Helsinki Biochar Project

piloting local production and use of biochars

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Helsinki Biochar Project Executive summary

The City of Helsinki pursues carbon neutrality by 2030 and aims to enhance carbon sinks within its geographic boundaries. Recognizing the challenges of carbon sequestration in dense urban areas, the city has recognized biochar use as one solution. As collaboration between the City of Helsinki, Helsinki Region Environmental Services (HSY), Aalto University, and The Technical Research Centre of Finland (VTT), this project studied the production and use biochar from urban biomass materials, and the capacity to create carbon sinks and climate-resilient vegetation areas through biochar use.

The project involved two lines of work. The first centered on biochar manufacturing and use experiments by the city. Objectives included mapping biomass feedstocks, manufacturing biochar, creating pilot sites for local learning and expanding expert networks. The second focused on citizen engagement, making carbon sequestration visible, involving citizens in biochar initiatives, and promoting awareness of recycling organic materials.

HSY, with prior experience in biochar projects, utilized their existing pyrolysis pilot plant to test feedstocks beyond sewage sludge. Green reed, soft green waste, wood chips and crushed twigs were pyrolyzed, resulting in 75 m^3 of biochars. The woodchip and reed biochars met the legislative quality standards, but biochars from soft green waste and twigs were excluded due to high metal contents. The project concludes that woodchip char was of the highest quality, with a high carbon content of 82%, but further waste materials should be explored to develop suitable production methods and investigate co-benefits between the hygienic waste management and carbon storage which pyrolysis can provide.

The project sought to create professional knowledge through designing and constructing biochar applications and organizing biochar-related events. The ten new pilot sites significantly expand the city's practical experience from three pre-existing sites. The focus was on learning about biochar handling, logistics and the biological and physiological effects of diverse biochar adaptations in green infrastructures. Pilot design sites included trees both in structural and conventional soils, tram track pavements, a sports field, new and old lawns, and an urban meadow. Throughout the projects, challenges and lessons highlighted the need for information and thorough planning to properly consider biochar specifications and pretreatment methods, especially regarding biochar dose, particle size, moisture content, fertilizer needs, suitable equipment for logistics, and determination of maintenance procedures. The findings contribute insights for future urban planning projects involving biochar applications, but knowledge gaps remain to state the best practices for specific infrastructure designs. The impacts on soil and plant growth will be monitored in the following growing seasons.

In citizen engagement, biochar was distributed in four locations including a housing association, allotments, and rooftop gardens. The project sparked interest in soil and ameliorating plant growth conditions, especially through facilitating daily maintenance through water retention. Several paths can be taken to further engage citizens into grassroot climate action using biochar.

The evaluation of carbon sequestration potential remains pending. The project has contributed to practical knowledge relating to the production and application of biochars. Most importantly, woody biomass appears as a priority feedstock, as potential applications are manyfold and increasing.

To create further support for biochar use, we recommend the integration of and quantitative targets for biochar in the city's landscape design and further to its developing carbon accounting systems.

This will promote a wide range of applications including high-quality biochar for dedicated green areas and lower quality biochars for more plain carbon storage. Furthermore, the standardization of biochar-based designs is recommended, drawing insights from ongoing pilot projects and external sources to guide and promote the formulation of sustainable urban plans. The legislative aspect of biochar manufacturing is to develop strategies to avoid categorizing biochar as a waste.

Specific core recommendations are listed below

Pyrolysis of Materials:

- Redirect wood cut from urban forests into biochar manufacturing instead of burning for energy.
- Consider alternative uses, such as biogas production for fast-degrading biomasses or develop efficient logistics and pretreatment before pyrolysis to avoid composting and carbon loss.
- Test further potential materials as biochar feedstocks at HSY to especially promote circularity of waste materials that are of little interest to commercial biochar producers. Identify co-benefits for the climate and waste sanitation that derive from treating wastes with pyrolysis.

Utilization of Biochar:

- Integrate quantitative targets for biochar use in the city's landscape design.
- Expand practical experience by setting up more pilot sites and include testing the use of HSY sludge char.
- Establish best practices for biochar-based designs, practical use and maintenance procedures drawing insights from external sources and via monitoring the effects of established pilot structures.
- Re-estimate carbon sequestration potential for cities by biochar, co-benefits and financial aspects. Consider also potential use of lower-quality biochars and uses in solutions beyond growing media.
- Incorporate biochar as a means of carbon sequestration into the city's carbon stock accounting model which is currently in development.
- Involve citizens in biochar initiatives and support the concrete use of biochar in urban farming by providing expert guidance and low-cost or free materials.

Helsinki was successful in bidding to be one of seven cities that have been part of a two-year global biochar replication project, funded and supported by Bloomberg Philanthropies. Cities have been supported through implementation and technical support, funding, and access to a peer network and global best practice examples. The seven cities have all been developing city-wide biochar projects and engaging residents in the fight against climate change.

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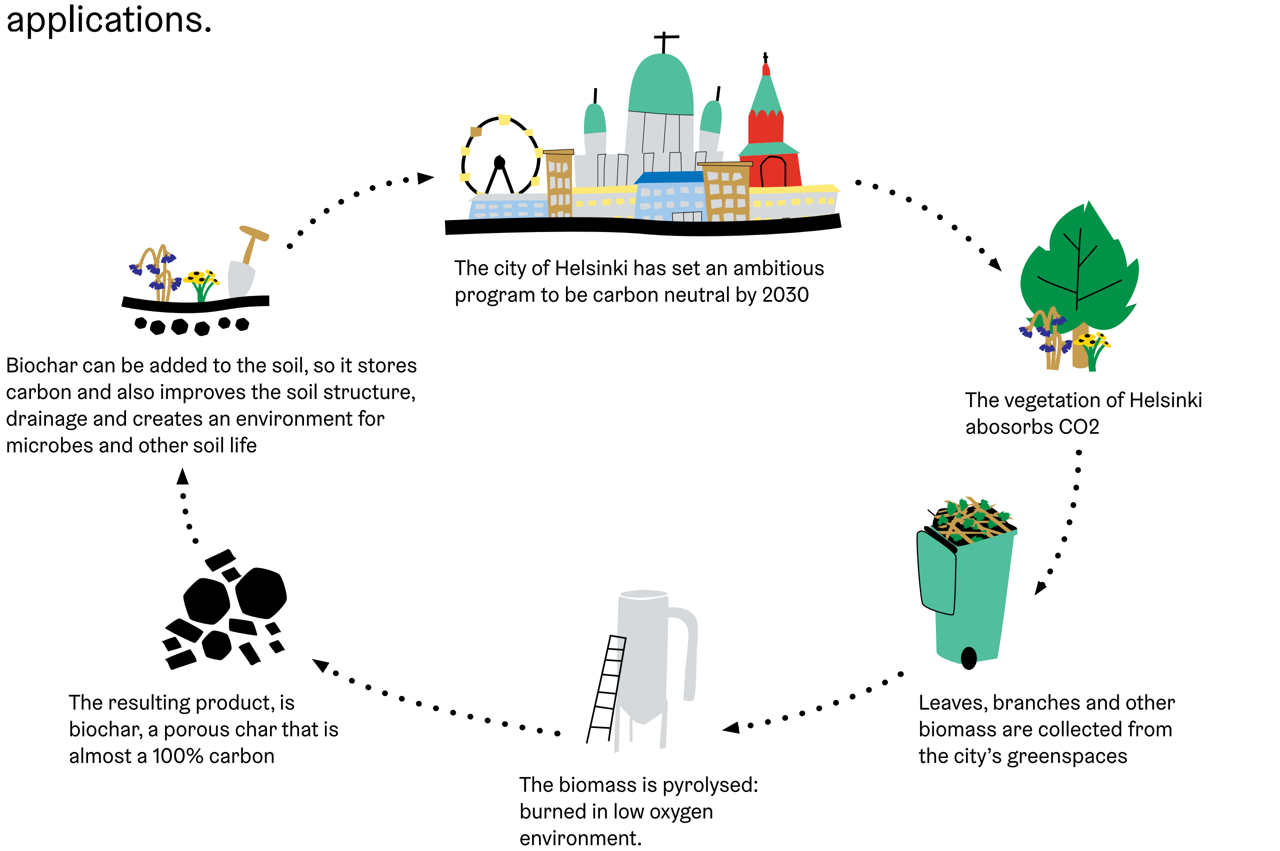
1 Project background and description

To achieve the goal of carbon neutrality by 2030, Helsinki city has set a target in its climate programme to strengthen its carbon sinks within its geographical boundaries. The solution involves seeking a combination of multiple carbon sequestration methods, but achieving the goal through afforestation, green roofs, street tree planting, and similar measures in a densifying urban structure is very challenging. At the start of the project, biochar had been identified as a potential partial solution to this challenge, prompting an exploration of its practical applications.

