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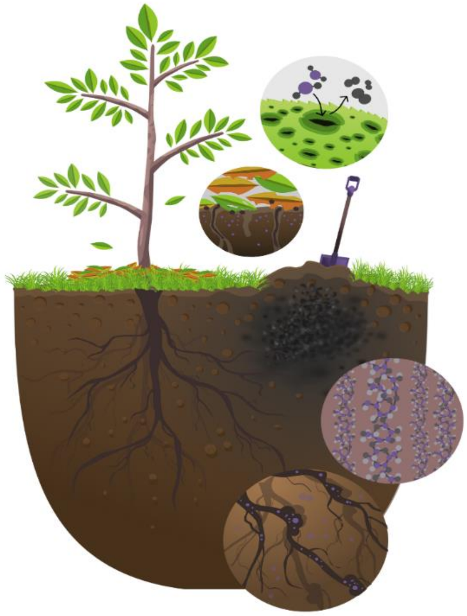
Report on principles of urban demonstration areas for carbon sequestration



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Key terms

Carbon sequestration	A process of carbon dioxide (CO_2) removal from the atmosphere into other secure, long-lived carbon pools, primarily fixed by plants through photosynthesis (IPCC 2018, Lal 2008). Carbon fixed in biomass can be turned into a more stable form (biochars) through heating the biomass in oxygen-depleted conditions (pyrolysis). Formation of secondary carbonates through the reaction of Ca^{2+} and Mg^{2+} and atmospheric CO_2 is another natural way of CO_2 fixation, but it is a comparatively slow process (Lal 2008).
Carbon sink	Any biological, geological or other process, activity or mechanism that removes CO_2 from the atmosphere into a carbon storage, e.g. forests, peat, soil or sediments (Bruce et al. 1999, IPCC 2014). Reliable estimation of the effect of different management practices on the amount of carbon sequestered is of special importance for carbon sink trading. Transparent and accurate measurements are necessary for the validation of carbon sinks.
Mineralization	A process where soil microorganisms turn soil organic substances into soluble inorganic compounds, releasing CO_2, H_2O and nutrients; final phase of organic matter decomposition.
Soil aggregate	Formed from groups of primary soil particles (silt and clay sized fractions) attached to each other more strongly than to the adjacent particles.
Soil inorganic carbon (SIC)	Carbon primarily found in carbonate minerals (e.g. calcite and dolomite) formed through the weathering of calcareous parent material or through the reaction of Ca and Mg silicate minerals and atmospheric CO_2.
Soil organic carbon (SOC)	Carbon fixed to the soil organic matter (SOM), including (I) plant and animal residues at various stages of decomposition, (II) organic compounds microbiologically/chemically modified from the breakdown products and (III) living microbial biomass and fine plant roots. For SOC stock accounting, SOC is defined as all organic carbon present in the fine-earth fraction (< 2 mm) of soil.
Soil respiration	Includes diverse soil processes that produce CO_2 because of biological activity of microbes, plant roots and soil animals. *Heterotrophic* respiration refers to CO_2 released during the decomposition of soil organic matter and *autotrophic* respiration to CO_2 respired by live roots.
Urban space	Urban space can be defined based on e.g. impervious surface area (ISA) and population density – different countries may use different criteria for the definition of urban (Raciti et al. 2012, United Nations 2019). For example, Raciti et al. (2012) defined ‘urban’ based on 1 km^2 moving window having > 25% ISA, while other areas were classified as ‘nonurban’. Urban land cover category was further divided into higher and lower population density classes (greater or less than 2,500 persons km^{-2}, respectively). Estimates of urban C stocks may vary greatly depending on how ‘urban’ has been defined (Raciti et al. 2012).
Weathering	Physical breakdown of rocks and disintegration of their original chemical structure. Occurs when rocks are exposed to natural conditions, including abiotic factors such as rain, wind and temperature differences and biotic factors such as microbes and vegetation.

Executive summary for policymakers

In order to achieve the goals of carbon (C) neutrality within next 15–20 year, cities worldwide need to increasingly apply negative emission technologies. Biochars, thanks to their stability against microbial degradation, suit well for application to both agricultural and urban soils as a C- fixing technology providing multiple co-benefits. Remarkable compensations to current emissions can be made by implementing more sustainable management practices to the urban green spaces. While providing support for the city planners and policymakers to develop tools for more sustainable management practices of urban green areas, high visibility and impact can be gained in the densely populated urban areas. This report focuses on main principles of urban demonstration areas for carbon sequestration and as such describes the work done in the WP 3 of the Carbon Lane project funded by EIT Climate-KIC.

Urban demonstration sites for carbon sequestration offer unique opportunities for research, urban planning, citizen engagement and combining multiple approaches and interests of different sectors. Better scientific understanding can be acquired, alternative ways for managing urban green areas developed and citizens may get new information and inspiration to act and support climate-friendly solutions. Examples of practices for carbon sequestration that may be relevant in an urban park include e.g. biochar-based planting soils and the use of CO_2-fixing minerals such as olivine.

Demonstration sites, in order to facilitate validation of C sequestration, need to be designed in a way that is also sound scientifically. Thus, it is crucial to document well all practices, carefully plan the experimental design as well as a reliable and cost-effective verification of C sequestration. In order to tackle random variation in environment and between biological entities, all treatments need to be randomised and replicated, e.g. there should be 5–10 trees per treatment located randomly across the area. A control treatment is needed to investigate the effect of the introduced practices; e.g. in Finland, business-as-usual (INFRA-RYL) could be used as negative control and a sewage sludge-made compost as a positive control. Sampling and analyses of quality of all materials used as well as initial measurements at the demonstration site are highly important. Preferably only standardised and certified products should be used. In the case of biochars, the European Biochar Certificate ensures that the biochar in question is sustainably produced and safe to use, e.g. it does not exceed threshold values for polycyclic aromatic hydrocarbons or heavy metals.

Verification of carbon sequestration requires that

- Sampling procedure is carefully planned to get meaningful results; e.g. for planting soils, the undisturbed (intact) soil core method could be used to determine the relevant parameters for the calculation of SOC stocks, including SOC concentration of the fine-earth fraction (< 2 mm), content of rock fragments (> 2 mm) and soil bulk density
- Carbon stocks can be reliably estimated; e.g. for soil carbon measurement, dry combustion method is recommended - SIC can be accounted for with acid pre-treatment
- The external carbon input is taken into account; in the case of biochars, C content of biochars should be analysed and the amount of C input to soil recorded
- Pyrogenic carbon fraction in soil is preferably quantified if there are resources for that; e.g. thermogravimetry – differential scanning calorimetry or mid-infrared spectroscopy could be used

To optimise the use of biochars for carbon sequestration, it is important to consider the stability of biochars in soil. Certain properties of biochars (e.g. H/C_{org} ratio) can be used to predict its persistence in soil.

All carbon fixing treatments need to be applicable to urban space. Most importantly, they must be safe for humans and environment and hard to vandalise. All materials used in urban environment should comply to safety standards (REACH, EBC) and the raw materials should be traceable. In the case of biochar, the treatments need to be evaluated and planned with respect to their applicability to urban environment, considering e.g. fire safety and dustiness.

One of the key objectives of the Carbon Lane project is to explore how similar projects could, in the future, **engage citizens and other stakeholders of the potential of urban carbon capture.** The means of communication are divided into those, that are implemented inside the park and those that are off-site, such as online materials or trainings organized outside the park. The focus is on communication within the park, as it is probably the most effective way to influence on people when they are already inside the park. However, many of the communications within the park also utilize online communication tools to widen the impact.

The **final plan of the Hyväntoivonpuisto demonstration area includes 79 deciduous trees and nine different treatments from seven different suppliers of growing media.** The number of different treatments and repetitions was determined by how different growing media could be delivered on the given schedule, and also the randomisation principle was compromised on. To facilitate construction, the trees are planted in connected pits with several trees per pits clustered together

Following up the C sequestration in Jätkäsaari demonstration site is recommended to follow plan of measurements on stepwise levels of importance and carry them out in this order according to the time and resources available (Appendix 4). The time horizon to be considered is potentially centuries, but at least a few decades are required to be able to gain insights on the potential of e.g. tree C sequestration. The measurements aiming to document biomass and soil C stocks and sequestration are typically performed on annual scale.

Helsinki is committed to achieving carbon neutrality by 2035. The vision includes an annual carbon sink equivalent to 20% of the current emissions. With the biochar application rate of 10–15% in the planting soil, annually 60 000–90 000 m^3 of biochar could be used in the new soils in the metropolitan area and 20 000–30 000 m^3 respectively in Helsinki. One cubic meter of biochars consists of at least 300 kg of product and if one kilogram of biochars would correspond to 3.11 net negative carbon removal, the annual potential of carbon removal in the Metropolitan area would be 55 000–84 000tn CO_2eq and respectively 18 000 - 28 000 tn CO_2eq in Helsinki**. In Helsinki, the annual potential of using biochar in new planting soils equals to 0.7 to 1 % of the annual emissions and 3.5–5% of the targets of negative emissions of Helsinki.**

The biochar market is at its introductory phase and the commercial availability is limited to small-scale production. However, the production of biochar is expected to rapidly increase during coming years. The current price of biochar for the soil amendment on Finnish market is around 225–250€ per m^3.Technological advancement and scale-up activities can significantly increase the feasibility of biochar, making it more competitive carbon removal solution in the future.

The potentials and costs of carbon sequestration compared. The number in the brackets represent the total variation in the literature. Data is based on the study conducted by Fuss et al (2018)

Negative Emissions Technology	Potential (Gt CO_2 yr^{-1})	Cost (US$/t CO_2)
Bioenergy with carbon capture and storage (BECCS)	0.5–5 (1–85)	100–200 (15–400)
Afforestation and reforestation (AR)	0.5–3.6 (0.5–7)	5–50 (0–240)
Soil carbon sequestration	2–5 (0.5–11)	0–100 (−45–100)
Biochar	0.5–2 (1–35)	30–120 (10–345)
Enhanced weathering	2–4 (0–100)	50–200 (15–3460)
Direct air carbon dioxide capture and storage (DACCS)	0.5–5	100–300 (25–1000)

1 Introduction

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels (IPCC 2019), mainly due fossil fuel combustion and land use change, especially deforestation. These actions produce greenhouse gases (GHGs), compounds that may occur naturally or anthropogenically in the atmosphere. Industrialisation has led to growing concentrations of GHGs in the atmosphere, thereby strengthening the greenhouse effect and warming up the land surface remarkably from the pre-industrial period (1850-1900) to the beginning of the 21st century (IPCC 2019). Carbon dioxide (CO_2) is the most important greenhouse gas influenced by human activities (Bruce et al. 1999). Other GHGs of concern are methane (CH_4) and nitrous oxide (N_2O). While reducing emissions of GHGs needs to be the primary goal, it is important to consider strategies that aim at developing tools to enhance fixation of CO_2 from the atmosphere. Climate policies worldwide are increasingly acknowledging the importance of the latter process. For instance, the current government of Finland (from 2019) aims at securing living conditions for the future generations by means of e.g. cutting emissions, growing carbon (C) sinks and enhancing cooperation of different sectors (e.g. construction, transport and land-use sectors).

While the development and implementation of more sustainable management practices in agriculture and forestry to mitigate climate change are in key roles, the importance of urban vegetation and soils may have been underestimated. Urban areas are characterised by large impervious surface areas that typically have high surface water runoff (Pataki et al. 2011). Flooding is expected to be more serious in many places as extreme weather events (e.g. heavy precipitation events) become more frequent in future (IPCC 2014). Besides being potential carbon sinks, urban vegetation and soils have other important functions in e.g. stormwater management and food production. In general, green built environment and nature-based solutions in the cities yield both environmental and social benefits by improving the quality of urban life.

Currently, urban areas act as net sources of CO_2 (Velasco & Roth 2010). Moreover, population growth centres in the cities, indicating that the CO_2 emissions of the cities are expected to grow even more in future. That is why more sustainable practices are needed in the cities to change the trend. Like many other cities, Helsinki aims to become carbon neutral by 2035 (City of Helsinki 2018). Despite ambitious goals, there is a long way to go to C neutrality. While keeping in mind that remarkable reductions to current emissions are essential, one opportunity is to use negative emissions technologies, such as biochars. These are C-rich materials produced from biomass that would otherwise finally mineralize in a relatively short time as CO_2 to the atmosphere. In biochars, carbon is fixed in a form that may be stable in soil for hundreds or even thousands of years (e.g. Kuzyakov et al. 2014).

Implementation of methods for C sequestration at large scale requires that the emissions and reductions can be quantified by measuring and monitoring accurately and cost-efficiently - this remains challenging (Paustian et al. 2016). Understanding terms additionality and baseline is important while implementing activities that are expected to cause emission reductions or CO_2 removal from the atmosphere. Additionality refers to the difference in the effect of the implemented activity (e.g. adding biochars to planting soil) in comparison to the baseline scenario (e.g. negative control or business as usual). The baseline scenario is an option that would happen if the activity was not implemented or in other words, no policy effort was made (IPCC 2018). In carbon market context, it is important that the emission reductions or CO_2 removal are additional to the baseline scenario and the effect of the implemented activity can be reliably estimated.

Carbon Lane project was funded by EIT Climate-KIC and aimed to bring together actors from different sectors (e.g. suppliers, researchers and policymakers) in a co-creation process that included multiple workshops where knowledge was shared. Currently, the city is building a new residential area (100 ha) in Jätkäsaari, a fill-in peninsula located in the shoreline of central Helsinki. As part of the Carbon Lane project, an urban demonstration site with biochar-based planting soils from various suppliers was established in Hyväntoivonpuisto, the central park of Jätkäsaari. The area is ideal for this purpose as it will accommodate 21 000 new residents, including an active community with high interest towards climate-friendly solutions.

In this report, we describe the general principles of urban demonstration sites for carbon sequestration, considering the technologies and practices that may be relevant based on scientific soundness and applicability to urban space. We present an overview of the currently available methods for measuring the change in carbon stocks of soil and vegetation. A proposal and a final plan with descriptions and visual layout of the Jätkäsaari demonstration site are included in this report, combined with a follow-up plan for the monitoring and verification of carbon sequestration at the site. Lastly, we also present the estimated carbon impacts of the proposed solutions for Jätkäsaari demonstration site as well as the ideas for citizen engagement in the park.

2 General principles of urban demonstration sites for carbon sequestration

2.1 Scientific soundness

2.1.1 Proper documentation of all practices

All materials used (biochars, composts, fertilisers) should be sampled representatively prior to adding them in soils, and their quality analysed. This is how the effect of added biochars can best be predicted (Bird 2015). Sampling and analysing of biochar should preferably be done according to the guidelines of the European Biochar Certificate (EBC 2012). Due to the heterogeneous nature of biochars, however, the sampling procedure described by EBC (2012) has been shown to have limitations especially for the determination of polyaromatic hydrocarbons (PAHs) in terms of accuracy and reproducibility (Bucheli et al. 2014). Therefore, Bucheli et al. (2014) recommended the use of incremental cross-stream sampling devices that were mentioned in the EBC guidelines, too, as an alternative sampling method (EBC 2012).

It is important to know the amount and quality of C added to the soil with biochar. Carbon content of the EBC-certified biochar needs to be more than 50% of the dry mass. The effect of a biochar can be estimated by analysing its C content prior to its addition in soil and recording the amount of added biochar. As a part of the carbon sequestration verification process, however, we need also to assess the persistence of biochar in soil. In addition to measurements characterising the fractions of black C (e.g. by benzene polycarboxylic acid (BPCA) technique), the stability of biochars in soil can also be predicted, at least to some extent, from proxy characteristics like temperature of pyrolysis as well as the molar H/Corg ratio of biochar (< 0.7 for EBC-certified).

The amounts of materials added, and their C content needs to be measured and documented because the external C input must be considered as a part of the verification process. The starting points including e.g. tree dimensions and initial soil C content should be measured and documented properly. Fertilisation and other maintenance practices (such as irrigation) affect soil nutrient status and water content and therefore, plant growth. Consequently, the C sequestration potential of the site is affected which is why it is important to record the amount of fertilisers added as well as the other maintenance practices, too.

2.1.2 Experimental design

2.1.2.1 Controls: positive and negative

In order to assess the effectiveness of the treatments tested (e.g. different biochar-based growing media), it is crucial to plan well the use of experimental controls for having the treatment effect clearly stand out. Control units (e.g. trees) should be as identical to the treatments as possible except the treatment groups go through experimental manipulation (Ruxton & Colegrave 2016). Controls and treatments are kept under same conditions; for example, similar management practices like watering the trees are conducted for the controls and treatments. Two different types of controls can be used: negative and positive.

Negative controls
Negative controls receive manipulation that is expected to have no effect. Business as Usual (In Finland the national standard called INFRA-RYL) could be used as a negative control. The business-as-usual control treatment follows current Finnish national subcontracting quality requirements used in constructing urban green (Appendix 1).

Positive controls
Positive control in an experiment is a treatment which is expected to produce expected results and can be used to show that the experimental procedure is working. Positive control can also be used to benchmark a new method against an older, better known one.

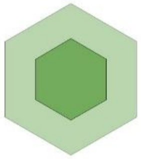
Literature indicates that biochar properties and effects are to some degree similar to those of other organic soil amendments, such as compost or peat (e.g. Abujabhah et al. 2016, Schulz & Glaser 2012, Ohsowski & Brian 2012, Ow et al. 2018). These have much longer history of use in urban greening soils (e.g. Scharenbroch 2009). To lesser degree, biochar may act similarly to inorganic fertilisers, but as the C cost of their production is known to be high, inorganic fertilisers are not considered a good positive control in this case. Currently, both composts and peat are much cheaper soil amendment option than biochar, so in order to justify biochar use in planting soils it should provide higher benefits.

Peat is considered a fossil carbon source and its use accelerates climate change (IPCC 2006); therefore, biochar or compost are preferable as a material for planting soils instead of peat. Phasing out the use of peat in planting soils is already in progress, leaving compost as the most reasonable positive control material for experiments with biochar planting soils. Composts are also manufactured from biomass, usually as a side product of waste management. Their C footprint varies based on e.g. raw materials and the conditions during composting process (e.g. Hermann et al. 2012), and thus should be assessed case by case, which is currently rarely feasible. In addition, the longevity of compost C storage in soils is poorly known (e.g. Prasad & O'Shea 1997, Prasad & Maher 2003). Despite these problems, in regards to the effect of biochar on soil properties and plant performance, compost makes for the most reasonable positive control provided that the properties of the compost used are well documented.

In Finland, one suitable option for positive control in C-fixing demo parks is HSY sewage sludge-made compost Metsäpirtin multa.

2.1.2.2 Randomisation and replication

To avoid random variation or "noise" due to variations in environment and organisms (e.g. trees), each treatment needs to be randomised and replicated. There should be 5-10 trees per treatment, and the grass areas need to be at least 3 x 3 m. All measurements and samplings must be conducted avoiding the edge effects. Thus, it is important to have as big as possible the "experimentally relevant" area which is more than 100 cm from the edges of the area (Figure). Grass areas should have at least three replicates. Each treatment should be randomly assigned over the area, while representatively considering shade, hilltops and valleys as well as the distance from the paved routes (so that all treatment combinations occur both close and far from them).



Diameter measured at widest point 5 m
Diameter of the experimentally relevant zone 2,7 m

Total area 16,2 m^2
Area of the experimentally relevant zone 4,7 m^2

Figure 1. Example of the grass experimental areas and the "experimentally relevant" zone of these.

