction, they are the only carbon sinks that can be actively created during construction. This opportunity could be utilized much more than it currently is (Hautamäki et al. 2025). The goal of green construction should be, at a minimum, not to increase the overall emissions from construction. The intention is not to offset construction emissions with carbon sinks from green infrastructure, but primarily to preserve existing carbon stocks and sinks as much as possible, minimize emissions caused by green construction, and create new carbon sinks whenever feasible.

Enhancing carbon sequestration is also likely to bring additional benefits, such as promoting biodiversity (Ariluoma et al. 2024).

Uncertainties

The numerical values included in the green factor carbon calculator are indicative, as in reality the carbon cycle between the atmosphere, vegetation, and soil is influenced by numerous factors, such as growing conditions, maintenance practices, and climate. There are also differences between plant species. Furthermore, for some vegetation types there is not yet sufficient relevant research data available to comprehensively assess their carbon sink potential. In addition, in built environments, the initial carbon emissions from imported growing media may vary significantly depending on its composition. Therefore, the carbon emissions associated with growing media require further research.

Additional information

For more information on the carbon calculator values and calculation methodology:

Ariluoma, M. & Kulmala, L. 2024. *Supplementary study 1: Assessing the carbon sink potentials of urban vegetation types.* Part of the doctoral dissertation: Ariluoma, M. 2025. *Green capture – Enhancing carbon sinks within urban residential green spaces.* Aalto University.

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