Concurrently, Helsinki Region Environmental Services (HSY) expressed interest in experimenting with pyrolyzing materials as an alternative to sewage sludge which was the subject of a previous project. The synergistic benefits of the city and HSY's goals facilitated the formation of a collaborative project where biochar would be produced from city materials and used in green structures to strengthen carbon sinks and design vegetation areas more resilient to climate change.

In the background of the project were previous collaborative initiatives by the city, through which cooperation related to biochar had been established among various organizations. The most notable of these were the Carbon Neutral Cities Alliance (CNCA), Carbon Lane, and the subsequently derived practical research pilot, Carbon Park.

Figure 1 Concept diagram of the Helsinki Biochar Project



2 Objectives

The project could be divided into two sections with overlapping aims, actions and realization time. The first concentrated on biochar manufacturing, setting up pilot experiments and strengthening biochar awareness and networking among professional actors. The second part focused on engaging the civil community with biochar use and grassroot climate action.

The main objectives for the first part were described as to:

- Map out the potential biomass feedstocks based on waste materials produced in the city that are suitable for pyrolysis in the HSY facility.
- Manufacture biochar from selected materials and conduct required chemical and physical analyses.
- Seek out potential sites either in planning or in realization phase and create concrete piloting experimental sites with biochar incorporated. Maximize the learning from these projects to promote the know-how of biochar use.
- Expand the biochar expert networks
- Generate an estimate about the concrete potential to increase carbon storage and sinks by using biochar in growing media within the city.

Specific objectives for community engagement were:

- to make carbon sequestration and storing visible and to engage biochar as one means for doing that.
- to demonstrate citizens that carbon sequestration through biochar is concrete action ready to be used on a grassroot level.
- to raise awareness about the need to close the loop of recycling organic materials back into the soil and to link biochar to this cycle

Project funding and organization

The local core team consisted of four main actors. The project was led by The Climate Unit of Helsinki Urban Environment Division and The Department of Design at Aalto- University was responsible for coordination of concrete actions. HSY (Helsinki Region Environmental Services) and VTT (Technical Research Centre of Finland) acted as partners. The project was financially supported by Bloomberg Philanthropies between July 2022 and July 2024.

3 Biochar manufacturing process

The participation of the Helsinki region environmental services HSY into the project enabled the experimentation of pyrolysis with four biomass materials which were derived either from the city's green management sector or from HSY waste sorting stations called "Sortti". Various materials presented challenges in production and char quality, yet half of the produced chars were utilized in creating pilot designs for green infrastructure in the city.

The principles of the HSY pyrolysis plant

HSY has experience with pyrolysis projects from two overlapping R&D projects carried out in 2014–2017: a research project studying biochar use in biowaste management that found wood-based biochars to be promising, but quite expensive. After that, as HSY continued to study new ways of utilizing sewage sludge with a goal of finding a processing method that would cover the company's environmental ambitions, pyrolysis proved the most suitable in the case of Ämmässuo eco-industrial centre. These projects gave HSY the confidence to continue into the industrial pilot-scale. The pilot period ends in 2024. HSY's goals for piloting were to secure and optimize operation across the whole process and to gather user experience and to overall learn about waste streams and products. Hence, HSY was interested in trying out the pilot plant for other biomasses. HSY pyrolysis pilot plant capacity is estimated at 3 000 tons sewage sludge and, 600 tons woody material per year.

Before materials are placed into the reception bunker, they must undergo initial crushing. Subsequently, they are transported to a thermal dryer, where a conveyor belt facilitates the movement of the material through the drying furnace. Drying is achieved by introducing heated air, utilizing energy derived from combusting the gas generated in the pyrolysis process. The moist exhaust air is cooled before being led to the acid scrubber and the biofilter to treat odors.

A conveyor transfers the dried material to the pyrolysis unit from the buffer hopper. The feeding to the pyrolysis reactor occurs through two gate valve joints. The pyrolysis unit is a rotary kiln with double mantel (rotating drum-based model) in terms of structure. The temperature range of the pyrolysis can be adjusted, but in this experiment approximately 580-610 °C was used, and the retention time varied for different feedstocks (Appendix 1). The gases formed in pyrolysis are led avoiding condensation directly to combustion. The energy from the combustion is utilized in the heating of the pyrolysis unit by leading the flue gases into the jacket of the pyrolysis unit.

The ready product is cooled on a conveyor with indirect water cooling. The cooled char is moistened on the next conveyor with water. The finished biochar product is transferred to an outdoor block-structure storage silo. Most of the char was put into big bags and stored until transporting to sites.

Selection of feedstocks

To serve the interest of HSY and Helsinki to test the pyrolysis pilot plant on different feedstock materials other than sewage sludge, several sources of carbonaceous waste materials were mapped and found to be suitable for testing. Also, some materials were considered but rejected due to various reasons. The main criteria for approval were a low sand content to prevent damage for certain moving parts of the plant, and possibilities of storage. Also, a minimum batch availability of 20 000 kg was set due to the sizing of the plant.

Figure 2 Feedstocks that were succesfully pyrolyzed into biochars at the HSY plant, their forms when entering the process and resulting biochars and amounts.

Pyrolyzed feedstocks and general processes

Four materials were pyrolyzed during the period between autumn 2022 and early spring 2023. In this period, a total of 75 m^3 of biochars were produced while more experiments were still in planning (Table 1). The pilot plant was designed for sewage sludge treatment, and handling various other materials posed some challenges. Sludge char is wet and heavy, and very different from the materials used in this experiment. That is why efficiency would greatly benefit from standardizing the input and optimizing the equipment for each specific material.

HSY's pilot plant is primarily intended for the pyrolysis of wastewater sludge, a material with low energy value. For this reason, wood material is also mixed into the sludge to increase the energy balance. Energy balances were different in the other materials pyrolysed. Wood chips, for instance, displayed an excess of thermal energy, while lake reed and meadow waste had notably lower energy content. Due to the plant's design for a specific heat load, wood, being energy-dense in comparison to wastewater sludge, posed challenges in maintaining optimal operating conditions. Consequently, the heat recovery system of the equipment imposed limitations on the amount of material that could be fed into the process, particularly concerning wood material, necessitating a reduced feeding rate to prevent overheating.

Lighter materials resulted in a finer –textured biochars with smaller particle sizes, making it more prone to dusting. Lighter materials also resulted in lower biochar yields (Table 1), most likely in part because of the lower carbon content of the original feedstocks (Appendix 2). Another hypothesis related to lighter materials is that some of the material may end up in the combustion chamber, (where pyrolysis gas is burned to produce process heat) carried there by the airflow in the pyrolysis plant and subsequently incinerated. It's challenging to determine the exact quantities involved, but this scenario is plausible.