2.1.3 Methods for the validation of carbon sequestration

Methods for estimating carbon sequestration are available from laboratory and field scale to ecosystem and regional level measurements (Nayak et al. 2019). Measurements of C stocks are needed for the validation of carbon sequestration especially in smaller scale, but in regional level, modelling is a useful tool for predicting changes in C stocks. Several well-established models for estimating C stocks and predicting SOC stability are already available (e.g. Yasso, Finnish Meteorological Institute), but there is still continuous need to evaluate the performance of models with long-term field experiments (Bispo et al. 2017). In general, the estimation of C stocks and potential C sequestration should not be based on only one method but a combination of data from the laboratory and field measurements, satellite pictures, remote sensing and modelling. It must be noted though, that the geographic information system (GIS) data (acquired from e.g. satellites and remote sensing) with low spatial resolution used in many national inventories of C stocks may not be suitable for urban environment that is characterised by patchy vegetation. For example, Edmondson et al. (2012) found OC storage of urban vegetation to be higher than estimated in the national inventory.

When using biochar as a tool for C sequestration, new challenges emerge from the separation of positive and negative priming effects of the native SOC. 'Priming' is a term that refers to the interactions of the added organic matter (e.g. biochar) with the native soil organic matter, commonly used to describe the effect of e.g. biochar addition on SOM mineralization (Figure ; Whitman et al. 2015). Priming effects can be both positive (resulting in increased mineralization of SOM) and negative (decreased mineralization). In short-term, both positive and negative priming effects have been observed but the long-term effects of biochar on native SOM are largely unknown. Ideally, we would like to know the difference between added biochar-C and negatively primed char. Term 'apparent priming' should be understood and distinguished from the 'true' priming. Addition of biochar (or other organic matter) may cause increased microbial activity and consequently, increased microbial biomass C turnover, phenomenon called apparent priming (Blagodatskaya & Kuzyakov 2008). Recently promising results were presented by Blanco-Canqui et al. (2020), where SOC increased by twice the amount of biochar carbon applied after six years in Midwestern USA, so strong negative priming was found due to biochar addition for the first time under field conditions.

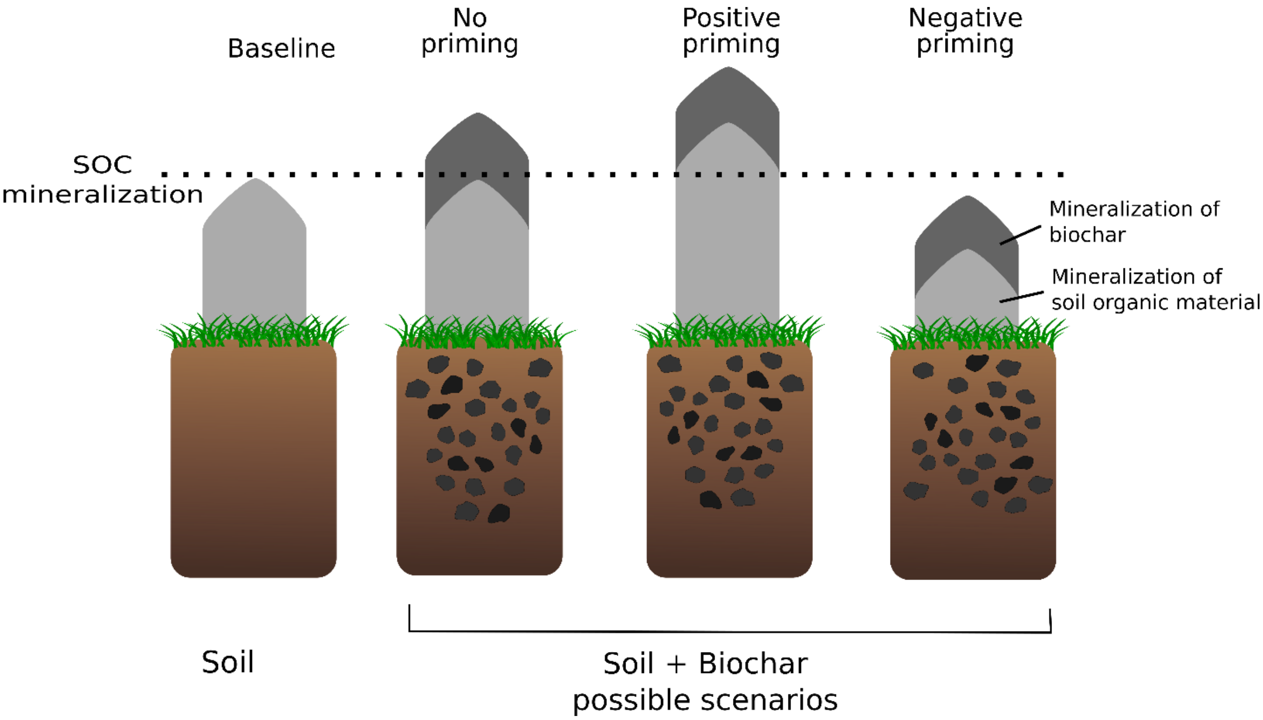


Figure 2. Priming effects of biochar. Adapted from Whitman et al. 2015. Illustration by Suvi Tikka.

2.1.3.1 Materials

Minerals that can fix carbon

Weathering of certain rocks can transfer carbon from its atmospheric pool to the geological carbon pool. This occurs as a part of the global, long-term carbon cycle (Boot-Hanford et al. 2014) and as a result, thermodynamically stable carbonate minerals are formed. When considering the potential for carbon sequestration, carbonate-forming stone material may not be the most efficient tool (see Appendix 2 for more details). Carbonation reaction has low reaction kinetics in natural conditions, but if the raw material is attained from a by-product, could still add some C – sequestering potential to a certain location/park. Carbonation is a surface reaction, hence amount of surface area determines the carbonation potential of mineral. The smaller the particle size is, more carbon can be fixed to the mineral surface. To attain maximal carbon sequestration, stone material has to be small in particle size and also preferably have lots of cracks in it.

Soil

The major soil C fractions can be classified as soil organic C, soil inorganic C (i.e. carbonates) and black C. This classification is arbitrary, as black C is organic C in origin, but the separation of black C from organic C in terminology is useful for the methodological consideration. Black carbon is a general term for recalcitrant, C-rich residues formed through incomplete combustion of biomass to char or recondensation of volatiles to soot (Schmidt and Noack 2000). The black C fraction is of special interest due to its stability and slower turnover than organic C fraction. Charcoal, soot, elemental carbon or pyrogenic carbon are examples of synonyms used in the literature for black carbon. Here, the term pyrogenic carbonaceous material (PCM) is used to describe the continuum of C-rich materials from char and charcoal to soot and graphitic carbon (Schmidt and Noack 2000). Biochar differs from charcoal in that it is intended to be applied in soil or in broader context, used for environmental management (Lehmann & Joseph 2015). Biochar contains not only PCM but also inorganic ash constituents and in some cases also various amounts of partially or completely unpyrolysed organic matter (Bird 2015). Consequently, biochars differ in their chemical composition and persistence in soil, depending on e.g. pyrolysis conditions (Schmidt et al. 2011) and the feedstock used.

In SOC sequestration studies, soil sampling and analysis procedures need to be well-designed (e.g. Bruce et al. 1999, Nayak et al. 2019, Olson et al. 2014). To verify that SOC sequestration has taken place with a certain treatment at the site, it is necessary to be able to show an increase in SOC stock over time and to consider the external C input (Olson 2013). Challenges in SOC measurements arise from the spatial variability of SOC content in heterogeneous soil matrix and the relatively slow temporal changes in SOC content. Changes in the chemistry of biochar over time in soils may cause further challenges for the analysis (Bird 2015). Therefore, long-term experiments would be of great importance for the verification of biochar and SOC sequestration as it is necessary to show how long the fixed C is retained in soil.

Isolation, quantification and characterisation of different C fractions in soil

The choice of the methods for the verification of soil and biochar C sequestration is important and deserves careful consideration as there are wide range of techniques available but none of them is ideal (see the table in Appendix 3 for the comparison of the methods). While choosing a method for a certain research question, issues such as the accuracy required, the type and degree of characterisation needed, the number of samples as well as the accessibility and cost of the equipment required for the analyses need to be considered (Bird 2015, Hammes et al. 2007). The methods (and if possible also devices) used for C determination need to stay same throughout the monitoring period to ensure the comparability of data acquired from different points of time (Olson 2013).

Widely adopted laboratory methods for the measurement of SOC content are dichromate oxidation (Walkley-Black method), loss on ignition and dry combustion in an elemental analyser (Nayak et al. 2019). Overall, chemical oxidation techniques (including dichromate oxidation) alone cannot probably provide reliable isolation and quantification of PyC and SOC, but further characterisation of the oxidation residues is needed with e.g. solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy (Knicker et al. 2007) that is expensive. Dry combustion measures SOC directly in non-calcareous (no carbonates present) soils and if SOC content is to be measured in calcareous soils, it requires that the carbonates are first removed with hydrochloric acid (HCl). For routine analysis, dry combustion has been proposed as the most suitable method for the measurement of total C content in soil (Sollins et al. 1999) but this method by itself does not provide isolation of SOC and PyC fractions.

Recent development of spectroscopic techniques is encouraging and indicates that these techniques could provide rapid and accurate estimation of soil C stocks in the field (Nayak et al. 2019). However, even though e.g. visible and near-infrared (Vis-NIR) spectroscopy has already been used for estimating multiple soil properties in the field (e.g. Pei et al. 2019), collection of soil samples and further laboratory analyses are still required. Furthermore, the field measurements are still lacking the required accuracy because soil moisture and texture interfere with spectral features and hence, the laboratory measurements from a pre-treated soil are still more preferable. Bird (2015) proposed mid-infrared (MIR) spectroscopy as the most promising technique for biochar analysis in soils with a drawback that another technique needs to be adopted for the calibration of MIR. As a calibration technique, he proposed the use of hydrogen pyrolysis (hypy), NMR spectroscopy or benzene polycarboxylic acid (BPCA) technique. BPCA method has been further improved recently by Llorente et al. (2018) to reduce the cost and time of the analysis.

Persistence of biochar-C in soil

Persistence of biochar in soil is a challenging question. Even biochar degrades in time and the degradation needs to be accounted for in the analyses and calculations. In addition to mineralization, there are also other possible fates for the added biochar. It may be eroded or leached, affected by the freeze-thaw cycles or degraded into nanoparticles. In these cases, it is lost from the analyses and calculations but not necessarily as CO_2 to the atmosphere. As a part of the verification process, we may need to assess biochar persistence in soil. For this, it would be useful to measure the condensed component of biochar that is expected to be stable in soil for centennial timescales.

Most suitable methods for estimating carbon sequestration in urban demonstration sites

In Finland, load-bearing soils (known as “structural soils” in urban greening trade) are constructed for the street trees to act as structure of the street while enabling enough space for the tree roots to grow in it. They contain 65-

75% coarse rock material (Rakennustietosäätiö 2016; Krook et al. 2005), are paved or sealed over, and consequently it is challenging and expensive to take soil samples from these media. These kinds of soils are a marginal issue however; they are only being constructed in cases where tree planting area must be entirely load bearing. In addition, this specialised tree establishment method is only used in northern parts of the world (e.g. Scandinavia, northern USA) because of the climatic conditions.

Picture 1. Load-bearing planting soils are expensive to sample later on, as they are paved over. Pavement must be removed to access the soil below. Soil augers do not penetrate the stony mix and any sampling must be done by digging soil pits. Image by Anu Riikonen.

One important thing to note is that the planting soils constructed in Hyväntoivonpuisto contain hardly any clay. Clay interferes many techniques, e.g. LOI, TG-DSC and spectroscopic techniques. As the interference of clay can be excluded, the use of spectroscopic techniques might be an appealing option. Moreover, the possibility to measure soil C stocks with a non-destructive way and to deeper soil depths by spectroscopic techniques (Nayak et al. 2019) without possibly challenging and expensive soil sampling would be of special interest in urban context. While causing difficulties for the physical soil sampling, the presence of coarse-textured material in the planting soils (especially the load-bearing soils) affects the in-situ performance of spectroscopic techniques, too. Even though the development of these techniques is promising, they may not yet be robust enough for field use (Nayak et al. 2019).

To sum up: what are the most feasible methods for soil C measurement?

The accessibility and cost of the equipment and analyses define the choice of the methods for a certain site. In the case of Hyväntoivonpuisto, the most feasible method in this context could be ***dry combustion*** as the equipment is widely available, it is routinely used, and the analysis is relatively cheap. Currently, dry combustion is still probably the most robust method for the measurement of soil C content despite the recent developments in e.g. spectroscopic methods.

At simplest, we could measure the total C stock over time to verify that C sequestration has taken place. If we want to know more about e.g. changes in the chemistry of biochar in soil, the priming effects of biochar on native SOM or the changes in different soil C fractions however, some other methods could be used in addition. From the scientific point of view, that would be interesting because the knowledge of the structure, distribution and reactivity of PyC in soil is scarce (Simpson and Hatcher 2004a). Even though there is no such a method that would specifically quantify biochar, *thermogravimetry – differential scanning calorimetry (TG-DSC)* could be one option as it is operationally simple, and different C species (including carbonates) can be quantified based on their thermal stabilities (Hammes et al. 2007). Another option could be *MIR spectroscopy* that can predict multiple soil components with good prediction found for pyrogenic carbon (Janik et al. 2007).

Water

In principle, the *watering need effects C balance of urban parks*. Biochar addition likely reduces the watering need at least in coarse-textured soils (less in clay soils) by changing the pore size distribution and increasing the waterholding capacity of soil. Therefore, it may somewhat improve the C balance of the park. Watering is a routine practice in only a small fraction of Finnish urban parks (less than 2% of constructed urban green area in Helsinki, for example, are classified to maintenance class A1 which is the only class with any regular irrigation (as of 2019, Helsinki Region Infoshare, hri.fi)), and therefore C footprint of watering is not an issue of major concern here. In some drier places (e.g. Phoenix, Arizona), situation would be different, and watering may have a significant impact on the C footprint of urban park.

Biochar has *potential for decreasing nutrient runoff and eutrophication*. This has significance especially in humid climate regions such as Finland, and in areas with high proportion of surface runoff generating landcover, typically urban areas. For example, Kuoppamäki and Lehvävirta (2016) found that biochar amendment in green roof substrate decreased the runoff of both nitrogen and phosphorus. Biochar properties such as the content of labile matter, total surface area, volume of micropores and cation exchange capacity, however, affect the composition of leachate (e.g. DOC quality and content of total nitrogen) from biochar-amended soil (Yang et al. 2019). Because Hyväntoivonpuisto is situated close to the Baltic sea, it is important to prevent nutrient leaching from the soil into the sea.

2.1.3.2 Vegetation

Plant growth over certain period of time is a simple measure for the success of planting and its carbon sequestration to its standing biomass. Measuring change in plant dry biomass integrates the effects of C sequestration (via photosynthesis) and loss (e.g. respiration, grazing by pests, branch pruning).

Monitoring tree growth

Trees allocate the increase in biomass, and thus stored carbon, to plant compartments (such as trunk, fine roots, leaves) with varying longevity. The long-living woody compartments, trunk and branches, are relatively easy to monitor and measure for biomass. The more short-lived fine roots and leaves, which are a significant C sink within tree on annual scale, are more difficult to monitor in terms of C capture and loss.

For trees, biomass equations (e.g. Ter-Mikaelian & Korzukhin 1997) can be used to estimate the dry biomass from trunk diameter, which allows for easy assessment of aboveground woody biomass C sequestration. These equations are traditionally based on trees in managed forests, which causes some issues with accuracy (McHale et al. 2009), but these are likely to be relatively small for whole tree C sequestration estimates (Tanhuanpää et al. 2017, Riikonen et al. 2018). Trunk diameter in itself is fairly simple to measure, but for repeated measurements aiming for capturing small changes in plant size, the measuring height should be permanently marked on the trunk.

If biomass equations are not available for a given taxa or are judged to be unsuitable, the traditional method of measuring plant C stock is based on destructive sampling (Riikonen et al. 2018). This is relatively cumbersome and labour intensive, but well-known and reliable method. Arguably the best non-destructive method is terrestrial laser scanning (McHale et al. 2009, Tanhuanpää et al. 2017), which gives excellent volume estimates for tree aboveground biomass, but will require the conversion to mass basis to attain C content.Leaf biomass of deciduous trees is often left out of tree biomass C estimates, as on a momentarily basis, they contain typically less than 5% of the biomass of the tree (e.g. Ter-Mikaelian & Korzukhin 1997) and are only transiently present. Similarly, fine roots are estimated to contain ca. 1% of the whole tree biomass (Chojnacky et al. 2014). Leaf biomass can be measured by sampling and measuring a subset of leaves (e.g. Nowak 1996), or with biomass equations, similarly to woody biomass.

Picture 2. Collection of leaf biomass samples from street trees is complicated, because trees usually cannot be felled as has traditionally been done with similar forestry measurements. Image by Anu Riikonen.

Fine and coarse root biomass can be estimated by collecting root samples, e.g. alongside soil sampling, and separating and weighing the roots (e.g. Johnson & Gerhold 2003). Scaling from the collected root samples to tree level is difficult however, due to non-even and non-random spatial distribution typical for trees in urban areas. Biomass equations are available for both fine and coarse roots, but vast majority of these are not tested for urban trees. While leaves of deciduous trees have known longevity, such information is scarce for fine roots. Root longevity can be best studied with minirhizotron technique (e.g. Majdi 2006).

Observing grass growth

Just as with trees, biomass production is a simple and integrative measure of C sequestration by non-woody plants. Due to their smaller size and some degree of tolerance for destructive sampling, collecting biomass samples is more feasible for grasses and forbs than for trees. In addition, grass height increase over certain period and percent vegetation cover are useful indicators for the growth of lawns or similar grassy vegetation managed by mowing.

In the case of amenity lawns, the aim is not to maximise grass biomass growth; that would also maximise the need for mowing, which increases expenses of management. Rather, a good visual appearance (greenness, evenness) and in case of meadow, presence, diversity and abundance of flowering plants (e.g. Norton et al. 2018) may be used as indicators of lawn or meadow quality. Among these variables, the percent ground cover by the sown grasses, and various visual scores based on greenness and evenness, are widely regarded as the most important for both perceived quality (e.g. Alumai et al. 2009) and as a cue for management interventions such as re-seeding.

2.1.3.3 Ecosystem level measurements

Quantifying CO_2 fluxes

Eddy covariance (EC) technique

The eddy covariance technique is currently a commonly accepted and used direct method to measure the exchange of various compounds, such as CO_2, methane, nitrous oxide and water vapour, between the atmosphere and land surface. Airflow in the surface-atmosphere boundary layer is turbulent, consisting of small eddies. These carry the energy and compounds being exchanged, and can be measured, and used to derive the fluxes of matter and energy on ecosystem scale.

Typical footprint area, i.e. area from which the measured fluxes originate, is some hundred metres upwind from the measuring point, depending on the location and height of the measurement. Setting up EC measurements require considerable investment in infrastructure, towers and buildings, data archives and measuring devices, and therefore these measurements are usually carried out by large institutes and networks. In Helsinki area, there is an urban EC measuring station with some flexible, movable units (Wood & Järvi 2012, Nordbo et al. 2012).

EC measures fluxes on ecosystem scale, integrating over its entire footprint area. The finer scale understanding of processes behind the measured fluxes require partitioning fluxes to their sources (e.g. Constantin 1999, Nordbo et al. 2012). This may be partially done by analysing wind directions and times of day and year, but commonly, some direct independent measurements of flux components are needed. For example, a measured CO_2 flux may consist of both biogenic and anthropogenic sources, such as soil respiration, photosynthesis, traffic exhaust, industry etc. Independent information on e.g. number of cars on adjacent roads, plant photosynthesis and soil respiration measurements, and environmental permit documentation of factories can be used to partition the measured fluxes to their sources.

Chamber methods

Carbon dioxide, methane and other greenhouse gas exchanges between soil, plants and atmosphere can be measured locally with various chamber methods, both stationary and portable. These consist of a chamber which is sealed against soil surface or e.g. a leaf, and an analyser for the gases which either are accumulated in the measuring chamber or led to the analyser while replacement air is vented into the chamber. Stationary chambers require some degree of research infrastructure, notably a constant power source, data logger and in urban environment, protection from vandalism. Portable chambers on the other hand, are usually operated on batteries, and can be used in short-term measurements under supervision.

Picture 3. Portable chamber system with infrared carbon dioxide analyser and temperature and relative humidity probe for soil CO_2 flux measurement. Image by Anu Riikonen.

Portable chambers for both applications offer lower initial costs and cost-effective means to make measurements over large areas but require more labour to operate. Stationary, automated systems (e.g. Pumpanen et al. 2015) are more expensive to establish, usually limited number of replicates can be afforded, but in the long term, require less work to operate. Thus, these are preferred for long-term research setups. The measuring methods themselves are largely based on same principles both in stationary and portable systems. Plant gas exchange systems include various photosynthesis measurement systems, usually with infrared gas analyser, cuvette with controlled environment, and pumps operating airflow from cuvette to analyser (e.g. Cheng et al. 2019). Soil chambers are also well established, but more commonly based on an infrared analyser located inside the measuring chamber (e.g. Kumpu et al. 2018).

2.2 Applicability to urban space

All carbon fixing treatments need to be applicable to urban space. Most importantly, they must be safe for humans and environment and hard to vandalise. All materials used in urban environment should comply to safety standards (REACH, EBC) and the raw materials should be traceable. The use of chemicals is regulated with REACH (registration, evaluation, authorisation and restriction of chemicals) in the European Union. It is aimed at protecting human health and the environment from the risks posed by chemicals, applying to all chemical substances (ECHA 2019). European biochar certificate sets standards regarding the quality of biochar, setting threshold values for harmful contaminants e.g. polycyclic aromatic hydrocarbons (basic grade: < 12 mg kg^{-1} dry matter, premium grade: < 4 mg kg^{-1} dry matter) and heavy metals (EBC 2012), which is why only EBC-certified biochar is recommendable to be used.

In the case of biochar, the treatments need to be evaluated and planned with respect to their applicability to urban environment, considering e.g. fire safety and dustiness. For example, no fine-particle biochar should be on top because of potential risk of wind or water erosion. No big-particle biochar should be on top either, as it may tempt people to use it as barbeque or drawing coal. One option would be to cover the top 5 cm of soil with gravel or rocks.

Picture 4. Sensors installed on urban tree trunks can be protected by surrounding the entire tree base in custom made steel mesh cage. Image by Anu Riikonen.

Any additional devices or structures built for research purposes in public green areas should not interfere with accessibility; e.g. measurements with portable devices should be made outside path areas. Electrical and other valuable or hazardous research equipment must be installed behind safety screens and be difficult to vandalise. When sampling or performing measurements in public space, care must be taken not to occlude foot or vehicular traffic. Equipment cannot be left unattended, and any soil disturbances caused by sampling must be evened out so as not to cause trip hazards. Similarly, personnel safety must be ensured by wearing e.g. reflective vests, and appropriate training for working in traffic areas should be attended if needed.

2.3 Public awareness

One of the key objectives of the Carbon Lane project is to explore how similar projects could, in the future, engage citizens and other stakeholders of the potential of urban carbon capture. The parks itself, no matter how well planned, will have only a very limited capacity to absorb carbon. Therefore, disseminating knowledge and inspiring people to carry out their own actions elsewhere is highly important. Regarding to the Hyväntoivonpuisto park in Helsinki, the target group of the communication are the residents of the city of Helsinki.

The purpose of this section is to examine the various forms of communication and influencing, that could be used in similar projects later. The actual communication action of Hyväntoivonpuisto will be implemented on a smaller scale to be more suitable for the project budget and other factors. The plan of actions is presented on chapter 6 of the report.

The means of communication are roughly divided into those, that are implemented inside the park and those, that are not bound to the actual park location, such as online materials or trainings organized outside the park. The focus is on communication within the park, as it is probably the most effective way to influence on people when they are already inside the park. However, many of the communications within the park also utilize online communication tools to widen the impact.

2.3.1 Increasing public awareness on site

Visualizing measurements with art

Human beings collect information with all their senses, therefore written expressions are poor and limited way of communication. The measurements collected from the park could be presented more compelling way with interactive and transforming artworks. The artworks could react with the changes of the measurements, so the visitors could easily follow the changes happening on different natural phenomena.

One idea could be to use alighted water pipes, that would present the temperature and moisture in the soil of the park. Moisture of Finnish soils vary usually between 10 to 40% (Hiilipuu, 2019). Inside the pipes, water pillars would alter rising or falling depending of the real time moisture measurement. The temperature of soil would be presented with different colours, blue demonstrating cold temperatures and red warm temperatures. There could be also broader colour-spectrum to demonstrate temperature variations more exactly. Normal Finnish soil temperature usually varies between 1 to 20°C (Hiilipuu, 2019). Usually, soil temperature and moisture vary even in small land areas, due to vegetation and soil type, so the pipes would be a demonstrative and visually interesting presentation. The pipes would be located preferably around the street crossing the park area, to offer nice visual experience especially in night-time. (Reference image 1.)

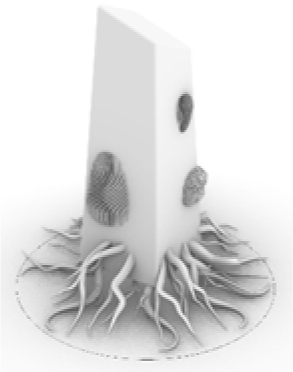
Soil is constantly releasing atmospheric gases, but the phenomenon is completely out of human perception. These gas exchanges of the soils could be measured and demonstrated with lights. Lights located on ground or around trees, with changing light intensity, could be used to demonstrate this flow. Lights could also be changing their intensity in the rhythm of human breathing, creating the sense of soil as living being. (Reference image 2.) Sounds, like low whistles or whoosh -sounds, could be also used to describe the movements of atmospheric gases.

Reference image 1.
LED light Stick lamps. Ebay

Reference image 2.
Forest lighting. Image by Geir Pettersen

Reference image 3. Outside in: Meir Lobaton Corona, Ulli Heckmann, Julia Pankkofer

The life underground is unfamiliar to us even though it is just under our feet. Cameras or microphones could be useful tools for displaying the underground world. They could capture and record the growth of roots and life of soil animals. These records could be done in advance and shown on park as a wall of underground life. (Reference image 3.)



Reference image 4.
Interactive statue.
Illustration by Sushant Passi

Reference image 5.
Field of light, Bruce Munro

Infographic posters and screens

Infographic posters and screens could be used to explain carbon cycling and sequestration as well as the research treatments with visually interesting and approachable charts, illustrations and text. The advantages of the screens compared to posters, would be that they would be able to present much more information and also give visitors chance to select the topics most interesting to them. The screens could give also the opportunity to present collected data in the way that visitors could have chance to investigate and compare the data in real time and make their own observations about the research.

The screens and posters could be made more interactive by using QR-codes and hashtags. QR-codes could link to webpages or videos with more information. Hashtags could encourage people to tell their opinion and experiences over social media. (Examples of infographic posters and use of hashtags and QR-codes on Appendix 6.)

Events and hands-on-workshops

Events are a social and interactive way to raise public awareness and encourage people to repeat the demonstrated solutions in home gardens or other private areas. Event could also give an opportunity for people to discuss about their experiences and observations and create social togetherness around the project. Events could be more seminar-style, where experts and citizens could switch their insights, or more practical hands-on-workshops. Themes of workshops could be for example how to use biochar on home gardens or set up of edible garden. The events could be organized as cooperation with citizens' organizations, universities and companies, to attract more people to participate and organize more extensive activities.

2.3.2 Increasing public awareness online on webpages and social media

The online communication could take place on webpages and social media, like on Facebook, Twitter, Instagram, YouTube. In the case of Hyväntoivonpuisto, communication would be carried out by city of Helsinki, University of Helsinki (the AgriChar research group of Department of Agriculture of UH is committed to follow-up the park), Aalto University (hosting the Carbon Lane website), Finnish Biochar Association and the participating companies.

Jätkäsaari -residents have their own active Facebook group where they are sharing knowledge and opinions of the area. Facebook groups, that already exist or that would be created for the purpose, could be used to communicate between stakeholders and share information about activities taking place around the park.

Social media influencers

Influencers are actors who shape audience attitudes through blogs, tweets, and the use of other social media. Influencers could be efficient way to contact some target groups and especially young people. We encourage collaboration with both local an internationally recognized social media influencers, like video-bloggers, who could make a video where he/she visits the park and participates to the data collection together with researches. The benefit of using social media influencer is that, they already have a wide follower group and know-how to produce interesting content to their audience. By choosing an influencer whose followers fit to the desired target group, high impact and visibility of the urban carbon fixing areas could be gained.

Applications and gamification

Applications and gamification could be interesting way to teach and gain people's attention. One easy way to use gamification, could be placing QR-codes to park that would lead park visitors to online quizzes about carbon sequestration and climate change. Application could be also used. Maybe application using coordinates would explain the differences between the treatments and the changes of data collected in real time while moving around the park. Games could be also used teaching students and school groups.

Table 1. Different communication and engagement methods: green - on site and blue - online

Communication type	Location	Audience	Advantages	Disadvantages
Infographic posters	On site	Park visitors	No need for continuous maintenance, cheap, more interactivity with QRs and hashtags	Not surprising mean of communication
Screens	On site	Park visitors	Interactive, chance to share lot of knowledge	Expensive, vandalism
Visualizing measurements with art (Table 3)	On site	Park visitors	Visually interesting	Expensive, maintenance, vandalism
Events and hands-on-workshops	On site	Park visitors	Interactive	Expensive, workload
Competitions	Online, QR-codes to link on site	Park visitors, website/social media visitors	Interactive	Workload
Social media sites	Facebook, Twitter, Instagram, YouTube	Website/social media visitors	Easy to use and maintain	Demands continuous contribution
Websites	Online, QR-codes to link on site	Website/social media visitors	Easy to use and maintain, chance to share lot of knowledge	Workload
Videos	Online, QR-codes to link on site	Park visitors, online	An interesting and clear way to communicate	Lot of work to produce

Interactive research with hashtags	Online, QR-codes to link on site	Park visitors, online	Interactive	Workload
Social media influencers	Online	Website/social media visitors	Link to different groups, especially young people, influencer produces the material	Expensive, difficult to target correctly
Applications	Online, on site	Park visitors	Link to different groups, especially young people, efficient way to teach	Expensive, lot of work to produce, maintenance

Table 2. Visualizing measurements with art

Type of data	Art idea	Interactivity
Soil water content and temperature	Alighted water pipes with lights (Reference image 1.)	Water level would change inside the pipes depending on current soil water content and pipes' colour would vary depending on soil temperature
GHG-emissions	Machine producing water vapor clouds	Different shape and colour of clouds
GHG-emissions	Lights	Changes of light intensity
Root growth	Underground cameras	Screens to see underground
Soil temperature	Lights (Reference image 1.)	
Root growth	Underground lights presenting the whole area that roots cover around the tree (Reference image 3.)	Changes of light volume
Atmospheric CO_2 content	Screen with real-time value	
Data combined: soil activity or carbon sequestration	Interactive statue (Reference illustration 4.)	Favorable and unfavorable moments

3 A proposal with descriptions and visual layout of the Jätkäsaari demonstration site

This section presents two visual layouts with descriptions, first a proposal of experimental arrangements and then the final layout of the demonstration area, which was implemented in Jätkäsaari during the Carbon Lane project in November 2019.

Size of the demonstration area approximately:

- Total area 2330 m²
- Lawn 1320 m²
- Meadow 620 m²
- Hard surfaces 390 m²

3.1 A proposal of the Jätkäsaari demonstration site

The first proposal of the Jätkäsaari demonstration site, which was submitted by the Carbon Lane project team to the City of Helsinki (Figure 4) was designed following closely the principles outlined in Chapter 3. The proposal includes six different experimental treatments (biochar containing planting soils) +control in grass areas and five different treatments (+control) with trees. Different treatments are not defined in this proposal.

The proposal includes 76 deciduous trees of four species and each treatment contains five to six randomly located trees. All species included are commonly used as urban trees in the City of Helsinki. Randomly assigned treatments for trees are mainly either in the lawn or meadow areas. 12 of the trees (*Fraxinus excelsior*) are on structural soil which will be partly covered by asphalt and around the trees with gravel. The number of treatments and replications depends on the number of different trees existing in the plan of the park. Grass areas have five randomly placed replicates which all includes six different treatments plus controls. Due to the limited size of the demonstration area and the number of different treatments, the grass areas are divided into separate sections instead of complete blocks. As circulars the sections could be placed into the area so that there are no trees or stormwater drains in the middle of the "experimentally relevant" zone.

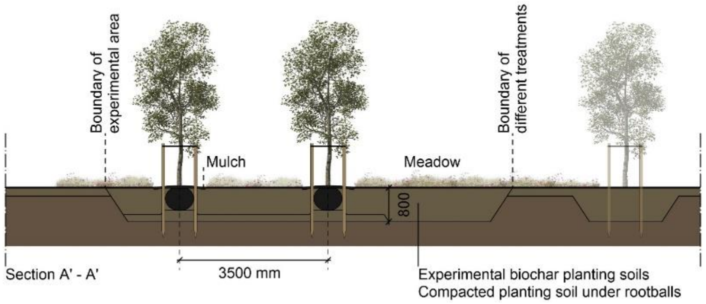


Figure 3. Sectional view of experimental biochar planting pits. Adapted from VSU landscape architects Ltd. 2019. Illustration by Minja Koivunen.

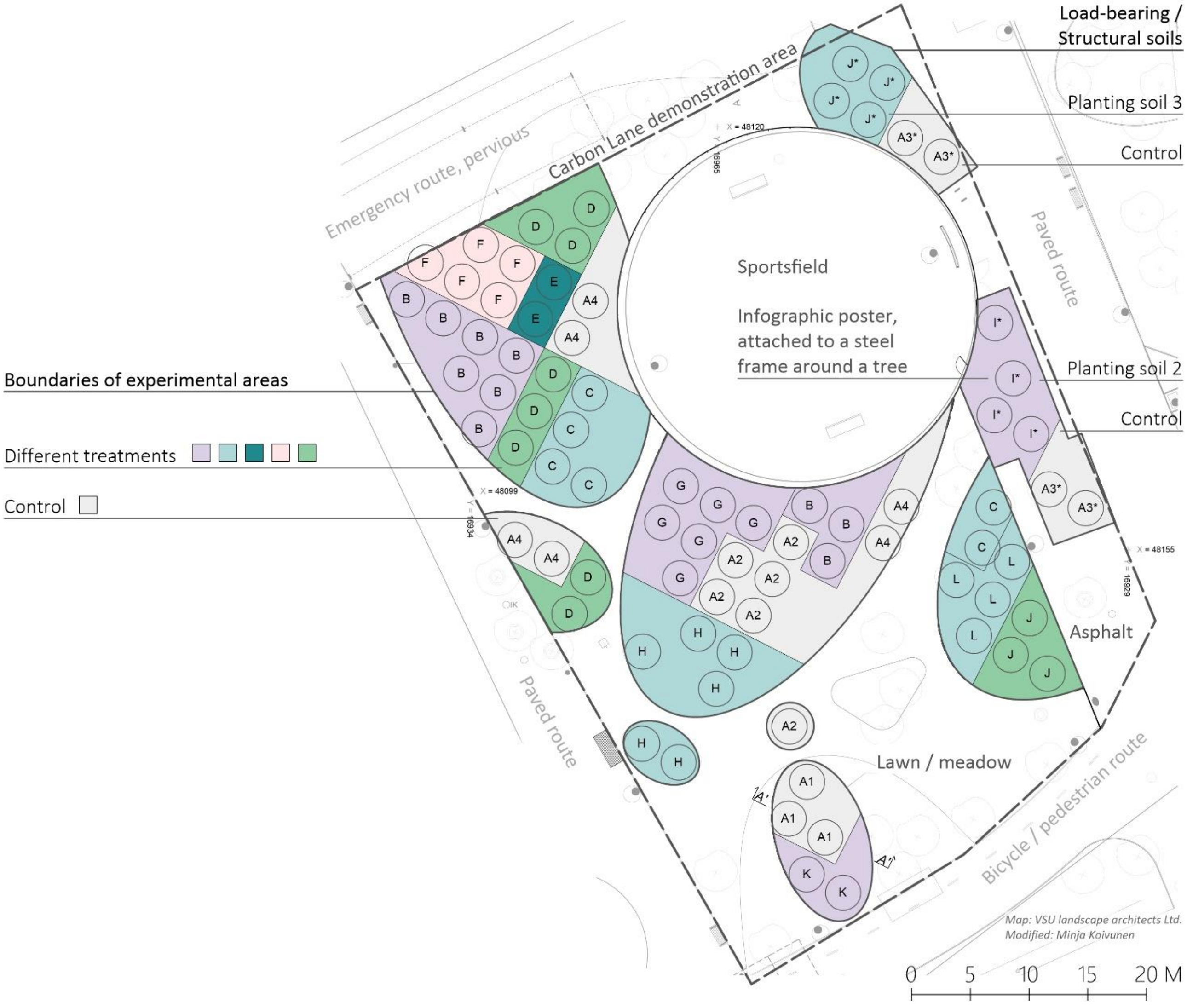
Treatment	Small-leaved Lime *Tilia cordata* 12 pcs	Pin cherry *Prunus pensylvanica* 18 pcs	Ash *Fraxinus excelsior* 12 pcs	Apple 'Makamik' *Malus x purpurea* 38 pcs	Lawn / meadow
1 Control * Structural soil	A	A	A*	A	A
2 Planting soil * Structural soil	J	G	I*	B	K
3 Planting soil		H		C	L
4 Planting soil				D	M
5 Planting soil				E	N
6 Planting soil				F	O
7 Planting soil					P

Figure 4. A proposal with descriptions and visual layout of the Jätkäsaari demonstration site. Illustration by Minja Koivunen.

3.2 The final plan of the Jätkäsaari demonstration site

After the first proposal was submitted, discussion and planning started with city representatives and landscape architects on feasible compromises between following the good scientific principles as well as possible while considering the available resources for the demonstration area. The proposal was amended several times in response to the feedback received. The final plan of the demonstration area includes 79 deciduous trees and nine different treatments from seven different suppliers of growing media. The number of different treatments and repetitions was determined by how different growing media could be delivered on the given schedule, and also the randomisation principle was compromised on. To facilitate construction, the trees are planted in connected pits with 2 to 7 trees per pits clustered together (Figure).