Reed

Reed (Phragmites australis) was collected by a contractor from the sea bay areas in Porolahti and Pikku-Huopalahti. The collection was done in early September when the shoots were still green. To our knowledge, green reed had not been pyrolyzed before while tests had been made with dry, winter-harvested shoots. The major difference between green and dry shoots is that the green shoots still contain more water and nutrients, especially nitrogen, as the plant has not yet matured for winter. The expectation was that the green shoots would also be harder to shred due to their tougher outer layer (ELY-centre 2022). However, the shredding was easily done with a hammer shredder at HSY, but the following storage time allowed for a period of degradation of the material.

Attempts were made to dry the material by laying it flat indoors to hinder the decomposition, but it was likely that some carbon loss occurred.

The reed material was soft and light, which caused several blockages and a need for reducing the speed in the machinery, extending the handling time into 16 days with a total operation time of 27 hours. Out of the 9 metric tonnes metric tonnes of fresh mass that arrived and that was fed into the facility's drying process, a roughly estimated 2 tonnes, or 4 m^3 of biochar was obtained. The weights are expressed for fresh products, not devoid of water.

Soft green waste from parks

Green waste in this experiment consisted of two main sources. First the city park management division at Stara collected conventional garden waste, including weeding waste and related soft green wastes that normally are composted. Secondly, waste from meadows was collected at mowing time. The material mostly included some woody material from willows, but mostly herbaceous shoots and seeds. Normally this waste is disposed of by burning in the general waste facility due to seeds from alien plant species. The material was shredded after arrival, but not directly dried.

Material	Raw amount of feedstock (kg)	Biochar produced (kg)	Biochar produced (m3)
Reed	9000	2000	4
Soft green waste	16550	3800	6
Wood chips	100200	20150	57
Twigs	12000	3000	8

Table 1 Data of feedstock amounts pyrolyzed into biochar and amounts of produced biochars at the HSY pilot plant. The product weights are expressed as fresh weight.

We suspect that similar to the reed, but likely to a higher extent, this feedstock was likely to experience carbon loss before pyrolysis due to decomposition and a long waiting time. The pyrolysis process was initiated in the beginning of December and ended on the 9th of February. The 16,6 tonnes kg of raw material which was inserted into the drying process yielded 3,8 metric tonnes or roughly 6 m^3 of biochar. Due to the compactness of the material, it did not advance on conveyors without mechanical human assistance. Additionally, foreign objects in the material, such as ropes, gardening tools, and stones, caused interruptions in the process. The waste had a relatively low calorific value, which could have been compensated for by increasing the conveyor speed if the material had advanced fluently in the process. The material would require another crushing round, followed by screening, for the process to be more successful in the future.

Wood from urban forests

The City of Helsinki conducts forest harvesting for various reasons. Typically, the felled trees are chipped and sold for energy combustion. The primary motivation for using wood chips was to more reliably produce a larger, 100 m^3 quantity of biochar with a quality sufficient for use in green areas. Within the scope of the project, woodchips from trees felled in the North Helsinki areas for the control of bark beetles, was subjected to pyrolysis. The wood was chipped slightly finer than usual to avoid the need for separate screening of particles larger than 5 cm at the plant. Most of the wood consisted of spruce, with various deciduous trees present in smaller quantities.

The approximate amount of 229 m^3 of woodchips, corresponding to 100 metric tonnes yielded 20,2 tonnes or 57 m^3 of biochar.

Twigs from waste stations

Twig and branch material obtained from the public HSY Sortti-waste collection station was tested for pyrolysis to supplement the aim of manufacturing 100 m^3 of biochar. It was obtained via HSY´s own sorting stations, encompassing brushwood, branches, and coniferous litter. Twigs are brought to the station by households and businesses in the vicinity. While pinpointing the exact origin may be challenging, the majority of these twigs are from private individuals' gardens. Therefore, whereas the woodchips originated mainly from larger spruce tree trunks, twigs consisted more of narrow tree- and shrub branches. Relatively, the twig material included more of bark and conifer needles in comparison to the woodchips. Also, the handling of the two materials differed, as the twigs were crushed and not chipped due to the availability of such machinery.

The manufacture of twig biochar was discontinued after an initial chemical analysis was conducted for the first batch. In comparison to the woodchip material, the twig raw material contained substantial amounts of many harmful metals which was also then reflected into the end product, rendering the biochar unfit to be used in green infrastructures. This may have been due high amount of bark and eg. pine needles in the material that have been shown to accumulate metals from polluted atmospheres (Saarela et al. 2005). The chemical analyses of feedstocks and the respective biochars generated are presented in Appendix 2.

Biochar physicochemical analyses and quality

The biochars were analyzed with methods complying with the European biochar certification (EBC 2023). For economic reasons, a single sample was analyzed from each feedstock and biochar, with the exception of the woodchip biochar of which two samples were analysed. Water-soluble fractions of main nutrients were not analyzed. The threshold values that were applied for screening harmful substance concentrations were in accordance with the regulations of Finland's fertilizer legislation in force in summer 2023. Particle size distribution curves displayed on the next page of this report were internally analysed at HSY using a wire screen series.

Overall, it was considered that the woodchip char was of the best quality as anticipated. In comparison to the total carbon content of the other biochars (28 - 44%), it had a much higher value (82%). Correspondingly, the ash content in other materials was above 53 % and less than 7 % in woodchip chars. The most widely used parameter used in the industry to reflect the permanence of biochars in soils is the ratio of hydrogen (H) to organic carbon (Corg). As the value was below 0,4 in all produced biochars (Appendix 1), it could be considered that a minimum of 70 % of the carbon is likely to remain stabile in soils for the next 100 years (Budai et al. 2013).

Based on Finnish regulations, biochars made from lake reed and wood chips were permissible for use in field trials. However, chars produced from soft green waste and chipped twigs and branches had to be excluded from use due to high content of harmful metals. Detailed information on the analysis results of the biochars is available in Appendix 1. Interestingly, the soft green waste biochar had a very strong scent of ammonia and it inflicted fast

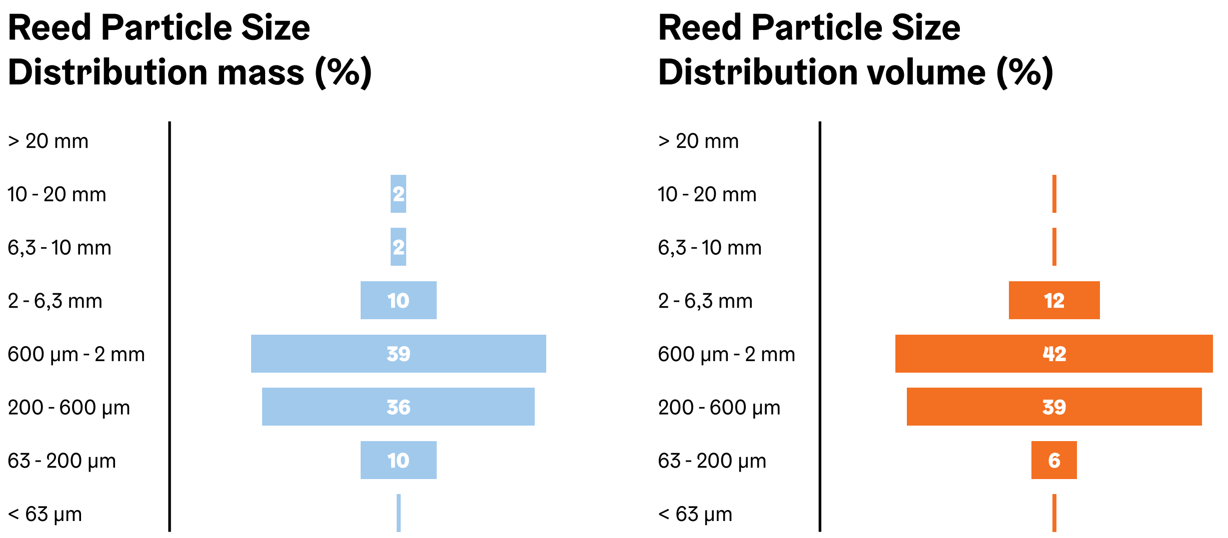


Figure 3 Results of particle size distribution based on weight and volume on reed biochar.