The focus of this demonstration site is on the trees and the grass areas were left out of the experiment. However, the City of Helsinki also showed interest in studying lawn areas and in the future, it may be possible to test different treatments in some other part of the park.



Treatment	Small-leaved Lime *Tilia cordata* 12 pcs	Pin cherry *Prunus pensylvanica* 18 pcs	Ash *Fraxinus excelsior* 12 pcs	Apple 'Makamik' *Malus x purpurea* 37 pcs	Media volumes approx.
1 Control * Structural soil	A1	A2	A3*	A4	303 tn 88 m^3
2 Planting soil * Structural soil	K	G	I*	B	313 tn 80 tn
3 Planting soil * Structural soil	L	H	J*	C	320 tn 99 tn
4 Planting soil	M			D	134 tn
5 Planting soil				E	25 m^3
6 Planting soil				F	42 m^3

Figure 5. The final plan of the Jätkäsaari demonstration site. Illustration by Minja Koivunen.

4 Feasibility and estimated carbon impacts of proposed solutions

5.1 Biochar and other carbon removal technologies

Removing carbon dioxide from the atmosphere is essential in order to not exceed global warming of 1.5°C. IPCC:s special report “Global Warming of 1.5 ºC” (de Conick et al, 2018 p. 342-352) recognizes six carbon dioxide removal techniques which can contribute towards drawing down massive amounts of carbon from the atmosphere. These technologies include:

- Bioenergy with carbon capture and storage (BECCS) - capturing and storing carbon dioxide from biomass combustion.
- Afforestation and reforestation (AR) – sequestration and storing atmospheric carbon through forest plantations.
- Soil carbon sequestration – increasing carbon storage in soils through agricultural practices.
- Soil carbon sequestration and biochar – converting (pyrolyzing) biomass into biochar and applying it as a soil amendment.
- Enhanced weathering (EW) – accelerating the natural process of rock decomposition through physical and chemical processes causing atmospheric carbon to react with silicate minerals and form carbonate rocks.
- Direct air carbon dioxide capture and storage (DACCS) - removal of atmospheric carbon with engineered systems.

Table 3. The carbon sequestration potential and cost. The number in the brackets represent the total variation in the literature. Data is based on the study conducted by Fuss et al (2018)

Negative Emissions Technology	Potential (Gt CO_2 yr^{-1})	Cost (US$/t CO_2)
Bioenergy with carbon capture and storage (BECCS)	0.5–5 (1–85)	100–200 (15–400)
Afforestation and reforestation (AR)	0.5–3.6 (0.5–7)	5–50 (0–240)
Soil carbon sequestration	2–5 (0.5–11)	0–100 (−45–100)
Biochar	0.5–2 (1–35)	30–120 (10–345)
Enhanced weathering	2–4 (0–100)	50–200 (15–3460)
Direct air carbon dioxide capture and storage (DACCS)	0.5–5	100–300 (25–1000)

Biochar’s maximal carbon removal potential can be achieved with large-scale application such as applying biochars and storing carbon while improving crop yields in the open field. It has been estimated that this type of use would require 2.5-20 tons biochar per hectare (Jeffery et al. 2011). In 2018, Finland had in total of 2 2271 900 hectares of usable agricultural land (Maatalousmaa, 2019). According to DNV GL (2019) audit statement based on Puro (2019) carbon removal methodology, one ton of biochar was verified of having 3.11 net negative CO2eq removal capability. Thus, in Finland, and discounting 10% of agricultural areas as peatlands, use of biochar in agricultural lands equals the total national emissions of 3 to over 20 years.

Biochars can be produced on both large and small-scale. For instance, farmers could use locally available biomass such as agricultural and forestry side streams. Even though the potential for carbon removal seems to be significant, large-scale use of biochar in agriculture is currently not feasible or even possible for several reasons. Firstly, the market of biochars is currently at an introductory phase and commercial availability is based on small-scale production. Secondly, production technology is currently at an early stage of development (Salo, 2018). Both factors lead to a high market price of biochars which limits its large-scale applications as recognized by Vochozka et al. (2016) and Dickinson et al. (2014).

When biochar is used in soil amendment, it is often sold and measured in cubic meters. Since biochar is porous and light material, one cubic meter of biochar is around 300kg, but could also be close to 500kg. The price of one cubic meter of biochar (300kg) for the soil amendment is currently around 225-250€. There are several factors which impact the price of biochar. For instance, raw materials, production method, conditions, production quantities and particle size. The current market price of biochar is based on raw materials such as thinnings, low-diameter trees and pulp wood. In 2018 stumpage price of pulp wood in Finland was around 17-20€ per cubic meter depending on the tree species (Peltola, 2019). Production of one cubic meter of biochar requires around 4-5 higher amount of raw wood and therefor raw material has a significant role in the overall costs.

Higher environmental and economic benefits can be achieved when biochar production is integrated into another process (e.g. biorefinery, sawmill), where side streams could be used as a raw material. In addition, commercialization of side-products of biochar such as excess energy and pyrolysis liquids have a major impact on the final price of biochar. In addition, biochars could benefit from carbon trade systems such as Puro (2019) as the net negative impacts of biochars could be sold as offsets. Even though biochars are often seen as too valuable for certain applications, these developments could significantly change the situation. Technological advancement and scale-up activities could significantly increase the feasibility of biochar and make it highly competitive carbon removal solution.

Costs related to application of biochars itself can be minimized by including biochars in already ongoing processes. For instance, in planting soils biochars can be used in the production phase of planting soils. Biochars could also be purchased separately and mixed on-site before application, however, this would create additional costs.

Curently in Finland, municipalities, companies, universities and institutes are having an increasing number of projects and research related to applications biochars in various fields such as animal agriculture, cultivation, soil and gardening, and urban areas. It has been estimated that in the future biochars will achieve a strong position in the gardening and green building sectors, in particular in composting, green roofs, planting soils, filtering and managing stormwater and urban runoff (Salo, 2018). In Finland, the potential of biochar in agriculture has also been recognized on a governmental level, namely in the Programme of Prime Minister Antti Rinne's Government where biochar's (biohiili) potential in sequestration was highlighted (Valtioneuvosto, 2019: 119). The program promises support for the utilisation of biochars. For instance, it is expected that the government will launch support mechanisms such as funding programs during the following years, which will also include biochars.

4.2 Biochars as part of planting soils and urban trees

4.2.1 Planting soils

According to the 2017 annual report of the Finnish Food Authority, in total of 1 804 000 m^3 of planting soil mixture (seosmulta) was manufactured in Finland (Ruokavirasto, 2018). Besides national production volume, there is no area-based information available about production or consumption volumes of planting soils. Companies involved in the Carbon Lane project have significant market share in Finnish planting soil market. According to the information provided by the companies, the annual consumption of planting soil is around 600 000 m^3 in the metropolitan area. In Helsinki, the consumption is estimated to be a maximum of 200 000 m^3.

It has been estimated that around 10–15% of biochars could be used in the plating soils. Higher rates could be also applied in case specific cases. For instance, the City of Stockholm is using planting soils for urban trees which contain 15-25% of biochar (Embren, 2016). With the biochar rate of 10–15% in the planting soil, in total of 60 000–90 000 m^3 of biochar could be used in the new soils in the metropolitan area and 20 000 - 30 000 m^3 respectively in Helsinki. One cubic meter of biochars consists of at least 300 kg of product and if one kilogram of biochars would correspond to 3.11 net negative carbon removal, the annual potential of carbon removal in the Metropolitan area would be 55 000–84 000 t CO_2eq and respectively 18 000 - 28 000 t CO_2eq in Helsinki.

In order to illustrate the potential of biochar, it could be compared to wood construction which is considered as an effective way to create carbon sinks in the urban areas. The average annual construction volume in Helsinki in 2010-2018 was 500000 m^2 (Helsinki 2018). Following Vares et al (2017) we estimate the carbon sink created by the use of wood in the building activities in Helsinki to be 200 kg CO_2eq/m^2. With a 30% market share, wood construction would contribute an annual carbon sink of 34000 tCO_2eq/a. This indicative comparison illustrates the significant potential of biochar addition in the seedbeds as a way to draw down carbon.

Helsinki is committed to achieving carbon neutrality by 2035. The vision includes an annual carbon sink equivalent to 20% of the current emissions. In Helsinki, the annual potential of using biochar in new planting soils equals to 0,7 to 1 % of the annual emissions and 3,5-5% of the targets of negative emissions of Helsinki. There is no exact data of reused soils, but they also offer a similar potential to use biochar as amendment. The potential of biochars pairs with a major transition in wood construction; amendment in new planting soils corresponds to using wood in 35-50% of all new construction activity of 350.000 m2 in Helsinki. Yet, scenarios for increasing wood construction point at difficulties in a many fold increase of the current market share of 6% in multi-story buildings (Hurmekoski 2018). To set these figures in further perspective, the existing carbon stock of trees, plants and soil in Helsinki has been estimated to be around 1250 kt of carbon, which equals to around 1,5 years of Helsinki GHG emissions (~4600 ktCO2) if converted to CO2 (Rasinmäki & Känkänen, 2014). The stock has been growing with an annual rate of around 35kt (estimated in 2014). However, due to land use changes, the stock is threatened and it has been estimated that the stock will start to decrease in the future (City of Helsinki p. 102-103). The action plan of the City of Helsinki (2035 p. 128) identifies this problem and suggests the following action:

> *"The impact on carbon storage will be taken into account when designing urban forests and nature and public green zones. Planning and green zone design will be complemented with procedures to compensate for the carbon storage lost during construction"*

The average carbon footprint of a Finnish person has been estimated to be around 10 tonnes of CO2eq (Sitra, 2018). However, the carbon footprint is calculated differently in municipal carbon neutrality targets as it considers only selected co2 sources. For instance, in 2018, a resident in the metropolitan area had an average carbon footprint of 4.1tn and in Helsinki the number was 3.9tn. To put this into perspective, addition of biochars in soils could offset the annual carbon footprint of 4600-7100 residents. Furthermore, the benefits of carbon sequestration could increase the use of planting soils. In addition, biochars could be added to the soils which are recycled and reused inside metropolitan area, which is not currently considered.

4.2.2 Urban trees

In Helsinki, there are around 30 000 street trees and 200 000 park trees. Urban trees can be between 50-200 years old. Helsinki maintains urban tree database (2019) which is publicly accessible and where all the urban trees are mapped. In the upcoming years, the city aims at replacing a notable number of older trees for safety reasons. In addition, the city is actively looking for ways to increase the number of urban trees since this is also demanded by the Helsinki residents and Helsinki City Council members. For the new urban trees, the city of Helsinki aims at providing lifespan of at least 80-100 years. Currently, Helsinki plants around 1000 street or park trees and 4 000-10 000 forest seedlings on annual basis.

Helsinki's street and park trees can be divided into three cost categories: 2900€, 12 800€ and 15 200€ (Fig. 6). The cost categories are presented below, and they are based on a widely used cost management software - Rapal (2019). The total price includes all related costs such as building materials, seedbed (and its transportation), planting, site work, procurement and maintenance (incl. 2 years warranty).

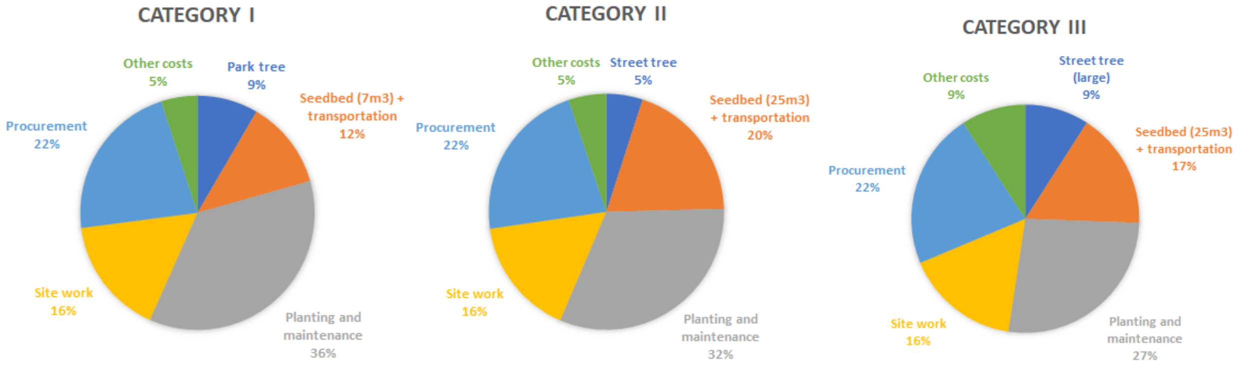


Figure 6. Cost categories I –III of Helsinki's street and park trees, respectively 2900€, 12 800€ and 15 200€ (VAT 0%).

Category I is the most common urban tree category and it covers the majority of the park trees and street trees planted on the unpaved surfaces. The estimated cost for the $7m^3$ seedbed is 274€ and its transportation around 80€. Addition of biochars of 10-15% (0,7-1,05 m3) would increase the cost of seedbed by at least 157-236€ (price of biochar 225€ per m^3), which is around 5-8% of the overall cost per tree. Category II is the most common cost for the street tree plantations on paved surfaces. Street trees require multiple times more seedbed than park trees, around 25m^3. 10-15% biochar (225€ per m3) addition would increase the cost by at least 560-844€, corresponding to 4-7% increase of the total cost per tree. Category III is for rare and demanding tree plantation situations, such as planting a large size tree on exceptional location. These types of plantations require 25m^3 seedbed as well. 10-15% biochar (225€ per m3) addition would increase the cost by 560-844€, corresponding in 4-6% increase in the total cost per tree.

5 Engagement formats and communications materials for stakeholder engagement at the demonstration area

The communication materials and engagement formats relating to urban demonstrations of carbon sequestration vary greatly. In the CarLa project we considered measures which range from providing scientific information in lay terms to visual and audio engagements in parks to theme events. In below we first present the infographics which are designed for the Hyväntoivonpuisto park. Appendix 5 includes the webpage, which is designed to provide background material, and a digital platform to report the findings of the experiment and communicate activities at the park. Other poster materials produced for the CarLa events are also included in this section. In the later part of section 6 we introduce ideas for more evocative forms of engagement including sound, light and visual art as well as possible other communication strategies.

5.1 Infographic posters

During the Carbon Lane -project, infographic posters were created and proposed to the City of Helsinki to be used on-site for providing information to the park visitors. In total of three posters were created from which, poster 1 and poster 2 are preliminary agreed to be used in the park. The posters can be seen in Appendix 6.

- Poster 1 explaining the purpose of the research on the park
- Poster 2 explaining the carbon flows and functions of biochar in the park
- Poster 3 explaining the difference of soil treatments

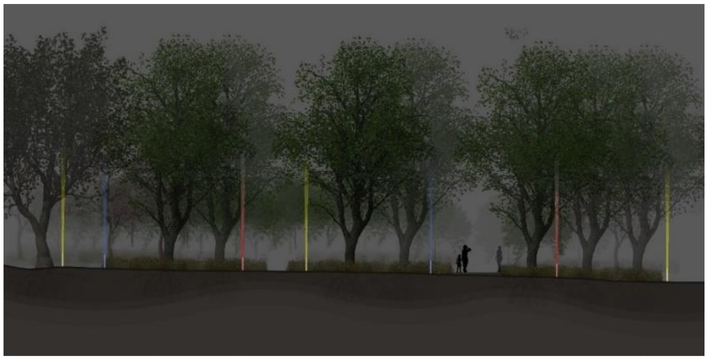
In addition, Poster 1 will include QR code which redirects to the home page of Carbon Lane project: www.aalto.fi/fi/carla. Also, trees, planting soils and research devices could be marked with QR-codes, that would lead visitors to see more information in the form of text or videos or inquiries to participate.

In addition, Poster 1 encourages audience to use hashtag #hiilipuisto (which translates into carbon park) to post feedback, questions, opinions and pictures of the park. In addition, stakeholders of Carbon Lane project have been encouraged to communicate Carbon Lane in social media using as well.

5.2 Light art as a mean to visualize scientific data

Light art is a form of visual art where light plays a dominant role. In Hyväntoivonpuisto, light art could be used to demonstrate data visually in an interesting, pretentious and united way.

Alighted water pipes could represent soil temperature and moisture. Moisture of Finnish soils vary usually between 10 to 40% (Hiilipuu, 2019). Inside the pipes, water pillars would alter rising or falling depending of the real time moisture measurement. The temperature of soil would be presented with different colours, blue demonstrating cold temperatures and red warm temperatures. There could be also broader colour-spectrum to demonstrate temperature variations more exactly. Normal Finnish soil temperature usually varies between 1 to 20°C (Hiilipuu, 2019). Usually, soil temperature and moisture vary even in small land areas, due to vegetation and soil type, so the pipes would be a demonstrative and visually interesting presentation. The pipes would be located preferably around the street crossing the park area, to offer nice visual experience especially in night-time. (Reference picture 6.)



Reference picture 6. Light art presenting soil temperature and moisture. Illustration by Minja Koivunen.

Hyväntoivonpuisto has already had experiments with interactive lights. Get Home safely -project has located interactive lights around the park. These lights react on people bypassing by changing the intensity of the light. People can also edit the lights preferable with an application. According to the conversations in local Jätkäsaari liike -Facebook group, the residents of the area have liked the lights and wanted even more lights to be added to the park area.

5.3 Workshops and events for the Jätkäsaari site

One logic of engaging local resident is to transfer the here-used good carbon fixing practices from urban green infrastructures to the private green areas. In Jätkäsaari, there is little private green area housing consists of high-rise apartment buildings. However, even a balcony garden scale is enough for residents to try out e.g. biochar containing planting soil. Hence future use of the Jätkäsaari demonstration can include the provision of materials and knowledge for those residents that are interested of balcony gardening. Furthermore, many Finns do engage annually with summer cottages, where they can apply the new tips and hints a successfully established demonstration park of carbon sequestration enables them to.

Another planned future engagement format is the use of lightweight movable biochar production unit in the park as a demonstration. Due to management rules of the city, no fixed instalments of composting or biochar production were regarded as feasible. However, mobile equipment is an opportunity to introduce and disseminate knowledge of biochar production

5.4 Social media influencers

Cooperation with some social media influencers could be a useful way to contact people. Influencers are actors who shape the attitudes of their audience through blogs, tweets, and the use of other social media. This could be a way to contact especially young people. Maybe a local video-blogger could make a video where he visits the park and discusses about his experience there to his followers to see. Benefit of using social media influencer is that, they already have a broad follower group. Choosing the influencer whose followers fit to the desired target group of the communication, huge impact and visibility could be gained.

Helsinki city has #HelsinkiSecret Residence -project where the city is hosting internationally established bloggers, vloggers and Instagrammers to a residence for three nights to report their experience on the city. Carbon Lane -project area could be recommended as one of the visiting locations to get more visibility.

References

Abujabhah, I. S., Bound, S. A., Doyle, R., & Bowman, J. P. 2016. Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. Applied Soil Ecology, 98, 243-253.

Alumai, A., Salminen, S. O., Richmond, D. S., Cardina, J., & Grewal, P. S. 2009. Comparative evaluation of aesthetic, biological, and economic effectiveness of different lawn management programs. Urban ecosystems, 12(2), 127-144.