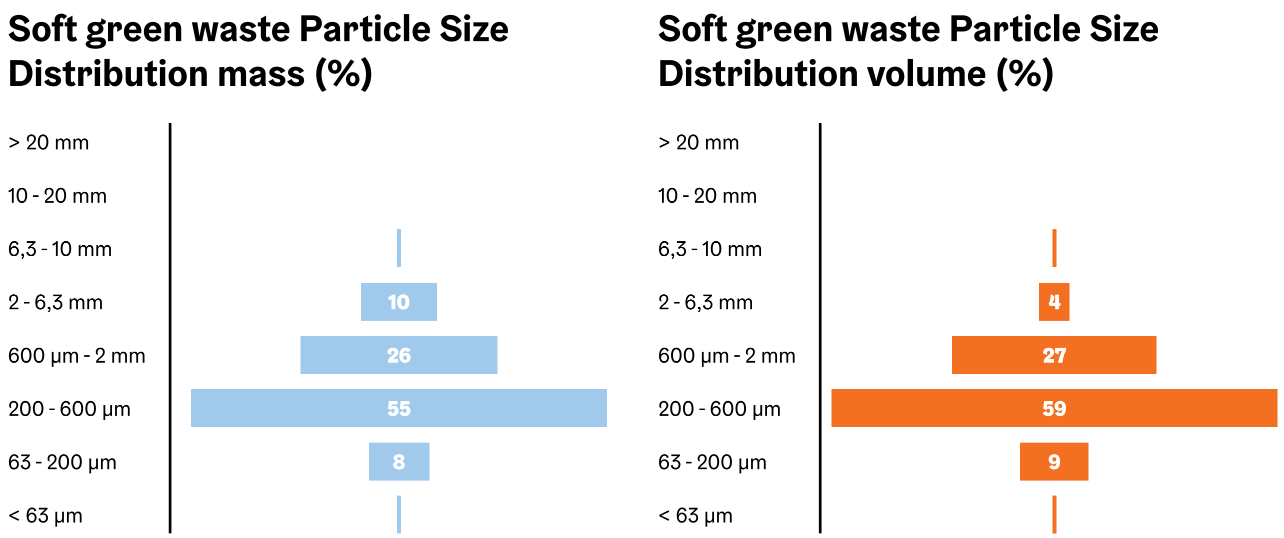


Figure 4 Results of particle size distribution based on weight and volume on soft green waste biochar

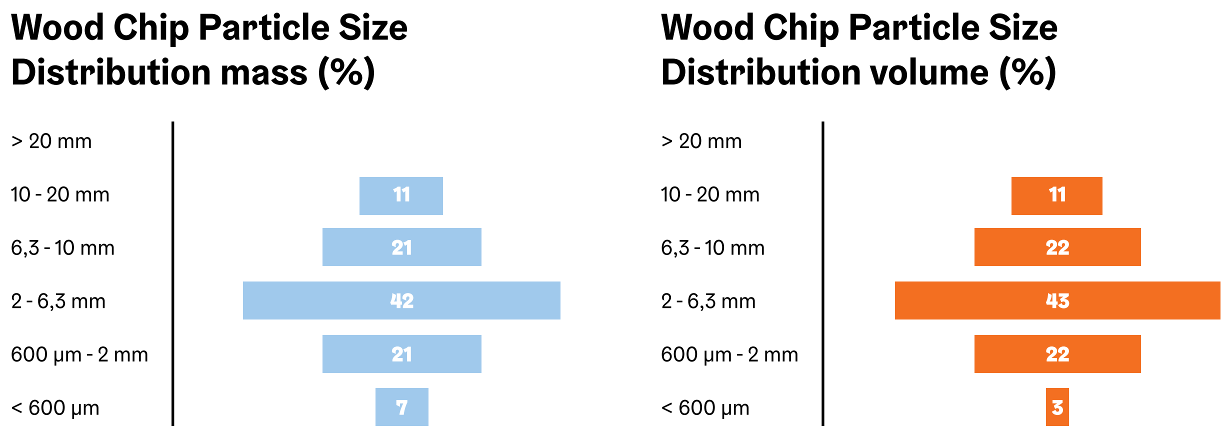


Figure 5 Results of particle size distribution based on weight and volume on woodchips biochar

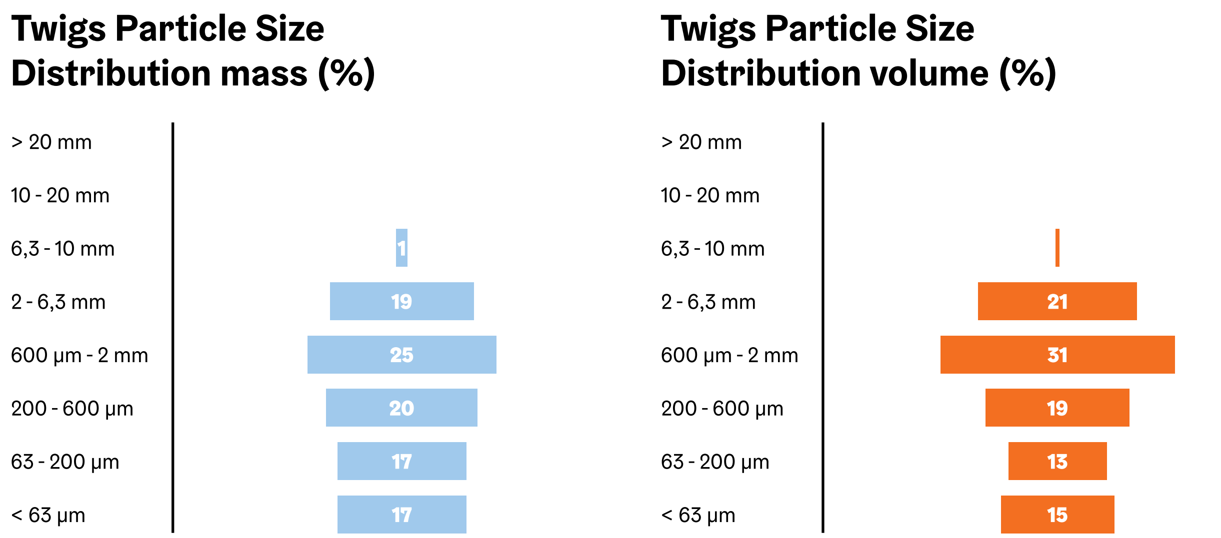


Figure 6 Results of particle size distribution based on weight and volume on twigs biochar

corrosion and other chemical reactions in the sample bucket made of tinplate steel (Figure 7). The reason for this remained unclear. Some corrosion was also caused by the reed biochar, but to a much lesser extent.