Bird, M. 2015. Test procedures for biochar analysis in soils. In: Lehmann, J., Dr, & Joseph, S. (ed.). Biochar for environmental management: science, technology and implementation. Second edition. Routledge, Abingdon, Oxon; New York. pp. 679-716.

Bispo, A., Andersen, L., Angers, D.A., Bernoux, M., Brossard, M., Cécillon, L., Comans, R.N.J., Harmsen, J., Jonassen, K., Lamé, F., Lhuillery, C., Maly, S., Martin, E., Mcelnea, A.E., Sakai, H., Watabe, Y. & Eglin, T.K. 2017. Accounting for Carbon Stocks in Soils and Measuring GHGs Emission Fluxes from Soils: Do We Have the Necessary Standards? Frontiers in Environmental Science, 5.

Blagodatskaya, E. & Kuzyakov, Y. 2008. Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. Biology and Fertility of Soils 45: 115–131.

Blanco-Canqui, H. & Lal, R. 2004. Mechanisms of carbon sequestration in soil aggregates. Critical Reviews in Plant Sciences 23: 481-504.

Blanco-Canqui, H., Laird, D., Heaton, E., Rathke, S., & Acharya, B. S. 2020. Soil carbon increased by twice the amount of biochar carbon applied after six years: Field evidence of negative priming. *GCB Bioenergy*. https://doi.org/10.1111/gcbb.12665

Boot-Handford, M. E., Abanades, J. C., Anthony, E. J., Blunt, M. J., Brandani, S., Mac Dowell, N.Fernandez, J.R, Ferrari, M-C., Gross, R., Hallett, J.P,Haszeldine, R. S., Heptonstall, P., Lyngfelt, A., Makuch, Z., Mangano, E., Porter, R. T. J., Pourkashanian, M., Rochelle, G.T., Shah, N., Yao, J. G. & Fennell, P. S. 2014. Carbon capture and storage update. Energy & Environmental Science, 7(1), 130-189.

Bricklemyer, R.S., Brown, D.J., Barefield, J.E. & Clegg, S.M. 2011. Intact soil core total, inorganic, and organic carbon measurement using laser-induced breakdown spectroscopy. Soil Science Society of America Journal 75: 1006-1018.

Bricklemyer, R.S., Brown, D.J., Turk, P.J. & Clegg, S. 2018. Comparing Vis–NIRS, LIBS, and combined Vis–NIRS-LIBS for intact soil core soil carbon measurement. Soil Science Society of America Journal 82: 1482-1496.

Brodowski, S., John, B., Flessa, H. & Amelung, W. 2006. Aggregate-occluded black carbon in soil. European Journal of Soil Science 57: 539-546.

Bruce, J.P., Frome, M., Haites, E., Janzen, H., Lal, R. & Paustian, K. 1999. Carbon sequestration in soils. Journal of Soil and Water Conservation 54: 382-389.

Bucheli, T.D., Bachmann, H.J., Blum, F., Bürge, D., Giger, R., Hilber, I., Keita, J., Leifeld, J. & Schmidt, H-P. 2014. On the heterogeneity of biochar and consequences for its representative sampling. Journal of Analytical and Applied Pyrolysis 107: 25-30.

Cheng, Y., & He, D. 2019. A photosynthesis continuous monitoring system for CAM plants. International Journal of Agricultural and Biological Engineering, 12(3), 141-146.

Chojnacky, D.C., Heath, L.S., Jenkins, J.C., 2014. Updated generalized biomass equations for North American tree species. Forestry 87, 129–151.

Churkina, G. 2012. Carbon cycle of urban ecosystems. In: Lal, R. & Augustin, B. (eds.). Carbon Sequestration in Urban Ecosystems. 1st ed. Springer Verlag, Dordrecht. pp. 315-330.

City of Helsinki. 2018. The Carbon-neutral Helsinki 2035 Action Plan. Publications of the Central Administration of the City of Helsinki 2018:4. 121 pp. https://www.hel.fi/static/liitteet/kaupunkiymparisto/julkaisut/julkaisut/HNH-2035/Carbon_neutral_Helsinki_Action_Plan_1503019_EN.pdf

Constantin, J., Grelle, A., Ibrom, A., & Morgenstern, K. 1999. Flux partitioning between understorey and overstorey in a boreal spruce/pine forest determined by the eddy covariance method. Agricultural and Forest Meteorology, 98, 629-643.

Culman, S.W., Snapp, S.S., Freeman, M.A., Schipanski, M.E., Beniston, J., Lal, R., Drinkwater, L.E., Franzluebbers, A.J., Glover, J.D., Grandy, A.S., Lee, J., Six, J., Maul, J.E., Mirksy, S.B., Spargo, J.T. & Wander, M.M. 2012. Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. Soil Science Society of America Journal 76: 494-504.

de Coninck, H., A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong, J. Ford, S. Fuss, J.-C. Hourcade, D. Ley, R. Mechler, P. Newman, A. Revokatova, S. Schultz, L. Steg, and T. Sugiyama, 2018: Strengthening and Implementing the Global Response. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Dickinson, Dane & Balduccio, Ludovico & Buysse, Jeroen & Ronsse, Frederik & Van Huylenbroeck, Guido & Prins, W.. (2014). Cost-benefit analysis of using biochar to improve cereals agriculture. GCB Bioenergy. 7. 850-864. 10.1111/gcbb.12180.

DNV GL. (2019). Puro CO2 removal marketplace: production facility audit statement output audit statement. Available at: https://puro.earth/app/uploads/2019/06/Puro_Audit_Statement_Biochar_1.pdf

EBC. 2012. 'European Biochar Certificate - Guidelines for a Sustainable Production of Biochar.' European Biochar Foundation (EBC), Arbaz, Switzerland. http://www.europeanbiochar.org/en/download. Version 8.2E of 19th April 2019.

ECHA. 2019. Understanding REACH. European Chemicals Agency. https://echa.europa.eu/regulations/reach/understanding-reach. Visited October 31,2019.

Edmondson, J.L., Davies, Z.G., McHugh, N., Gaston, K.J. & Leake, J.R. 2012. Organic carbon hidden in urban ecosystems. Scientific reports 2: 963.

Edmondson, J.L., Stott, I., Potter, J., Lopez-Capel, E., Manning, D.A.C., Gaston, K.J. & Leake, J.R. 2015. Black Carbon Contribution to Organic Carbon Stocks in Urban Soil, Environmental science & technology, 49: 8339-8346.

Embren, B. 2016. Planting Urban Trees with Biochar, the Biochar Journal 2016, Arbaz, Switzerland. ISSN 2297-1114 www.biochar-journal.org/en/ct/77 Version of 20 th April 2016 Accessed: 22.12.2019
England, J.R. & Viscarra Rossel, R.A. 2018. Proximal sensing for soil carbon accounting. SOIL 4: 101-122.

FAO. 2019. Measuring and modelling soil carbon stocks and stock changes in livestock production systems: Guidelines for assessment (Version 1). Livestock Environmental Assessment and Performance (LEAP) Partnership. Rome, FAO. 170 pp. Licence: CC BY-NC-SA 3.0 IGO.
Fertiliser Product Act, https://www.finlex.fi/en/laki/kaannokset/2006/en20060539 Retrieved 8-1-2019

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., . . . Minx, J. C. (2018). Negative emissions—part 2: Costs, potentials and side effects. Environmental Research Letters, 13(6), p. 063002. doi:10.1088/1748-9326/aabf9f
Ghani, A., Dexter, M. & Perrott, K.W. 2003. Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. Soil Biology & Biochemistry 35: 1231-1243.

Goff, F., & Lackner, K. S. (1998). Carbon dioxide sequestering using ultramafic rocks. Environmental Geosciences, *5*(3), 89-101.

Glaser, B., Balashov, E., Haumaier, L., Guggenberger, G. & Zech, W. 2000. Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. Organic Geochemistry 31: 669-678.

Glaser, B., Haumaier, L., Guggenberger, G. & Zech, W. 1998, Black carbon in soils: the use of benzenecarboxylic acids as specific markers. Organic Geochemistry 29: 811-819.

Hammes, K., Schmidt, M.W.I., Smernik, R.J., Currie, L.A., Ball, W.P., Nguyen, T.H., Louchouarn, P., Houel, S., Gustafsson, Ö, Elmquist, M., Cornelissen, G., Skjemstad, J.O., Masiello, C.A., Song, J., Peng, P., Mitra, S., Dunn, J.C., Hatcher, P.G., Hockaday, W.C., Smith, D.M., Hartkopf-Fröder, C., Böhmer, A., Lüer, B., Huebert, B.J., Amelung, W., Brodowski, S., Huang, L., Zhang, W., Gschwend, P.M., Flores-Cervantes, D.X., Largeau, C., Rouzaud, J-N., Rumpel, C., Guggenberger, G., Kaiser, K., Rodionov, A., Gonzalez-Vila, F.J., Gonzalez-Perez, J.A., de la Rosa, J.M., Manning, D.A.C., López-Capél, E. & Ding, L. 2007. Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere. Global Biogeochemical Cycles 21: GB3016.

Helsinki. 2018. Helsingin seudun aluesarjat. http://www.aluesarjat.fi/.

Hermann, B. G., Debeer, L., De Wilde, B., Blok, K., & Patel, M. K. 2011. To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment. Polymer Degradation and Stability, 96(6), 1159-1171.

Hiilipuu, 2019. Page visited 13.12.2019. Maaperän lämpötila: http://www.hiilipuu.fi/fi/artikkelit/maaper%C3%A4n-l%C3%A4mp%C3%B6tila ; Maankosteus: http://www.hiilipuu.fi/fi/artikkelit/maaper%C3%A4n-l%C3%A4mp%C3%B6tila

Hsieh, Y.P. & Bugna, G.C. 2008. Analysis of black carbon in sediments and soils using multi-element scanning thermal analysis (MESTA). Organic Geochemistry 39: 1562-1571.

Hurmekoski, E., Pykäläinen, J., & Hetemäki, L. (2018). Long-term targets for green building: Explorative Delphi backcasting study on wood-frame multi-story construction in Finland. Journal of cleaner production, 172, 3644-3654.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

IPCC. 2018. Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press

IPCC. 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Janik, L.J., Skjemstad, J.O., Shepherd, K.D. & Spouncer, L.R. 2007. The prediction of soil carbon fractions using mid-infrared-partial least square analysis. Australian Journal of Soil Research 45: 73-81.

Jeffery S, Verheijen FGA, van der Velde M, Bastos AC. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agric. Ecosyst. Environ. 144(1), 175–187 (2011).

Jensen, J.L., Schjønning, P., Watts, C.W., Christensen, B.T., Peltre, C. & Munkholm, L.J. 2019. Relating soil C and organic matter fractions to soil structural stability. Geoderma 337: 834-843.

Johnson, A. D., & Gerhold, H. D. 2003. Carbon storage by urban tree cultivars, in roots and above-ground. Urban Forestry & Urban Greening, 2(2), 65-72.

Knicker, H., Müller, P. & Hilscher, A. 2007. How useful is chemical oxidation with dichromate for the determination of “Black Carbon” in fire-affected soils? Geoderma 142: 178-196.

Krook, J., Peurasuo, P., Heino, M. 2005.Kantava kasvualusta – katurakenne ja katupuun kasvupaikka. Suomen kuntatekniikan yhdistyksen julkaisu 22.

Kumpu, A., Mäkelä, A., Pumpanen, J., Saarinen, J., & Berninger, F. 2018. Soil CO2 efflux in uneven-aged and even-aged Norway spruce stands in southern Finland. iForest-Biogeosciences and Forestry, 11(6), 705.

Kuoppamäki, K. & Lehvävirta, S. 2016. Mitigating nutrient leaching from green roofs with biochar. Landscape and Urban Planning 152: 39-48.

Kurth, V.J., MacKenzie, M.D. & DeLuca, T.H. 2006. Estimating charcoal content in forest mineral soils. Geoderma 137: 135-139.

Kuzyakov, Y., Bogomolova, I., & Glaser, B. (2014). Biochar stability in soil: decomposition during eight years and transformation as assessed by compound-specific 14C analysis. Soil Biology and Biochemistry, 70, 229-236.

Lai Fern Ow, Subhadip Ghosh & Yusof Mohamed Lokman Mohd. 2018. Effects of varying establishment approaches on the growth of urban street trees, Arboricultural Journal, 40:4, 201-209

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

Lal, R. 2018. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Global Change Biology 24: 3285-3301.

Lehmann, J. 2007. A handful of carbon. Nature 447: 143-144.

Lehmann, J. & Joseph, S. 2015. Biochar for environmental management: an introduction. In: Lehmann, J. & Joseph, S. (ed.). Biochar for Environmental Management: Science, Technology and Implementation. 2nd ed. Routledge, Abingdon, Oxon; New York. pp. 1-13.

Leng, L., Huang, H., Li, H., Li, J. & Zhou, W. 2019. Biochar stability assessment methods: A review. Science of The Total Environment 647: 210-222.

Liu, S., Xia, X., Zhai, Y., Wang, R., Liu, T. & Zhang, S. 2011. Black carbon (BC) in urban and surrounding rural soils of Beijing, China: Spatial distribution and relationship with polycyclic aromatic hydrocarbons (PAHs). Chemosphere 82: 223-228.

Llorente, M., Turrión, M-B. & Glaser, B. 2018. Rapid and economical quantification of black carbon in soils using a modified benzene polycarboxylic acids (BPCA) method. Organic Geochemistry 115: 197–204.

Maatalousmaa. (2019). Luonnonvarakeskus: Käytössä oleva maatalousmaa 2018. Available at: https://stat.luke.fi/k%C3%A4yt%C3%B6ss%C3%A4-oleva-maatalousmaa-2018_fi-0

Majdi, H. 1996. Root sampling methods-applications and limitations of the minirhizotron technique. Plant and Soil, 185(2), 255-258.

McHale M., Burke, I., Lefsky, M., Peper, P., McPherson, E., 2009. Urban forest biomass estimates: is it important to use allometric relationships developed specifically for urban trees? Urban Ecosystems 12, 95-113.

Meredith, W., Ascough, P.L., Bird, M.I., Large, D.J., Snape, C.E., Song, J., Sun, Y. & Tilston, E.L. 2013. Direct evidence from hydropyrolysis for the retention of long alkyl moieties in black carbon fractions isolated by acidified dichromate oxidation. Journal of Analytical and Applied Pyrolysis 103: 232-239.

Metz B, Davidson O, de Coninck H, Loos M, Meyer L (eds) 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press, New York, 431 pp.

Mäkipää, R., Liski, J., Guendehou, S., Malimbwi, R., & Kaaya, A. 2012. Soil carbon monitoring using surveys and modeling: General description and application in the United Republic of Tanzania. FAO Forestry Paper 168, Rome, Italy: Food and Agriculture Organization of the United Nations.

Nayak, A.K., Rahman, M.M., Naidu, R., Dhal, B., Swain, C.K., Nayak, A.D., Tripathi, R., Shahid, M., Islam, M.R. & Pathak, H. 2019. Current and emerging methodologies for estimating carbon sequestration in agricultural soils: A review. Science of the Total Environment 665: 890-912.

Nelson, D.W. & Sommers, L.E. 1996. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America and American Society of Agronomy, Madison, USA. pp. 961-1010.

Nordbo, A., Järvi, L., & Vesala, T. 2012. Revised eddy covariance flux calculation methodologies–effect on urban energy balance. Tellus B: Chemical and Physical Meteorology, 64(1), 18184.

Norton, B. A., Bending, G. D., Clark, R., Corstanje, R., Dunnett, N., Evans, K. L., ... & Hilton, S. 2019. Urban meadows as an alternative to short mown grassland: effects of composition and height on biodiversity. Ecological Applications, e01946.

Nowak, D. J. 1996. Estimating leaf area and leaf biomass of open-grown deciduous urban trees. Forest science, 42(4), 504-507.

Oelkers, E. H., & Cole, D. R. 2008. Carbon dioxide sequestration a solution to a global problem. Elements, 4(5), 305-310.

Ohsowski, B. M., et al. 2018. Plant response to biochar, compost, and mycorrhizal fungal amendments in post-mine sandpits. Restoration ecology 26.1: 63-72.

Olson, K.R. 2013. Soil organic carbon sequestration, storage, retention and loss in U.S. croplands: Issues paper for protocol development. Geoderma 195-196: 201-206.

Olson, K.R., Al-Kaisi, M.M., Lal, R. & Lowery, B. 2014. Experimental consideration, treatments, and methods in determining soil organic carbon sequestration rates. Soil Science Society of America Journal 78: 348-360.

Panettieri, M., Knicker, H., Berns, A.E., Murillo, J.M. & Madejón, E. 2013. Moldboard plowing effects on soil aggregation and soil organic matter quality assessed by ^{13}C CPMAS NMR and biochemical analyses. Agriculture, Ecosystems & Environment 177: 48-57.

Pataki, D.E., Carreiro, M.M., Cherrier, J., Grulke, N.E., Jennings, V., Pincetl, S., Pouyat, R.V., Whitlow, T.H. & Zipperer, W.C. 2011. Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. Frontiers in Ecology and the Environment 9: 27-36.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P. & Smith, P. 2016. Climate-smart soils. Nature 532: 49-57.

Pei, X., Sudduth, K.A., Veum, K.S. & Li, M. 2019. Improving in-situ estimation of soil profile properties using a multi-sensor probe. Sensors 19: 1011.
Peltola, A. 2019. Luke News, Roundwood prices rose in 2018. Available at: https://www.luke.fi/en/news/roundwood-prices-rose-in-2018/
Poeplau, C., Vos, C. & Don, A. 2017. Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. Soil 3: 61-66.

Pouyat, R., Groffman, P., Yesilonis, I. & Hernandez, L. 2002. Soil carbon pools and fluxes in urban ecosystems. Environmental Pollution 116: S107-S118.

Prasad, M., Maher, M.J. 2003. Stability of peat alternatives and use of moderately decomposed peat as a structure builder in growing media. In: South Pacific Soilless Culture Conference-SPSCC 648, pp. 145-151.

Pumpanen, J., Kulmala, L., Linden, A., Kolari, P., Nikinmaa, E., & Hari, P. 2015. Seasonal dynamics of autotrophic respiration in boreal forest soil estimated by continuous chamber measurements. Boreal Environment Research 20:637-650.

Puro. (2019). Puro.earth carbon removal marketplace: website. Available at: https://puro.earth/
Prasad, M., O'Shea, J. 1997. Relative breakdown of peat and non-peat growing media. In: International Symposium on Growing Media and Hydroponics, 481, pp. 121-128.

Raciti, S.M., Hutyra, L.R., Rao, P. & Finzi, A.C. 2012. Inconsistent definitions of “urban” result in different conclusions about the size of urban carbon and nitrogen stocks. Ecological Applications 22: 1015-1035.
Riikonen, A. 2019. Biohiili ja sen käyttömahdollisuudet viherrakentamisessa. Kaupunkiympäristön julkaisuja 2019:19. ISBN 978-952-331-652-2 (In Finnish).

Rapal. (2019). Software and services for work environment developers and infrastructure cost managers. Available at: https://www.rapal.com/

Rasinmäki, J. & Känkänen, R. (2014). Kuntien hiilitasekartoitus osa 2 - Hiilitaselaskuri ja toimenpidevalikoima. Helsingin kaupungin ympäristökeskuksen julkaisuja 10/2014. Helsingin kaupunki: Ympäristökeskus.

Riikonen, A., Pumpanen, J., Mäki, M., Nikinmaa, E. 2017. High carbon losses from established growing sites delay the carbon sequestration benefits of street tree plantings − a case study in Helsinki, Finland. Urban Forestry & Urban Greening 26, 85-94.

Ruokavirasto. (2018). Lannoitevalmisteiden valmistus- ja tuontitilastoja: Maanparannusaineet ja kasvualustat 2005 - 2017 (pdf). Available at: https://www.ruokavirasto.fi/yritykset/rehu--ja-lannoiteala/lannoitevalmisteet/valvonta/tilastoja/
Ruxton, G.D. & Colegrave, N. 2016. Experimental Design for the Life Sciences. Fourth edition. Oxford University Press, New York, NY. 202 p.

Salo, E. (2018). Current state and future perspectives of biochar applications in Finland. Available at: https://jyx.jyu.fi/handle/123456789/56920

Sainju, U.M., Terrill, T.H., Gelaye, S. & Singh, B.P. 2003. Soil aggregation and carbon and nitrogen pools under rhizoma peanut and perennial weeds. Soil Science Society of America Journal 67: 146-155.

Scharenbroch, B.C. 2009. A meta-analysis of studies published in Arboriculture & Urban Forestry relating to organic materials and impacts on soil, tree, and environmental properties. Arboriculture & Urban Forestry, 35, 221-231.

Schmidt, M.W. & Noack, A.G. 2000. Black carbon in soils and sediments: analysis, distribution, implications, and current challenges. Global Biogeochemical Cycles 14: 777-793.

Schmidt, M.W.I., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D.A.C., Nannipieri, P., Rasse, D.P., Weiner, S. & Trumbore, S.E. 2011. Persistence of soil organic matter as an ecosystem property. Nature 478: 49-56.

Schulz, H., & Glaser, B. 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. Journal of Plant Nutrition and Soil Science, 175(3), 410-422.

Setälä, H. M., Francini, G., Allen, J. A., Hui, N., Jumpponen, A., & Kotze, D. J. 2016. Vegetation type and age drive changes in soil properties, nitrogen, and carbon sequestration in urban parks under cold climate. *Frontiers in ecology and evolution*, *4*, 93.

Simpson, M.J. & Hatcher, P.G. 2004a. Determination of black carbon in natural organic matter by chemical oxidation and solid-state 13C nuclear magnetic resonance spectroscopy. Organic Geochemistry 35: 923-935.

Simpson, M.J., Hatcher, P.G., 2004b. Overestimates of black carbon in soils and sediments. Naturwissenschaften 91: 436–440.

Sitra. (2018).Keskivertosuomalaisen hiilijalanjälki. Available at:
https://www.sitra.fi/artikkelit/keskivertosuomalaisen-hiilijalanjalki/

Skjemstad, J.O., Janik, L.J., Head, M.J. and McClure, S.G. 1993. High energy ultraviolet photo-oxidation: a novel technique for studying physically protected organic matter in clay- and silt-sized aggregates. Journal of Soil Science 44: 485-499.

Skjemstad, J.O., Swift, R.S. & McGowan, J.A. 2006. Comparison of the particulate organic carbon and permanganate oxidation methods for estimating labile soil organic carbon. Australian Journal of Soil Research 44: 255-263.

Smith, P. 2004. Monitoring and verification of soil carbon changes under Article 3.4 of the Kyoto Protocol. Soil Use and Management 20: 264-270.

Smith, P., Soussana, J., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F., McNeill, S., Kuhnert, M., Arias-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Wollenberg, E., Álvaro-Fuentes, J., Sanz-Cobena, A. & Klumpp, K. 2019, How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal, Global Change Biology 00: 1– 23.

Sollins, P., Classman, C., Paul, E.A., Swanston, C., Lajtha, K., Heil, J.W. & Elliott, E.T. 1999. Soil carbon and nitrogen. Pools and fractions. In: Robertson, G.P. Standard Soil Methods for Long-Term Ecological Research. Oxford University Press, New York.

Stevens, A., van Wesemael, B., Bartholomeus, H., Rosillon, D., Tychon, B. & Ben-Dor, E. 2008. Laboratory, field and airborne spectroscopy for monitoring organic carbon content in agricultural soils. Geoderma 144: 395-404.

Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., de Courcelles, Vivien de Remy, Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Parton, W.J., Whitehead, D. & Zimmermann, M. 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems and Environment 164: 80-99.

Suárez-Abelenda, M., Kaal, J., Camps-Arbestain, M., Knicker, H. & Macías, F. 2014. Molecular characteristics of permanganate- and dichromate-oxidation-resistant soil organic matter from a black-C-rich colluvial soil. Soil Research 52: 164-179.

Tanhuanpää, T., Kankare, V., Setälä, H., Yli-Pelkonen, V., Vastaranta, M., Niemi, M. T., ... & Holopainen, M. 2017. Assessing above-ground biomass of open-grown urban trees: A comparison between existing models and a volume-based approach. Urban forestry & urban greening, 21, 239-246

Teir, S., Eloneva, S., Fogelholm, C. J., & Zevenhoven, R. (2009). Fixation of carbon dioxide by producing hydromagnesite from serpentinite. Applied Energy, 86(2), 214-218.

Ter-Mikaelian, M.T., Korzukhin, M.D., 1997. Biomass equations for sixty-five North American tree species. Forest Ecology and Management 97, 1-24

United Nations. 2019. World Urbanization Prospects 2018. Department of Economic and Social Affairs, Population Division. https://population.un.org/wup/

Urban tree database of the City of Helsinki. (2019). The maintainer of the dataset is Helsingin kaupunkiympäristön toimiala / Maankäyttö ja kaupunkirakenne / Kaupunkitila ja maisemasuunnittelu. The dataset has been downloaded from Helsinki Region Infoshare service on 07.12.2019 under the license Creative Commons Attribution 4.0. Available at: https://hri.fi/data/en_GB/dataset/helsingin-kaupungin-puurekisteri

Valtioneuvosto. (2019). Pääministeri Antti Rinteen hallituksen ohjelma 6.6.2019: OSALLISTAVA JA OSAAVA SUOMI – sosiaalisesti, taloudellisesti ja ekologisesti kestävä yhteiskunta. Retrieved August 8, 2019, from: http://urn.fi/URN:ISBN:978-952-287-756-7

Vares, S., Häkkinen, T., & Vainio, T. (2017). Rakentamisen hiilivarasto. VTT-CR-04958-17. VTT Technical Research Centre of Finland

Velasco, E. & Roth, M. 2010. Cities as net sources of CO2: Review of atmospheric CO2 exchange in urban environments measured by eddy covariance technique. Geography Compass 4: 1238-1259.

Viherympäristöliitto ry, 2016: Kestävän viherhankkeen prosessi. Selvitysraportti (The process of sustainable urban green project, in Finnish). Viherympäristöliitto 2016. https://www.vyl.fi/site/assets/files/1550/vyl_kesy_kestavan_viherhankkeen_prosessi_20160923-1.pdf Retrieved 8-1-2019

Vochozka, M., Maroušková, A., Váchal, J. et al. Clean Techn Environ Policy (2016) 18: 1225. https://doi.org/10.1007/s10098-016-1113-3

von Lützow, M., Kögel-Knabner, I., Ekschmitt, K., Flessa, H., Guggenberger, G., Matzner, E. & Marschner, B. 2007. SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms.

Wang, D., Chakraborty, S., Weindorf, D.C., Li, B., Sharma, A., Paul, S. & Ali, M.N. 2015. Synthesized use of VisNIR DRS and PXRF for soil characterization: Total carbon and total nitrogen. Geoderma 243-244: 157-167.

Washbourne, C. L., Lopez-Capel, E., Renforth, P., Ascough, P. L., & Manning, D. A. 2015. Rapid removal of atmospheric CO2 by urban soils. Environmental science & technology, 49(9), 5434-5440.

Whitman, T., Singh, B.P., Zimmerman, A.R. 2015. Priming effects in biochar-amended soils: implications of biochar-soil organic matter interactions for carbon storage. In: Lehmann, J. & Joseph, S. (ed.). Biochar for Environmental Management: Science, Technology and Implementation. 2nd ed. Routledge, Abingdon, Oxon; New York. pp. 1-13.

Wood, C. R., & Järvi, L. 2012. Urban climate observations in Helsinki. Magzine Finn. Air Pollut. Soc.(3), 3.

Yang, X.Y., Chang, K-H., Kim, Y.J., Zhang, J. & Yoo, G. 2019. Effects of different biochar amendments on carbon loss and leachate characterization from an agricultural soil. Chemosphere 226: 625-635.

Yli-Halla, M., Rimhanen, K., Muurinen, J., Kaseva, J. & Kahiluoto, H. 2018. Low black carbon concentration in agricultural soils of central and northern Ethiopia. Science of the Total Environment 631-632: 1-6.

Appendix 1. Quality guidelines of infrastructure constructions

In Finland, the established process of urban green construction and maintenance is well documented (Viherympäristöliitto 2016) and based on explicit quality guidelines. Contractors commonly follow the up-to-date version of quality guidelines of infrastructure constructions (Rakennustietosäätiö 2016), which state e.g. the required composition, depth and volume of planting soil for different plant types. In some cases, separate specifications exist for various landscape types such as parks, traffic areas or playing fields. In addition, relatively strict national legislation defines allowed materials in planting soils (Fertiliser Product Act 29.6.2006/539 and its amendment 24/11). The main requirements for common park lawns, shrub plantings, park and street trees are briefly summarised in Table 1.

Table 1.

Plant type	Soil SOM (LOI%)	Plant available N mg/l	Plant available P mg/l	Plant available K mg/l	Soil depth mm	Soil volume m^3
Park lawn	8%	50	15	200	200	n/a
Shrub planting	8-12%	10-35	15-20	200-300	400	
Park trees	8%	10-35	5-20	75-300	600 (small tree), 800 (large tree)	1.5-3.2
Street trees	12%	35	20	300	1000	7.2 (connected), 25 (single tree)

Since the vast majority of municipal urban green plantings in Finland follow these guidelines, the control treatments based on these specifications will be comparable and relatable to most urban greening practitioners as well as suitable as research controls. It is required however that used materials are well documented, since especially growing media requirements are in some cases given as ranges rather than single values. Planting soil product declarations, as required by legislation, form a key part of this documentation.

Appendix 2. Minerals that fix CO_2 from the atmosphere

Minerals that can fix carbon

Weathering of certain rocks can transfer carbon from its atmospheric pool to the geological carbon pool. This occurs as a part of the global, long-term carbon cycle (Boot-Hanford et al. 2014) and as a result, thermodynamically stable carbonate minerals are formed. Carbon fixed in this process can be stored in geological carbon pool as a part of carbonate minerals for millions of years. Carbonates are substantial carbon storage, as there are 39,000,000 Gt of carbon fixed in them worldwide (Oelkers and Cole 2008), whereas 2,344 Gt of carbon can be found in organic form from soils (Stockmann et al. 2013).

Carbon fixing minerals in urban landscaping

Rocks that contain carbonate-forming minerals can be found throughout the world (Goff et al. 1998). In many places, these rocks are mined to produce raw materials for different purposes. Mining industry produces many by-products. One of these is surplus rock material that for some reason is unsuitable for further processing. This rock material is often stored in piles close to the mining site.

As an example, a company called Suomen Kiuaskivi Oy manufactures sauna stove stones in Ristiina, Eastern Finland. Mined rock material contains 68-73% olivine (see Appendix 1 for carbonation reaction of olivine). Rock fragments that are too small for being used as stove stones are generated as a by-product. Currently, this rock material is piled up close to the mining site, with no further usage. These types of by-products could be suitable building material to urban landscaping even without further processing. Using by-product would be efficient method to curtail greenhouse gas emissions and other environmental impacts caused by urban landscaping, as long as the rock material is attained from relatively close distance from the building site to keep CO_2 -emissions from the transport in control.

When considering the potential for carbon sequestration, carbonate-forming stone material may not be the most efficient tool. Carbonation reaction has low reaction kinetics in natural conditions, but if the raw material is attained from a by-product, could still add some C – sequestering potential to a certain location/park. Carbonation is a surface reaction, hence amount of surface area determines the carbonation potential of mineral. The smaller the particle size is, more carbon can be fixed to the mineral surface. To attain maximal carbon sequestration, stone material has to be small in particle size and also preferably have lots of cracks in it. Carbonation reaction hinders when mineral surface fills up with carbonates. Ultimately surface gets saturated and reaction stops.

If carbonate-forming rock material is used as a part of load-bearing soil, degree of its carbonation can be determined in laboratory by measuring total carbon content (TC) and total organic carbon content (TOC). Difference (TC-TOC) reveals the amount of carbonates. To follow up the degree of carbonation in load-bearing soil, baseline measurement is needed when building a park. Because of the slowness of carbonation reaction, possible follow-up measurements could take place after few years.

Possible other benefits of using carbonate-forming by-products

Using by-product stone material like olivine described here for urban landscaping could have other benefits beside carbon sequestration. It would be necessary to find further use for all industrial by-products, including surplus material of mining industry. Minimising the environmental effects of all industries is in line with circular economy and greener society goals (for example, city of Helsinki aims to be carbon neutral by 2035). One potential use for by-products could be their usage as a raw material for building purposes, for example in landscaping and building parks. Taking full advantage of industrial by-products at every level of society also minimises the need to use virgin natural resources. In parks like Jätkäsaari demonstration area, carbonate-forming minerals could also be used for demonstration purposes when illustrating the global carbon cycle.

Gap-graded gravel and rocks are often used for constructing parks. Manufacturing and transporting creates CO_2 emissions. Could this be replaced with carbon sequestering mineral? Calcium carbonate content of soil has been shown to increase up to 1 m in urban development cite (Washbourne et al. 2015).

Silicate rocks that contain alkali or alkaline earth metal (Mg^{2+}, Ca^{2+}, Fe^{2+}) oxides (O^{2-}) or hydroxides (OH^-) can fix CO_2 and create long term storage for carbon in the form of carbonate minerals (Boot-Handford et al. 2014).

Weathering reactions of Mg - silicate minerals and Ca or Fe- rich silicates form stable carbonate minerals, for example calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), magnesite ($MgCO_3$) and siderite ($FeCO_3$) (Metz et al. 2005). Examples of these reactions can be found from below:

Olivine ($(Mg,Fe_2)\,SiO_4$)
Forsterite: $Mg_2SiO_4 + 2\ CO_2 + 2\ H_2O \rightarrow 2\ MgCO_3 + H_4SiO_4$
Fyalite: $Fe_2SiO_4 + 2\ CO_2 + 2\ H_2O \rightarrow 2FeCO_3 + H_4SiO_4$

Serpentine
$Mg_3Si_2O_5\,(OH)_4 + 3\ CO_2 + 2\ H_2O \rightarrow 3\ MgCO_3 + 2\ H_4SiO_4$

Wollastonite
$CaSiO_3 + CO_2 + 2\ H_2O \rightarrow CaCO_3 + H_4SiO_4$

Appendix 3. Techniques for the isolation, quantification and characterisation of soil C fractions

Comparison of techniques for separation and quantification of soil carbon and its different fractions. SOC = soil organic carbon, PyC = pyrogenic carbon, SIC = soil inorganic carbon, TC = total carbon, SOM = soil organic matter, PCM = pyrogenic carbonaceous material, DOC = dissolved organic carbon. Modified from Bird (2015) and Nayak et al. (2019).

Group/technique	Separated fraction(s)	Advantages	Disadvantages	Reference(s)
Physical				
Aggregate fractionation	SOC/PyC: distribution in aggregate-size classes	Separates free SOC from physically protected SOC (protected by occlusion in secondary organo-mineral assemblages).	Cannot separate SOC protected by occlusion in clay microstructures. Sieving and pretreatments alter the distribution of SOC in aggregates.	Blanco-Canqui & Lal 2004, Brodowski et al. 2006, Sainju et al. 2003
Particle size fractions	SOC: active, intermediate and passive fractions PyC	Low-cost and easy. Rough estimates of younger (sand-associated) and older (silt and clay associated) SOC fractions.	Time-consuming. Microaggregates may not always completely disaggregate during the procedure. May underestimate clay and silt associated fractions.	von Lützow et al. 2007
Density fractionation	SOC/PyC: contained in different density fractions (e.g. light, medium and heavy)	Low-cost and easy. Interactions between SOC/PyC and minerals can be studied.	Time-consuming. Fine material not easily quantified. Not very accurate.	Glaser et al. 2000
Chemical				
Dichromate oxidation	SOC: active fraction PyC estimated as: total SOC - dichromate-oxidizable SOC	Widely adopted, easy and rapid. Minimal equipment needed, relatively simple and cheap.	Laborious. Oxidation of SOC incomplete; residues contain non-PyC SOM. Conditions vary between laboratories. Soil type and SOC properties affect the result.	Meredith et al. 2013, Nelson & Sommers 1996, Sollins et al. 1999, Suárez-Abelenda et al. 2014
Ultra-violet (UV) photo-oxidation	SOC: aggregate-protected SOC (intermediate / passive pool) PyC	Measures aromatic C from wide range of PCM continuum.	Low accessibility. Relies on calibrations. Incomplete oxidation of SOC; most strongly bound SOC resistant (through physical protection) to photo-oxidation.	Hammes et al. 2007, Skjemstad et al. 1993
Sodium chlorite oxidation	SOC PyC	Rather easily accomplished in most laboratories. Lignin and other easily oxidizable components of SOM are removed, remaining fraction represents PyC.	Low accessibility. Should be further tested on various samples. Requires NMR for quantification.	Hammes et al. 2007, Simpson & Hatcher 2004a
Peroxide/weak nitric acid digestion	SOC PyC	Accurate, reproducible, simple and rapid.	Result depends on the soil type. May not oxidize all SOC; probably overestimates PyC content.	Kurth et al. 2006, Yli-Halla et al. 2018
Permanganate oxidizable carbon (POXC)	SOC: (stabilized pool of) labile fraction PyC	Easy, rapid and low-cost. Measures SOC fraction that responds to changes in management; early indicator of soil ecosystem change.	Little effect on e.g. sugars, amino acids; may not reliably estimate labile SOC fraction. May oxidize significant amount of PyC.	Culman et al. 2012, Panettieri et al. 2013, Skjemstad et al. 2006, Suárez-Abelenda et al. 2014
Hot water-extractable carbon (HWC)	SOC (and PyC): labile fraction (readily decomposable pool)	Indicator of soil quality; responds to changes in soil management. HWC content of biochar related to DOC loss from biochar-amended soil.	Less related to soil structural stability than POXC, represents fixed proportion of SOC (≈ 5 %); may be less relevant SOM quality indicator than POXC.	Ghani et al. 2003, Jensen et al. 2019, Yang et al. 2019