Figure 7 The metallic sample container reacted with the biochar made from softe green waste, showing corrosion (top right) and peculiar protruding crystalization on the metal bucket surface (top left)

Rejected feedstocks

The rejected materials are listed below with the main reason for rejection in brackets

- Street sweeping waste (high sand content), waste originating from mechanical cleaning of city streets in the autumn.
- Dog droppings from Molok- deep containers in dog parks (logistics, storaging and gravel)
- Outhouse waste from dry toilets (insufficient availability)
- Formwork wood material used in concrete casting (logistics, lack of time for coordination)
- Winter-cut reed shoots (insufficient easy availability)
- Expired cattle feed haystacks (late involvement into the project, low availability)

The most potential was seen in handling the outhouse waste, as it would offer a hygienic process, which to date has been very hard to organize in practice. The shortage of feedstock could be overcome as Helsinki is planning to increase the amounts of dry toilets, which are currently called "Helsinki-Huussi".
Also, given that the street sweeping waste (figure 8) could be sieved for excess gravel, it could become a potential future feedstock for pyrolysis experiments, benefitting greatly e.g. from the removal of harmful substances and microplastics that originate from the city driving streets.

Lessons learned from biochar production

One critical aspect in biochar (BC) production involves evaluating the suitability of specific feedstocks for both machinery and the resulting biochar. Key considerations include:

· Gathering, storing, and pretreating feedstocks effective methods for the collection, storage, adequate screening and pretreatment of feedstocks to avoid premature degradation of materials, machine clogging and to overall optimize the pyrolysis process for various materials.

Identifying and addressing unresolved issues, such as the presence of heavy metals in Sortti twig char and polycyclic aromatic hydrocarbons (PAHs) in other biochars. Investigating for potential methods for avoiding threshold-exceeding concentrations.

Figure 8 Street sweeping sample variations from lower (bottom center) and higher (bottom right) sand and gravel content. The material piles (bottom left) also contained considerable amounts of garbage (eg. coffee cups, candy wrappers) which were not included in the samples

· Exploring alternative materials and feedstock mixes: explore pretreatment options for softer materials and pyrolysis in combination with wood chips, to reduce calorific value of woodchips and to diversify options for pyrolysis feedstocks.

Also navigating the legislative landscape is vital for successful biochar production and utilization. Key aspects include examining the potential waste status of manufactured biochar and strategies to avoid it and understanding the restrictions for the end user regarding the use and application of biochar with waste status.

To advance both scientific understanding and municipal initiatives, the continued utilization of the HSY pilot plant for testing various waste materials through pyrolysis is recommended. Despite its optimization for sewage sludge, the facility provided, and can continue to offer invaluable experience beyond laboratory scales in understanding how different materials behave within a continuous pyrolysis system. For HSY as a municipal utility, engaging in the pyrolysis of waste streams that might not attract other biochar-producing companies can contribute to the circular economy and safe waste management.

To further explore the biochar production field, upcoming work should investigate the possibilities of local biochar production. Potential options include integrating biochar production into carbon-neutral district heating or decentralized biochar production, eg. in places akin to the city's recycling fields for biomass. An example of the district heating model is currently demonstrated by Keravan Energia, where the biochar producer Carboculture operates a pilot plant. Connecting the use of biochar to composting and the production of local recycled growing media could enhance composting efficiency and add value to growing media products.

4 Biochar piloting and use in green infrastructure

The project aimed for increasing biochar use experiences throughout the professional sector and among Helsinki citizens. The following chapters explain first the processes of setting up pilot experiments in the city parks. The second part will walk through the actions that were done to engage citizens in various locations. A total of 106 m^3 of biochars was used, including also commercial biochars in addition to HSY products to complete the project's needs.

The pilot sites were selected and planned in cooperation with the project managers in Helsinki Urban Environment Division during winter and spring 2022-23. Also, several consultant agencies responsible for the landscape planning were involved. Mainly the sites needed to be in construction in the year 2023 due to the duration of the biochar project. Availability of construction projects limited the selection, and the biochar component was mostly incorporated into semi-finished plans. This meant that only small alterations were possible to be made into the park designs, and mostly the aim to create scientifically sound, comparative and replicated experimental set-ups needed to be rejected. The focus was in local learning about the principles of planning biochar designs, getting familiar with practical handling methods, resolving potential logistical patterns and also setting up the monitoring of the sites to report the growth responses especially in the long term.

As a result, biochar was used in ten distinct park projects and one street tree design was planned for future realization. In addition, a small greenhouse pot trial was completed with bedding plants to screen differences between biochars produced by HSY. This was reported separately in a Helsinki internal document. The following chapters report the main aims, setups, and realization of each site.

Loations of the experimental sites.

Experiments took place in different locations and scales in Helsinki. The experimental sites were chosen by reaching out to city project managers, community (gardening) groups and the possibility to realise within the timeframe of the project.

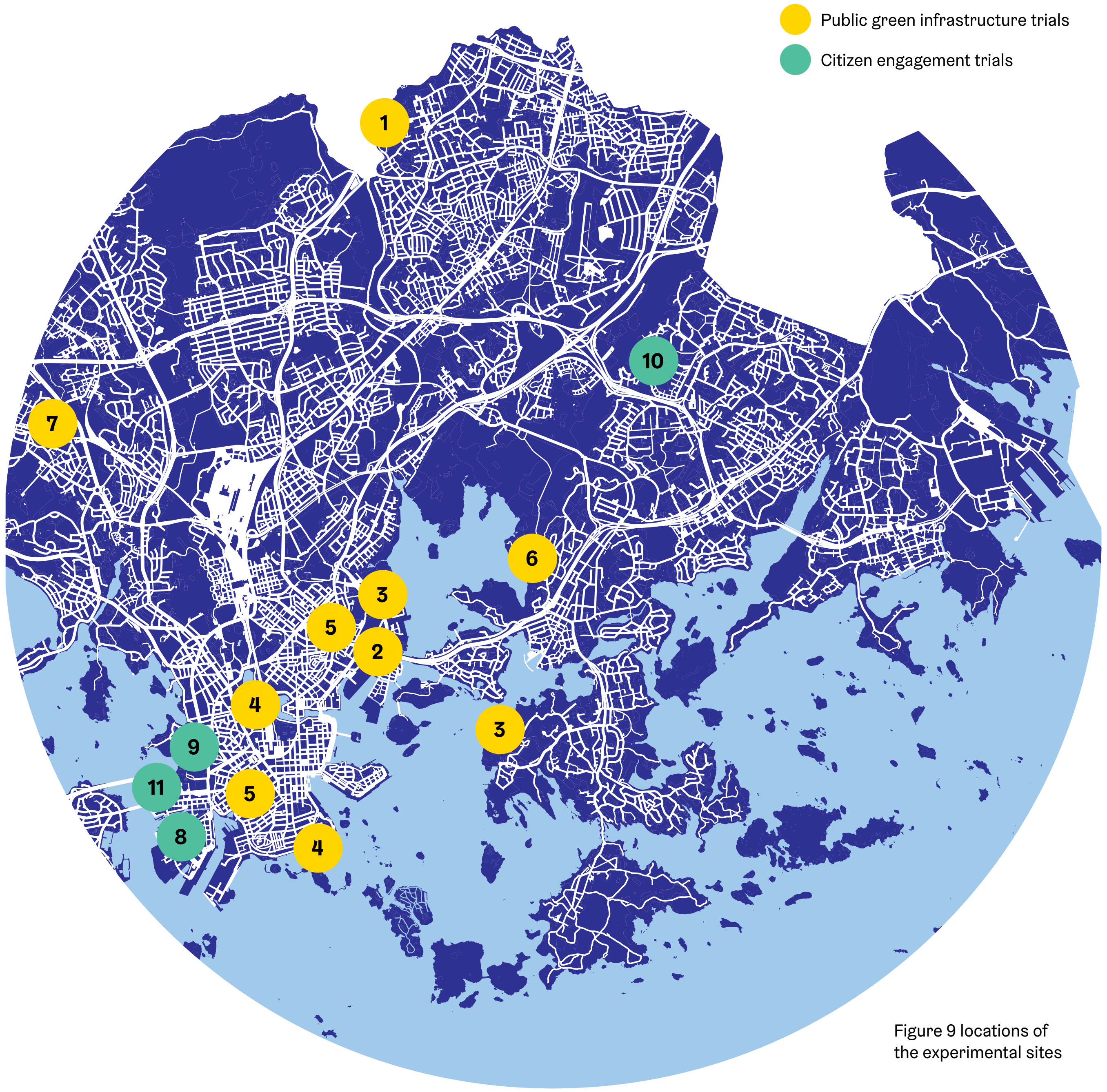


Figure 9 locations of the experimental sites

Football field (22m^3)