Group/technique	Separated fraction(s)	Advantages	Disadvantages	Reference(s)
Thermal				
Loss on ignition (LOI)	SOC PyC	Widely adopted, simple and low-cost. Minimal equipment required. No hazardous waste generated.	In clayey soils: loss of structural water.	Sollins et al. 1999
Dry combustion (DC)	TC SOC (after removal of SIC) SIC (indirectly)	Most suitable for routine analyses of TC content. Widely used. Relatively cheap and rapid analyses. Complete combustion of all SOC. Suitable for large number of samples.	High initial cost of the device. Loss of volatile organic compounds during drying/pretreatment.	FAO 2019, Sollins et al. 1999
Chemo-thermal oxidation at 375 °C (CTO-375)	SOC PyC: condensed component	Clearly defined protocol. Minimal handling required. Conditions can be tightly controlled.	Unreliable assessment of non-condensed PCM. Matrix effects/charring may cause under/over-estimation.	Hammes et al. 2007
Thermogravimetry – differential scanning calorimetry (TG-DSC)	SOC SIC PyC	Operationally simple. Wide analytical window. All C species (including carbonates) can be detected.	May overestimate PyC in low SOC soils. May not completely separate SOC and PyC in some samples.	Hammes et al. 2007
Hydrogen pyrolysis (hypy)	SOC PyC: mainly composed of > 7 aromatic domains	Rapid and precise. Measures highly condensed PyC component that is important for biochar C sequestration potential.	Low accessibility. Trace charring possible.	Meredith et al. 2013
Multi-element scanning thermal analysis (MESTA)	SOC PyC: resistant component	Sensitive, reproducible, no pretreatment required. Analyses PyC interesting in biochar C sequestration studies.	Low accessibility. May not always separate between SOC and PyC.	Hsieh & Bugna 2008
Spectroscopic				
Nuclear magnetic resonance (NMR) spectroscopy	SOC PyC: quantifies wide range of PCM continuum	Detailed structural information of organic compounds. Presence or absence of PyC can be confirmed.	Comparatively expensive. Used with other techniques that add bias to results. Not able to identify single compounds due to heterogeneity of SOM.	Simpson & Hatcher 2004b, Panettieri et al. 2013
Visible and near-infrared (Vis-NIR) spectroscopy	SOC SIC TC	Rapid, accurate, comparatively cheap. Laboratory, in situ and airborne measurements. Suitable for large number of samples. Small changes in SOC stock can be detected.	Requires calibration with other technique. Site-specific calibration needed due to the interference caused by surroundings (e.g. soil type and moisture affect spectra).	Bricklemyer et al. 2018, Stevens et al. 2008, Wang et al. 2015
Mid-Infrared (MIR) spectroscopy	SOC PyC SIC	Rapid, accurate, medium cost. Multiple soil components can be predicted.	Requires calibration with other technique and potentially site-specific calibration.	Janik et al. 2007
Laser-induced breakdown spectroscopy (LIBS)	SOC SIC TC	Non-destructive. In-situ estimation of bulk density and SOC stock. Accuracy comparable to NMR. Multiple soil components can be predicted.	Comparatively expensive. Interaction with the surroundings affects spectra.	Bricklemyer et al. 2011
Molecular marker				
Benzene Polycarboxylic Acids (BPCA)	PyC: wide range of PCM components captured	Polycondensation degree of PCM components can be investigated.	Multiple steps. Most condensed PCM not measured.	Glaser et al. 1998, Llorente et al. 2018
Pyrolysis GC/MS (Py-GC/MS)	SOC PyC	Provides isolation and characterisation.	High cost, low accessibility. Semi-quantitative only.	Suárez-Abelenda et al. 2014

Appendix 4. Follow up plan for the Jätkäsaari demonstration site

4.1 Vegetation measurements

In Jätkäsaari demonstration site, two types of vegetation could be established on experimental biochar planting soils: several species of trees, and lawn. Following up their quality and C sequestration must be planned taking into account the available resources. An established way to do this is mark measurements on stepwise levels of importance and carry them out in this order according to the time and labour available (Table 2). The time horizon to be considered is potentially centuries, but at least a few decades are required to be able to gain insights on the potential of e.g. tree C sequestration. Tree biomass increase is dependent on tree size itself – young and small trees are initially slower to sequester C, but their potential is better realised as tree crown size grows (Riikonen et al. 2018). Similarly, soil C sequestration is a process which operates on decadal and centennial scale rather than daily or annual scale. Thus, measurements aiming to document biomass and soil C stocks and sequestration are typically performed on annual scale.

Initially, all trees in the area should be coded on a map with treatment and tree individual identification code. This ensures that data is attributed to correct treatment, and any inconsistencies, such as dead or replaced trees, are documented. Tree code and sampling date is then used as sample identification code. Similarly, lawn plots are marked on maps with identification codes.

4.1.1 Trees: measured variables

For the planted trees, initial measurements of nursery plant dimensions are important to carry out. It enables the separation of C stock accumulated by the trees during the nursery phase and determination of C fixed by the trees after planting. This is increasingly important for larger tree transplants, which may already carry a C stock of several kilograms at planting (Riikonen et al. 2018), which should not be attributed to C sequestration at the site. In Finland trees are commonly planted as balled and burlapped (B&B), and the use of bare roots transplants is extremely rare due to the required timely logistics. The root systems of B&B trees cannot be documented as accurately as bare root nursery trees, but rootball dimensions are standardized based on tree DBH. Therefore, we can infer the proportion of root biomass retained in the rootball based on literature on root system spread (Riikonen et al. 2018). The assessment of aboveground biomass at planting is relatively straightforward from trunk circumference information, which can be enhanced if tree height is also known.

Picture 1. Park trees may be planted in relatively large size. Newly planted trees in Helsinki, Töölönlahti park, in summer 2016. Image by Anu Riikonen.

After planting, the follow-up of tree aboveground C sequestration is at its simplest, the repeated measurement of tree trunk circumference growth. Circumference measurement is preferable to diameter, as it does not rely on assumptions of trunk roundedness, and thus is more accurate. If more resources are available, the accuracy of the tree biomass measurement can be enhanced in several ways. Leaf biomass can be estimated from leaf samples. Trunk volume can be measured, as can the woody biomass volume of the entire tree, if laser scanning equipment and data processing is available. C content of wood can be measured by dry combustion, if higher accuracy than the use of literature values is needed. Tree coring for wood samples harms trees, so it should be used with caution, on as small number of trees as possible, and not too often.

Belowground biomass measurement can, at its simplest, be included in the soil C stock measurement. Tree roots are included in C measured in soil samples, if roots are not picked out prior to analysis and analysed separately. This whole-system soil C stock measurement is effective, simple, and does not require information on tree root biomass or longevity. Moreover, it integrates the addition of C into the soil from live roots, dead root litter, root C secretion and aboveground litter. Measuring these together provides no insight into the functioning of the soil C stock development in urban environment, but the margin of error in the overall values is much smaller than if an attempt is made to measure the components separately. However, information on root longevity and quantity of root litter in urban environment is entirely lacking and direly needed for optimizing urban tree C sequestration. Most commonly, root biomass, fine root turnover, and root C stock is estimated from root-shoot ratios, measurements of fine root turnover on forest trees, and biomass equations. These are not particularly accurate for urban trees. Root biomass samples and minirhizotron follow-up of fine root turnover would be preferable but are also extremely labour intensive.

One additional issue is that oftentimes urban trees must be pruned to fit their allotted living space. If such pruning is performed at Jätkäsaari experimental site, the biomass removal must be documented for each tree. At its simplest, this can be based on fresh biomass weight measurement for each tree pruned, and a sample of pruning material can then be dried and used to account for biomass removal (Riikonen et al. 2018).

4.1.2 Lawn

Unlike trees, which are planted in already considerable size, lawns are commonly sown from seed. Thus, biomass measurements do not need initial comparison value. Consideration must be made however on what season and growth stage plant cover, biomass and other measurements of lawn quality and C stock should be made to be most easily comparable and informative, and possible to repeat over several years. Overall, lawn aboveground biomass and C stock can be expected to be rather stable after the establishment phase, and C stock increase is expected to be predominantly belowground. Similarly to the tree root C stock, the best and most comprehensible method to measure the impact of lawn on the system C stock is to measure soil C stock change, including live roots also.

Table 2. Suggested vegetation measurements in the order of priority. After the initial measurements, the repeat interval of the follow-up measurements can be from one year to ca. 10 years, depending on resources.

Vegetation component	Minimum initial measurements	First priority follow-up measurements (annual)	2nd priority measurements	3rd priority measurements
Trees, aboveground	trunk circumference	trunk circumference OR tree volume	C content of wood (note: destructive)	leaf biomass
Trees, belowground	rootball size	soil C stock sampling	fine root longevity (minirhizotron)	live/dead root separation from soil samples
Lawn, aboveground	sowing density	cover and quality assessment	biomass sampling	
Lawn, belowground	initial soil C stock	soil C stock sampling	live/dead root separation from soil samples	

4.1.3 Sampling of vegetation

The research setup altogether consists of relatively small number of trees. All measurements would ideally be made from all trees in the treatment, but at least the initial measurements and DBH measurements in consequent years should include all trees in the experiment. For other measurements, if tree growth within treatment appears uniform, a random sample of 3 trees per treatment could be drawn. Any samples, e.g. wood cores and leaf samples, should be taken in triplicates if possible; if not, one sample from 3 random trees or all trees within each treatment should be taken. In such a case, these same trees should be measured, if a given measurement is to be repeated later. Wood C content is somewhat problematic in this respect due to the destructive nature of the sampling, so low number of samples is preferable especially when trees are young. Branches pruned for other reasons may also be used for this purpose.

For lawn treatments, sampling should be made at 1 m distance from the edge of a treatment area, i.e. on the central area of each treatment plot. Three biomass samples or 3 lawn quality scoring frames should be taken from random positions within the central area of the sampling plot.

4.2 Soil measurements

Like the vegetation measurements, soil measurements should be conducted stepwise in the order of priority (Table), depending on the time and resources available. The relevant timescale to see any significant changes in soil C stock is at least 6 to 10 years because the changes in soil C stock are slow and difficult to detect against the large background SOC content during a monitoring period of 5 years or less (e.g. Smith 2004). Soil should be sampled to at least 30 cm depth for the determination of C stock, but it would be preferable to sample the soil to 1 m if possible (Smith 2004).

4.2.1 Analyses of the quality of biochar

The quality of the biochar should be analysed before it is added to planting soils or at least the biochar used should be sampled and stored to wait for future analyses. As discussed above (section 3.1.1), the 1st priority measurement would be to analyse biochar C content by dry combustion in a CHN analyser to account for the C input with biochar. Simultaneously, biochar H and N contents can be determined, allowing to calculate the H/Corg -ratio of biochar, an indicator that can be used to predict the persistence of biochar in soil. Other relevant properties of biochar to analyse would be microbial available C, the contents of other nutrients (P, K, Ca, Mg), pH, liming equivalence, ash content, specific surface area and the pore size distribution (EBC 2012, Leng et al. 2019). Also, the documentation of production conditions (highest treatment temperature and residence time) and feedstock type are important and these together with the analyses suggested can be regarded as the minimum set of biochar properties to be characterised (Leng et al. 2019).

4.2.2 Soil: measured variables

Soil C content is usually determined for the fine earth (< 2 mm) fraction of the soil as the coarser mineral soil material is not thought to contain C. The living root fragments > 2 mm are not considered as part of SOC either but usually, as part of plant biomass (Poeplau et al. 2017). Relevant parameters for calculating soil C stock include C concentration of the fine soil fraction (< 2 mm), the content of rock fragments (= coarse mineral fragments > 2 mm) and soil bulk density or fine soil mass (FAO 2019, Poeplau et al. 2017). If possible, five soil depth increments could be studied: 0-10, 10-30, 30-50, 50-70 and 70-100 cm.

Different calculation methods of SOC stocks may produce highly variable estimates with most bias produced for soils containing > 30 % rock fragments if bulk density is not accounted for at all in the equation (Poeplau et al. 2017). For soil carbon accounting purposes, soil C content, bulk density and gravel content should thus be determined (England & Viscarra Rossel 2018).

At simplest, we can measure the change in soil total carbon stock with dry combustion that is currently the most feasible method for us (see section 3.1.3.1 - Soil). It is recommended to measure the share of inorganic C (carbonates) using pretreatment with HCl and calculating the SIC content as a difference between the results acquired by dry combustion in an elemental analyser for untreated (total C) and acid-treated (SIC removed, SOC remaining) samples. This would be the 1st priority measurement. To study the persistence of biochar-C in soil for the verification of C sequestration, it would be important to study the pyrogenic C content of the soil samples as well. This could be done by applying MIR spectroscopy that might be currently the most suitable method for quantifying PyC (Bird 2015, Janik et al. 2007). TG-DSC is also appealing because it is operationally simple and can separate different C species (including carbonates) based on their thermal stabilities. Chemo-thermal oxidation at 375 °C (CTO-375) or hydrogen pyrolysis (hypy) could be used to further investigate the condensed component of the PyC fraction (Hammes et al. 2007, Meredith et al. 2013).

Table 1. Suggested soil measurements in the order of priority. After the initial measurements, the repeat interval of the follow-up measurements can be from one year to ca. 10 years, depending on resources.

Soil property	Minimum initial measurements	First priority follow-up measurements (annual)	2nd priority measurements	3rd priority measurements
Soil C fractions	Total C stock and SOC fraction by dry combustion (pretreatment by HCl to account for SIC)	Total C stock and SOC fraction by dry combustion (pretreatment by HCl to account for SIC)	PyC fraction by MIR spectroscopy OR TG-DSC	Condensed component of PyC by e.g. CTO-375 OR hypy
Soil bulk density	Volume-specific soil samples from every layer studied	Volume-specific soil samples from every layer studied		
Gravel (> 2 mm) content	Sieving to separate fine earth fraction (≤ 2 mm) from gravel	Sieving to separate fine earth fraction (≤ 2 mm) from gravel		

Other soil properties relevant to measure would be for example soil moisture, temperature and pH, as well as the availability of various nutrients (e.g. N, P, K, Ca and Mg). Soil pH, cation exchange capacity, soil type as well as contents of many nutrients (e.g. P, K, Ca, Mg and S) could be studied by the protocols of national soil fertility analysis.

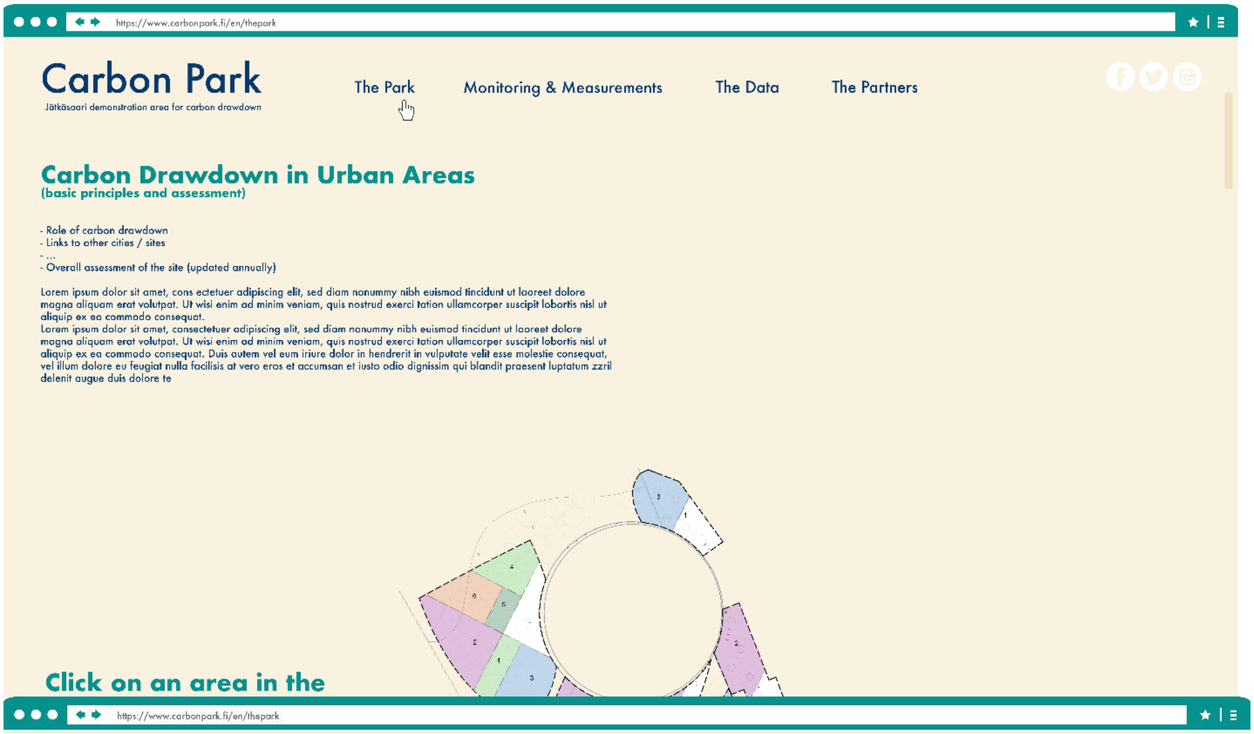
4.2.3 Soil sampling

Soil sampling strategies (e.g. sampling interval, sampling location, number of samples per plot) should be properly designed to get meaningful results. Soil sampling can be done by using either undisturbed (intact) core method or excavation method. Volume-specific soil samples are recommended to be taken for the determination of soil bulk density. They should be taken with a volume-specific cylinder from each layer for which soil C stock is to be determined (e.g. Mäkipää et al. 2012). This may be challenging for coarse-textured, stony soils where the use of smaller cylinders may be one option. For soils containing abundant rock fragments, a clod method has also been suggested (e.g. England & Viscarra Rossel 2018) but this method was not recommended by FAO (2019). In the end, the determination of bulk density for the load bearing (structural) soils in Jätkäsaari demonstration site is very difficult and practically impossible due to the abundant rock fragments in it (Picture 2). For planting soils, we could use the volume-specific cylinders for the determination of bulk density.

While the undisturbed core method could be the most suitable sampling method, soil compaction is an issue when taking soil cores. It probably causes some compaction that is why indicator layers consisting of e.g. perlite (or other inert material) would be a good idea. This is not however, applicable to the demonstration site in Jätkäsaari but would be relevant to consider in case this kind of park is constructed elsewhere. Indicator layers would be a possible way to address soil compaction caused by soil coring.

Picture 2. Soil sampling at the Jätkäsaari demonstration site in November-December 2019 while the park was under construction. Left: structural soil, right: planting soil. Images by Päivi Soronen and Priit Tammeorg.