Dynamic perennial planting (10m^3)

Tram rail roads with green paving stones (9.25m^3)

Existing park lawns (22.5m^3)

Structural soil renovations (17m^3)

Newly planted trees (10m^3)

Meadow on recycled soil (7m^3)

Jätkäsaari community garden (0.25m^3)

Lapinlahden Lähde community garden (1.25m^3)

Rinnekodit housing association (1m^3)

Rooftop garden (0.25m^3)

A new football field in Siltamäki

Siltamäki football fields were entirely renovated in 2023. Five new fields were constructed, and for one of them, approximately 4-5 vol-% of wood chip biochar produced by HSY was mixed into the top 10-15 cm layer of the growing medium. The neighboring pitch with similar care but without biochar in the soil acts as a comparison for monitoring the effects of biochar. The aims were to see if biochar could increase plant wellbeing through increased water and nutrient retention, water infiltration, microbial activity, and potentially reduce maintenance costs. The substructure of the fields consists of foam glass lightweight aggregate separated from a 30 cm thick sandy growing medium layer by geotextile. The field has dimensions of approximately 65 x 45 m (2925 m^2) (Figure 2). Moisture sensors have been installed on the field soils to digitally monitor the moisture conditions in the growing medium. The aim is to optimize water usage in the maintenance of the fields.

The biochar was delivered on-site in a covered container in July 2023. It was spread on the field using a top-dressing sanding machine, forming an even layer (picture on page 20), and then incorporated into the topsoil using disc harrows. The amount of biochar delivered was approximately 7.2 tons, equivalent to about 22 m^3 in volume. When mixed into the top 15 cm layer, this amount corresponds to approximately 5 % of the biochar content in the growing medium. The growing medium mixture consisted of 90 % sand and 10 % peat. In the biochar field, the biochar was added to this growing medium without replacing any component of the growing medium.

Sowing of grass seeds was done in mid-September with a mixture of 10% ryegrass (Lolium sp.) and 90 % 5-6 kg/ha Kentucky bluegrass (Poa pratensis). In the first year, ryegrass germinated well, resulting in a reported 100% green coverage on the fields, but the establishment of the Kentucky bluegrass was incomplete. Therefore, the field will be resown in spring 2024. Also, because the texture of the sand growing medium was coarser than planned, a series of top-dressings of fine sand will be done for all pitches in the year 2024, which is bound to dilute the biochar content in the soil.

The monitoring of potential biochar effects will be organized for a minimum of two years in cooperation with the ground maintenance personnel. The focus will be on conventional growth and soil condition parameters which are also followed in the conventional FIFA procedures.

A dynamic perennial planting in Kalasatama

The background for the experiment was to overall test various biochars in a novel vegetation area with a central location by the Urban Environment Division office building. The site features a relatively new kind of design, which includes planning dynamically changing plant communities inspired by naturalistic design principles. The original plan was to pilot the nutrient charging of biochar in HSY's compost and use two different biochars with and without charging. However, as the HSY twig biochar was excluded due to its heavy metal concentrations, the experimental setup was rapidly modified.

The completed pilot involved HSY woodchip biochar at two different concentrations (7 % and 20 % by volume). Additionally, the 7 % biochar concentration is tested both pre-charged and uncharged. The control group consists of a growing medium without biochar but with an equivalent amount (7%) of compost in relation to other growing medium materials. There are two types of plant mixtures in the experimental areas, but both have a similar base growing medium (Table 2, Figure 10). The vegetation areas were selected from the overall park plan based on that the plant mixtures designed can best tolerate a nutrient-rich growing medium. The species selection consists of about 30 species in each community, ranging from small trees and shrubs and large perennials into soil-covering perennials and various bulbous plants. The planting was done in September.

The pre-charging of biochar was made with HSY biowaste compost which had a total nitrogen content of around 2 %. Biochar and compost were mixed together in equal volume ratios around 4 months before being mixed into the final growing medium. To avoid excess nutrients and minimize variation between treatments, the expected nutrients deriving from the compost were considered when the growing media were made, but nevertheless, differences were visible in soil analyses conducted by the commercial soil mixing company (Table 3, analysis results). The analyses for biochar growing media were made as compost analyses according to the fertilizer law, whereas the base soil material was tested by the standard Finnish soil testing method (Vuorinen & Mäkitie 1955) using acid ammonium extraction for nutrients.

The following-up of the experiment will be coordinated and comparison in plant growth and community development between treatments will be possible between areas to gain insight on the following questions:

areas 2 and 3: how charged biochar affects vs. no biochar

areas 2 and 4: how pre-charging affects compared to no pre-activation of biochar?

areas 4 and 5: how raw biochar affects overall in comparison to no biochar

area 1: how 20% of charged biochar performs in comparison to 7% charged biochar

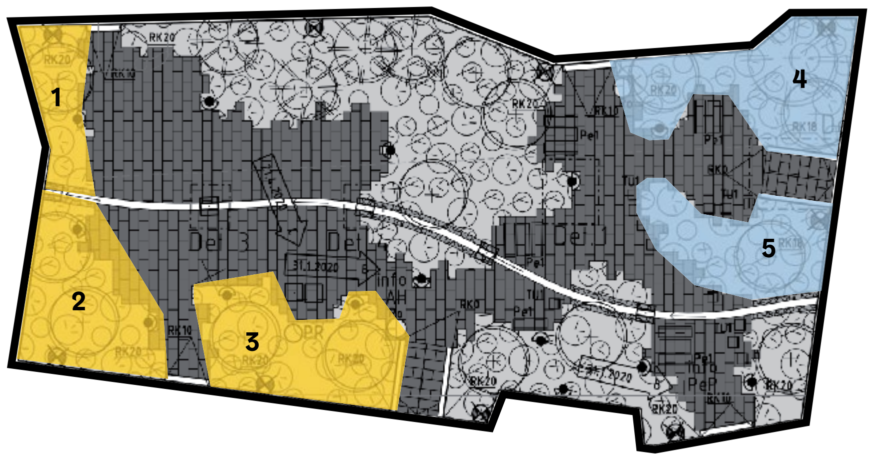


Figure 10 Lay-out of experimental areas. The two colors represent the two plant community designs planted onto the areas. The area number refers to growing media treatments given in table 2 and 3. Underlaying drawing by Sitowise.

Table 2 Growing medium treatments by plant communities and planting areas (1-5) referring to figure 10

Plant community	Area	Growing medium treatment	Area size (m^2)	Volume of growing media (m^3)	Biochar in soil	Compost in soil
"Auringon hellimät"	1	Compost pre-charged biochar 20%	24	19	20%	20%
	2	Compost pre-charged biochar 7%	49	39	7%	7%
	3	No biochar, compost 7%	57	46	0%	7%
"Perennojen paratiisi"	4	Uncharged biochar 7%, compost 7%	59	47	7%	7%
	5	No biochar, compost 7%	43	30	0%	7%

Table 3 Results of initial soil analyses conducted on treatment soils and the base growing medium at the soil mixing station.

Plant community	Area	Growing medium treatment	N (g/kg)	P (g/kg)	K (g/kg)	BD kg/m^3	pH	EC mS/cm	LOI%
"Auringon hellimät"	1	Compost pre-charged biochar 20%	0,1	100	1000	790	6,5*	0,6*	16,4
	2	Compost pre-charged biochar 7%	0,09	32	560	900	5,7*	0,5*	10
	3	No biochar, compost 7%	0,07	21	530	920	5,3*	0,5*	10,6
"Perennojen paratiisi"	4	Uncharged biochar 7%, compost 7%	0,04	30	490	920	5,6*	0,4*	8,6
	5	No biochar, compost 7%	0,07	21	530	920	5,3*	0,5*	10,6
			NO3-N (mg/L)						
		Base growing Medium	68	1,6	440	1070	4,5**	1,5**	10,6

N= soluble nitrogen and NO3-N= nitrate nitrogen, P= soluble phosphorus & K= soluble potassium (acid ammonium extraction pH 4,65), BD= bulk density, EC= electric conductivity, LOI= loss on ignition (organic matter content).

EC and pH measured in soil-water suspension in *1:5 or **1:2,5 w/v ratio

According to initial soil analyses made in the soil mixing station, the 20 % biochar and compost addition on area 1 markedly increased the content of soluble phosphorus (P), potassium (K) and content of organic matter in comparison to all other areas, but the level of soluble nitrogen was nearly the same as in 7% addition rates on pre-charged biochar. The 7% pre-charged biochar medium had slightly higher soluble nitrogen (N), phosphorus (P) and potassium (K) contents in comparison to 7% non pre-charged treatment on area 4. Nitrogen and potassium contents were also higher in area 5 with no biochar and 7% compost, in comparison to area 4 with 7% uncharged biochar and compost. Based on comparison between areas 4 and 5, biochar did not seem to add soil organic matter content as reflected by the share of material lost on ignition (LOI) (Table 3).

Two tram railroads with green paving stones

In year 2023, Helsinki was building three new tram routes. Biochar was experimented on two of them which included using specific kinds of hollow green paving stones called "riimukivi" with growing medium and plants in between (Figure 11).

In the background for these pilots was the challenging growth conditions for plants and a need to retain the permeability of the soil to allow infiltration of storm waters. The growing conditions feature a small root space and in an open area exposed to wind, heat, and especially to drought. To alleviate drought, the city has sometimes used super absorbent polymers (SAP) in soil mixtures, but concerns have been lifted about their ecological impacts through their degradation products. In these experiments, the aim was to investigate how biochar affects the success and development of vegetation, and the functionality of the permeable surface in regard to stormwater management.

Test sites were situated in Kruunuvuori and Kalasatama areas. The basic solution in Kruunuvuori was based on commercial sandy soil product, SAP (Terracottem Universal, 500g/ m^3) and a mixture of grasses as plants. Here, a comparison was set to observe how two different 10- vol% biochar growing media with either pre-charged biochar or raw biochar compare against each other and to one where biochar is replaced by SAP. Compost charging has been found to be an excellent way to pretreat biochar and eg. avoid potential nutrient deficiency caused by raw biochar addition, but logistically it involves an additional step. No pre-calculation of plant-available nitrogen in the compost was available to allow matching the nitrogen levels between mineral fertilized and pre-charged biochar treatments. The building was completed in November 2023, but the mineral fertilization (12 % N, 200kg/ha) remained to be applied in spring 2024.

In Kalasatama, where the second experiment was set up, the plant selection consisted of dicotylenous perennial flowering plants and some grasses. The base soil was a mixture of 0-18 mm screened, recycled street sanding sand and compost (0,9 % total N), which are both in excess in the city's soil recycling stations. Two biochars were used, the HSY reed biochar and conifer-based softwood biochar (Carbofex). The city soil station had not previously handled biochars, so the issues regarding the station's environmental permits had to be resolved to enable their compost charging. Afterwards, the biochars were mixed in with compost (1:1 v/v) for a minimum of 2 months (Figure 11). However, the volume of the available tractor scoop for mixing these components was not accurately known, which may have caused inaccurate mixing ratios.

The soil mix treatments featured using no biochar, biochars in 5- or 10 volume percentages, or a super absorbent polymer SAP, Terracottem Universal (Table 4). As the biochars and compost were first mixed together for charging, all biochar treatments

Treatments	Sand	Compost	0-10 mm woodchip BC	HSY reed BC	SAP
Control	90%	10%			
10% wood BC	80%	10%	10%		
10% reed BC	80%	10%		10%	
5% wood BC	90%	5%	5%		
5% reed BC	90%	5%		5%	
Super Absorbent Polymer (SAP)	90%	10%			0,6 L/m3

Table 4 Soil mix treatments in the Kalasatama tram track experimental setting

Figure 11 Stone paving in construction in the Kalasatama area. Biochar-based growing media were inserted between the stones.

Biochar activation for the tram tracks in Kalasatama was done by creating a windrow with alternating layers of biochar and compost before mixing in the materials. The pile was watered once in summer to avoid complete drying-out and to enable the transfer of nutrients into the biochar.

Figure 12 (top left, top right) The worst park lawns had highly layered growing media and a thick fiber layer. The Turf Gamechanger was able to aerate the lawn, apply biochar and fertilizer and brush the materials into perforations in one go. However, adjustments would be needed for further trials to maximize biochar delivery into the holes.

Makasiini park lawn (bottom) during the biochar application by the Turf Gamechanger with visible streaks of biochar on top of the lawn despite using brushes. An adequate large hole, a small particle size followed by brushing is essential for the delivery of biochar into the root zone.

Figure 13 application of structural soil. First the old soil was removed until bed rock (top left), after which it was quickly covered. The image on the top right shows an uneven layer of planting soil intended for perrennial planting.

The construction of the green island with structural biochar-based soil at Eerinkatu with a pre-existing linden tree (bottom left and bottom right).

Figure 14 The growth of selected newly planted park trees is monitored annually

had roughly an equal amount of compost in relation to biochar. However, as the biochar percentage varied between soil recipes, this practice delivered unequal amounts of compost, nutrients and organic matter between biochar treatments. Attempts were made to theoretically compare the water-retentive effects of biochars and the SAP. According to the manufacturer, Terracottem Universal absorbs 45 times of water in relation to its own weight and a minimum of 95% of this is available to the plant (Terracottem 2023). Similar information was not available for the biochars, as the water holding capacity (WHC) was defined for samples that were ground into < 2mm particles, and not for the actual and whole product in use. Grinding biochar is known to alter its water-retentive properties (Liu et al. 2017). Also to gain comparative data, the share of plant-available water from all water contained in the biochars should be separately analysed. However, as a reference, the results for WHC (<2mm) varied from 1,8 and 3,2 times water held in relation to the biochar's own mass in HSY reed and Carbofex wood biochars, respectively.

Existing park lawns on load-bearing soil

The background for the use of biochar in pre-existing park lawns was the goal of improving the success of park lawns built on compacted soil. The lawns shared characteristics such as an available fixed irrigation system, highly sandy, compacted, and dry growing medium covered with a varying thickness of fiber layer and a very poor-quality lawn. The fiber layer, geese, and continuous trampling posed maintenance challenges. The required intensity of care and machinery for these sports turf-like lawn solutions differed significantly from the maintenance of regular soil-based park lawns that prevail elsewhere in the cityscape, and new methods were welcomed to be tried to help eg. with moisture retention, soil aeration, and microbial activity. Advice for the project was taken from the report of the Swedish "Residues to best use" project (Fransson et al. 2020) and discussions with Swedish contractors as well as Finnish consultants for golf and turf lawns.