Appendix 5. Carbon Park webpage: a digital platform for engagement



Carbon Park
Jätkäsaari demonstration area for carbon drawdown

Carbon Drawdown in Urban Areas
(basic principles and assessment)

- Role of carbon drawdown
- Links to other cities / sites
- ...
- Overall assessment of the site (updated annually)

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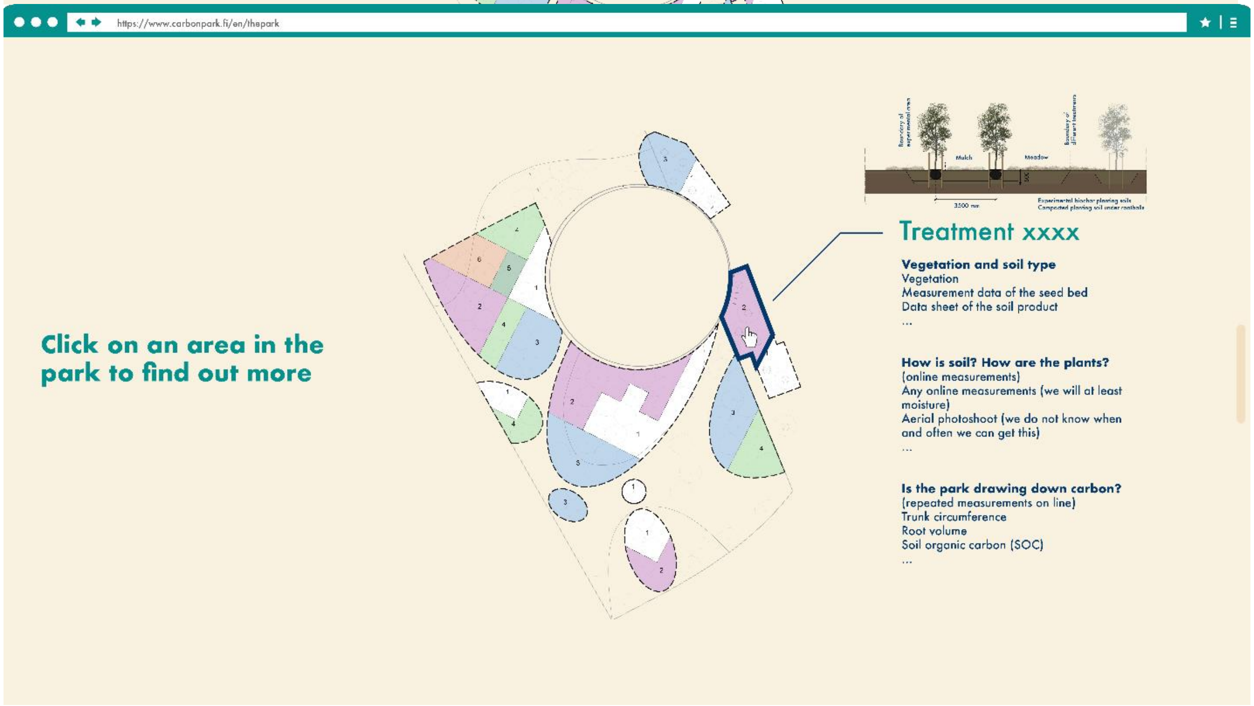
Click on an area in the



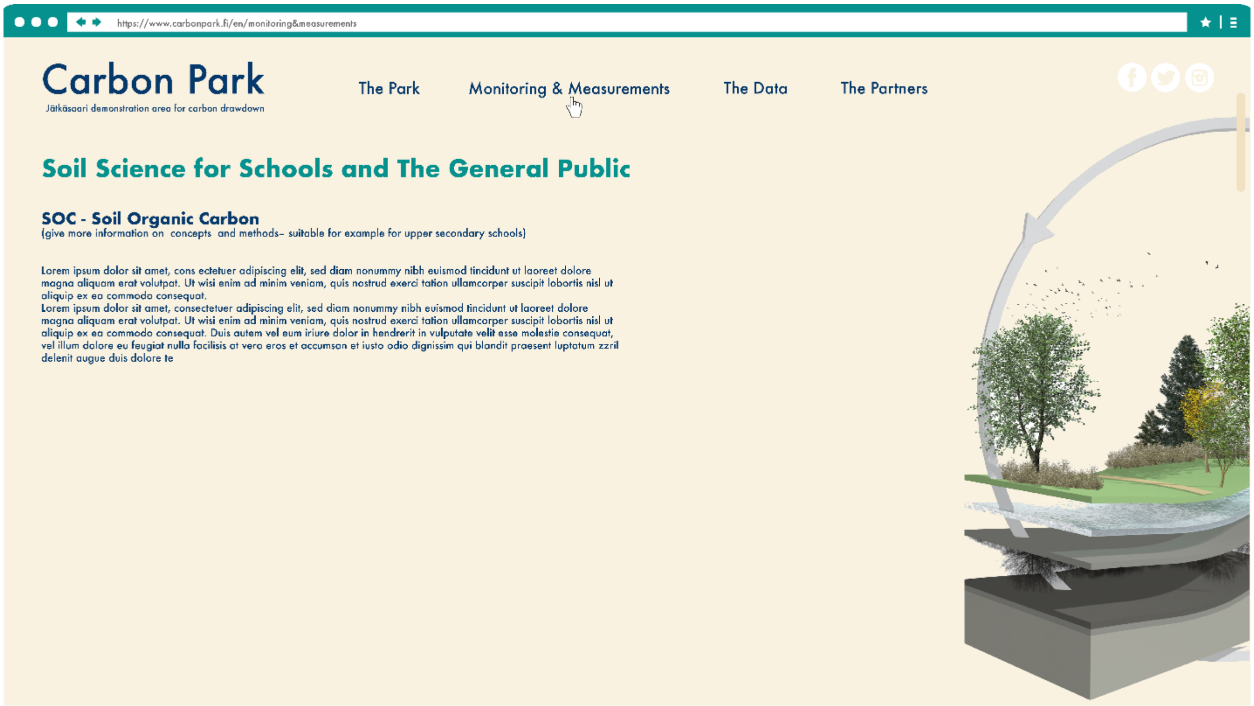
Click on an area in the park to find out more

Treatment xxxx

Vegetation and soil type
Vegetation
Measurement data of the seed bed
Data sheet of the soil product
...

How is soil? How are the plants?
(online measurements)
Any online measurements (we will at least moisture)
Aerial photoshoot (we do not know when and often we can get this)
...

Is the park drawing down carbon?
(repeated measurements on line)
Trunk circumference
Root volume
Soil organic carbon (SOC)
...



Soil Science for Schools and The General Public

SOC - Soil Organic Carbon
(give more information on concepts and methods– suitable for example for upper secondary schools)

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Appendix 6. Infographic posters

During the Carbon Lane -project, infographic posters were created and proposed to the City of Helsinki to be used on-site for providing information to the park visitors. In total of three posters were created from which, poster 1 and poster 2 are preliminary agreed to be used in the park. The posters were:

- Poster 1 explaining the purpose of the research on the park
- Poster 2 explaining the carbon flows and functions of biochar in the park
- Poster 3 explaining the difference of soil treatments

In addition, Poster 1 will include QR code which redirects to the home page of Carbon Lane project: www.aalto.fi/fi/carla. Also, trees, planting soils and research devices could be marked with QR-codes, that would lead visitors to see more information in the form of text or videos or inquiries to participate.

In addition, Poster 1 encourages audience to use hashtag #hiilipuisto (which translates into carbon park) to post feedback, questions, opinions and pictures of the park. In addition, stakeholders of Carbon Lane project have been encouraged to communicate Carbon Lane in social media using as well.

Puistossa tehdään tutkimusta
Parken är föremål för studier

Hyväntoivonpuistossa tutkitaan biohiilipohjaisten kasvualustojen vaikutusta maaperän toimintaan ja puiden kasvuun. Tutkimuksen piiriin kuuluu noin 80 puuta, joissa on mukana kontrollikasvualusta sekä eri suomalaisvalmistajien biohiilipohjaisia kasvualustoja. Hanke tukee Hiilineutraali Helsinki 2035 -tavoitetta.

Tavoitteena on puiden ja maaperän hyvinvoinnin parantaminen ja sitä kautta hiilensidonnan kiihdyttäminen. Biohiilipohjaisista kasvualustoista on hyviä kokemuksia, esimerkiksi Tukholmassa näitä kasvualustoja on käytetty jo vuodesta 2009.

Tutkijat vierailevat puistossa muutaman kerran vuodessa arvioimassa puiden kasvua ja maaperän tilaa. Eri käsittelyjen vaikutuksia seurataan muun muassa maan kosteuden, hiilen määrän sekä ravinnemäärien mittauksilla.

Havainnoi ja anna palautetta puiden hyvinvoinnista ja kasvusta hastagilla #hiilipuisto

I Godahoppsparken undersöks hur växtunderlag på basis av biokol påverkar jordmånen och trädens tillväxt. Undersökningen omfattar cirka 80 träd med kontrollväxtunderlag samt sådant växtunderlag från olika finländska tillverkare som innehåller biokol. Projektet stödar målet Kolneutralt Helsingfors 2035.

Avsikten är att bidra till trädens och jordmånens välbefinnande och därigenom att accelerera kolbindningen. Erfarenheterna av växtunderlag med biokol är goda, exempelvis i Stockholm används dylika växtunderlag redan sedan 2009.

Forskare besöker parken några gånger om året för att utvärdera trädens tillväxt och jordmånens tillstånd. Effekter av olika behandlingar kontrolleras bland annat genom att mäta såväl jordfuktighetsom mängder kol och näringsämnen.

Observera och ge respons på trädens välbefinnande och tillväxt med hashtaggen #hiilipuisto

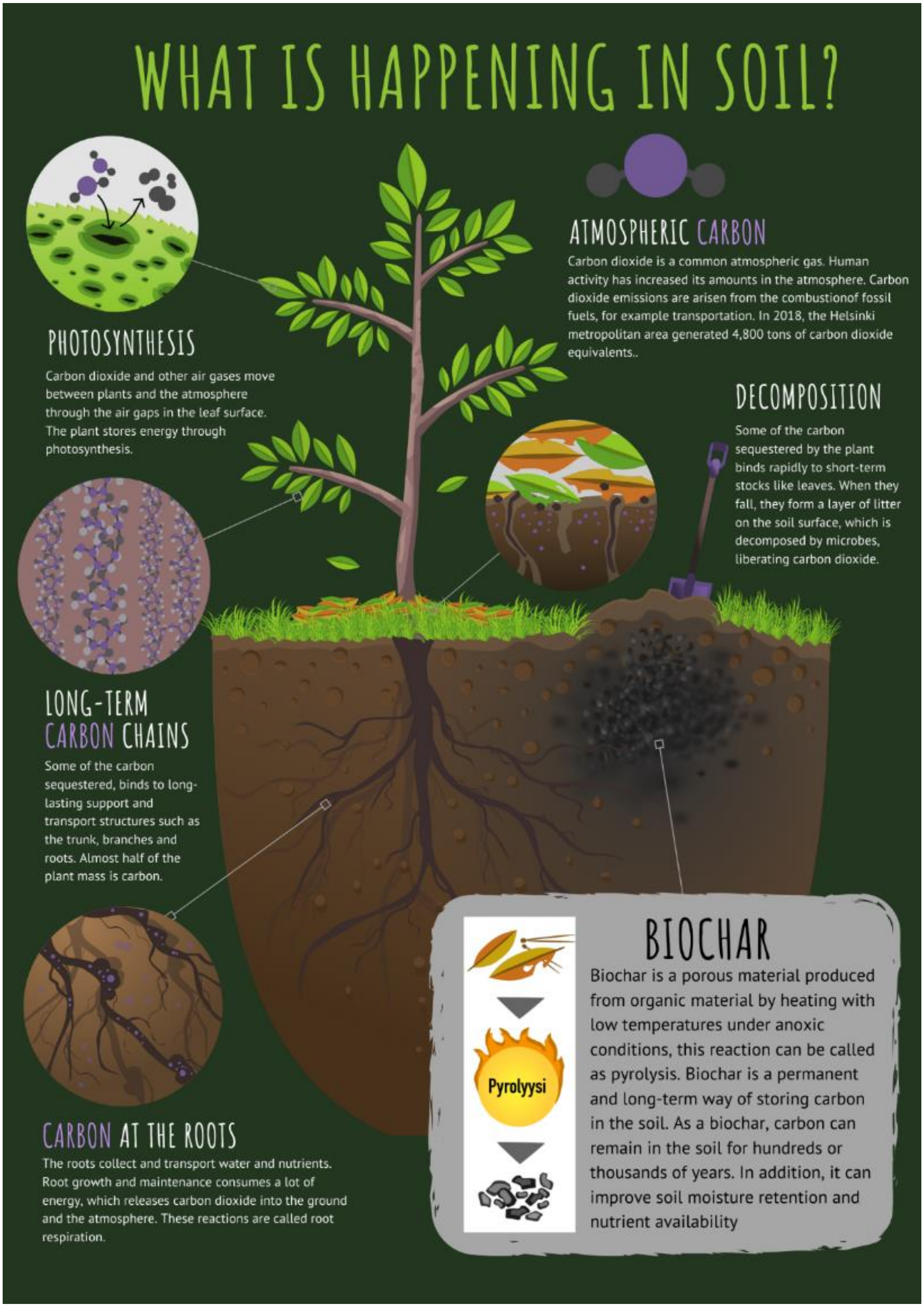
Tutustu kasvualustoihin ja hankkeeseen
Läs mer om växtunderlagen och projektet

Poster 1. Research is conducted in the park (English translation below)

Title: Research is conducted in the park
Text: The effects of biochar-based substrates on soil function and tree growth are researched in Hyväntoivonpuisto. The study covers about 80 trees, that grow on control plots and different biochar planting soils produced by Finnish manufacturers.

The project supports the goal of Carbon Neutral Helsinki 2035. The goal is to improve the well-being of trees and soil and thereby accelerate carbon sequestration. There are a lot of good experiences with biochar, for example in Stockholm it has been used since 2009.

Researchers visit the park a few times a year to assess tree growth and soil condition. The effects of different treatments are monitored, for example, by measuring soil moisture, carbon and nutrient levels.
Observe and give feedback on a tree well-being and growth with hashtag #hiilipuisto



WHAT IS HAPPENING IN SOIL?

ATMOSPHERIC CARBON

Carbon dioxide is a common atmospheric gas. Human activity has increased its amounts in the atmosphere. Carbon dioxide emissions are arisen from the combustionof fossil fuels, for example transportation. In 2018, the Helsinki metropolitan area generated 4,800 tons of carbon dioxide equivalents..

PHOTOSYNTHESIS

Carbon dioxide and other air gases move between plants and the atmosphere through the air gaps in the leaf surface. The plant stores energy through photosynthesis.

DECOMPOSITION

Some of the carbon sequestered by the plant binds rapidly to short-term stocks like leaves. When they fall, they form a layer of litter on the soil surface, which is decomposed by microbes, liberating carbon dioxide.

LONG-TERM CARBON CHAINS

Some of the carbon sequestered, binds to long-lasting support and transport structures such as the trunk, branches and roots. Almost half of the plant mass is carbon.

CARBON AT THE ROOTS

The roots collect and transport water and nutrients. Root growth and maintenance consumes a lot of energy, which releases carbon dioxide into the ground and the atmosphere. These reactions are called root respiration.

BIOCHAR

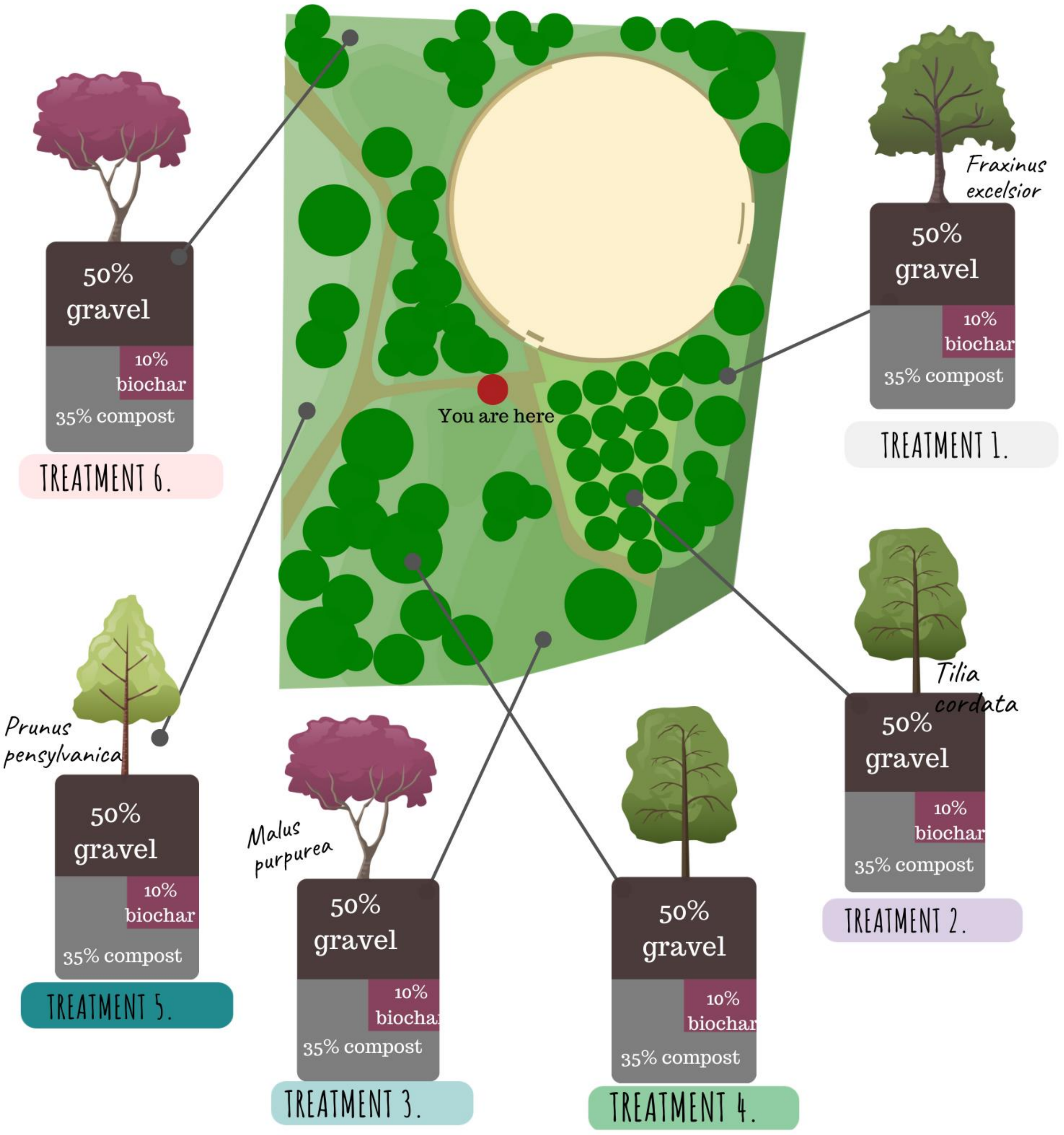
Biochar is a porous material produced from organic material by heating with low temperatures under anoxic conditions, this reaction can be called as pyrolysis. Biochar is a permanent and long-term way of storing carbon in the soil. As a biochar, carbon can remain in the soil for hundreds or thousands of years. In addition, it can improve soil moisture retention and nutrient availability

Poster 2. What is happening in soil? Illustrations by Suvi Tikka

PLANTING SOILS OF THE PARK

Planting soil refers to the material where the plant grows. Plants have very different requirements for their soil. For example, soil aeration, water retention, nutrient availability and acidity are the distinguishing factosr that effect on plants. At Hyväntoivonpuisto, we are testing six different soils for the trees. The park is home to cherries, limes, ashes and apple trees.

Do you notice some differences in tree growth between the different treatment areas?
Tell us about your observations with the hashtag #carbonpark



50% gravel
10% biochar
35% compost
TREATMENT 6.

Fraxinus excelsior
50% gravel
10% biochar
35% compost
TREATMENT 1.

Prunus pensylvanica
50% gravel
10% biochar
35% compost
TREATMENT 5.

Malus purpurea
50% gravel
10% biochar
35% compost
TREATMENT 3.

50% gravel
10% biochar
35% compost
TREATMENT 4.

Tilia cordata
50% gravel
10% biochar
35% compost
TREATMENT 2.

Poster 3. Planting soils of the park. Illustrations by Suvi Tikka