The biochar treatments for park lawns were divided into three parts. The first project involved the application of three different types of biochars in early May. It involved HSY reed and woodchip, and commercial wood biochar with 0-10 mm declared particle size. A sand dressing was applied as a control treatment. The work was done using the Turf Gamechanger (TGC), a novel multifunctional aeration device on two lawns in Töölönlahti Park (Figure 12). The device is able to perforate the lawn, apply dressing material and fertilizer, and brush the materials into perforations at one go. The aim was to apply 4 liters of biochar per m^2 into 15 cm depth but only 0,9-1,4 l/m^2 into 8 cm depth was somewhat succeeded as the turf's structure did not endure using thicker 25 mm spikes that would have made larger perforations. Most of the biochar did not penetrate the soil horizon despite that the particle size of HSY reed char was very fine and even the coarseness of HSY woodchip biochar was diminished for this project by running it twice through a screening bucket (Allu Finland Oy). The procedure mainly reduced the share of 10-20 mm particles from 11% to 4%. Application of compost-activated biochar was considered to increase microbial activity, but rejected as compost would have diluted the biochar content and considering the hole size, might not have been fine enough in texture. Therefore, the application was topped with an inorganic fertilizer (Symbio MycoGro Complete NPK 10-1,3-11,6) applied at 30g /m^2 rate (0,32 kg N/100m^2). Resowing of the lawn was planned to be done by a third party, but the work was not realized. No visible differences in growth were seen between any treatments by fall.

The second event was realized independently by the city's construction agency Stara in the summer. It included the application of 6 m^3 of commercial wood biochar in Kaivopuisto Park in conjunction with a quite traditional 18 mm-thick spike aeration, perforated into 15 cm depth. The perforation was followed by two sequential surface dressings: one with 0-10 mm particle-sized biochar and another with sand on top to weigh the biochar down. Further records of the success of this project are scarce.

The third project was implemented in September, also in Töölönlahti Park. It included the refurbishment of the lawn's topsoil by tilling biochar medium into the existing surface soil. The motivation was to try to recondition the lawn without changing the soil. The process was started by partly removing the fiber layer with an Uni-Scratch device (Campey). This was followed by tilling the soil into 15 cm depth, applying of 5,3l/m^2 of biochar and then tilled again. As a result, the rooting zone included about 4 % of biochar. The surface was then thinly dressed with new soil before grass seeds were sown. The monitoring of potential biochar-dependent effects to plants and soil remain extremely hard to conduct on these areas partly due to lack of controls in the summer- and fall-realized projects. Also, overall the areas which were handled in Töölönlahti area in the spring and summer, are subject to extensive park construction projects in the coming year 2024.

The core learning from the projects involved emphasizing the adequate moisture of biochar to avoid dusting during application. The best experience was with HSY woodchip char, containing <40% moisture but no batch-specific moisture information was available for the most dry, commercial biochar which showed more dusting on site. Also, the importance of selecting an adequately fine-grained product was highlighted, as during the application with aeration, most of the biochar remained on top of the soil (Figure 12). This was also promoted using too narrow, 12-18 mm diameter spikes which did not accommodate the larger biochar particles into the soil, and which also allowed for a rapid reclosure of the perforation holes. The biochars in these experiments were screened through 1 cm sieves, but also larger particles were passed due to the elongated form of the biochars. Also, it is important to brush the applied biochars into the formed holes to help them fill.

The projects provided valuable experience regarding the suitability of different equipment and types of biochar for spreading in parks. Based on the experiences, it is recommended to either refurbish the topsoil by tilling, making it easier to get enough biochar underground. In this case, biochar could be pre-fertilized with an organic fertilizer or soil amendment such as manure or compost.

On areas where tilling or is not possible, provided that the lawn can withstand the use of at least 25 mm aeration spikes without the surface layer lifting with the spike, surface application with aeration can be recommended. However, it is crucial to use biochar of relatively small particle size to avoid that the biochar will not remain on the soil surface. A suggested upper limit for future experiments would be >0,5 mm screening limit to avoid elongated particles larger than 1 cm. Biochar remaining on the soil surface is not equally beneficial for plant water and nutrient retention or increasing soil microbial activity. Additionally, biochar left on the surface is susceptible to erosion and may stain the clothes of park users.

Structural soil renovation for oak trees

In Sörnäinen metro station area, the Vaasanpuistikko square was going through a massive renovation and while some trees were felled, three oak trees planted in the 1980's were selected for a soil renovation. Due to communication issues, the soils here were changed twice.

The trees were growing below a paved surface in regular soil and were assumed to suffer from soil compaction. The old soil was sucked away with a high-power vacuum vehicle until the bedrock was visible at 60-200 cm depth. According to the contractor there were very few roots visible in the soil layers which were removed and most roots were winding along the cracks in the bedrock. To inhibit re-compaction of the soil, a weight-supporting design called structural soil was designed. The design features a load-bearing matrix consisting of stones with nutrient and water-retaining soil in the voids in between. Originally, stones of 50-150 mm in size were designed to be used, but their use had to be rejected as such large stones were very hard to level out into the shallow pits. Therefore, an available 31-90 mm size range was selected. Generally, the Finnish quality standards (InfraRyl) state that the lower limit for structural soil stones is 80 mm and that the size may vary 100 mm from 80 to 180 mm.

The work plan was not completed before the construction phase, and eventually lack of communication led to that the gaps between the rocks were filled with pure biochar instead of a compost-biochar mixture. When the mistake was noticed, the growing medium was removed again and replaced with a readily available commercial product including biochar. In addition to biochar, compost and regular soil were mixed into the spaces between the rocks. The rationale for this labor-intensive and potentially root-damaging correction was the fear that using only biochar as an intermediate material would result in conditions that would be too dry and nutrient-poor for the trees. As the three trees were handled equally, there is no point of comparison beyond two oak trees nearby that did not undergo any similar procedures.

An existing street tree and new perennial plantings

As a part of a project where spots of street parking were transformed into green areas, an individual pre-existing linden tree was designed to have a new kind of structural soil recipe. This tree is the first in Helsinki that had compost-charged biochar in the recipe. The initial plan was to realize the design according to the so-called Stockholm model including 75% stones and 25% of biochar-compost mixture, but the plan was adapted to 70% stones to comply with the conventions prevailing in Helsinki. Further, a soil component was added to the mixture of fine material, resulting in a recipe with 10 % commercial soil and 20 % of HSY woodchip biochar-HSY compost mix. The tree's old concrete planter box was partly demolished but not entirely to avoid damage to the roots. Structural soil was applied to replace the old soil as much as possible. A decorative perennial and shrub planting was designed around the tree, and the deeper layer of this area also features the same structural soil recipe with conventional soil on top.

Newly planted trees in traditional soils

Oravapuisto park was the second location in Helsinki where low-emission infra construction was piloted. The construction company GRK, working in the area, donated Helsinki Biochar Project 10 m^3 of pine-based biochar produced in their recently launched factory. This biochar was used in planting trees in the park.

A total of 85 trees were planted in the park, with 36 of them receiving 10% biochar in their planting pits. The trees included 5 species of conifers and 9 species of deciduous trees. The growing medium for deciduous trees consisted of city recycling soil, while commercial growing medium was used for conifers. The planting pits were calculated as 3.2 m^3 for larger trees and 1.5 m^3 for smaller ones.

During the project, there was an opportunity to experiment with mixing biochar into the growing medium on-site, and many people took the chance to observe. Adequately moistened biochar generated minimal dust, and the mixing process went according to plan when note was taken to use volume units for both biochar and the growing medium, instead of mixing volume and weight units.

The tree planting work started in the spring and progressed along with the development of the park, with the last trees planted at the end of September. Thirty-six individuals from six tree species were selected for annual monitoring of growth. Half of the trees serve as controls without biochar, while the other half have biochar in the growing medium. Potential biochar effects will be evaluated by measuring trunk thickness, plant height, and visually assessing their condition on a scale of 1-5. A thesis is in preparation at HAMK University of Applied Sciences to further explain the processes.

New street trees in structural soils - resolving watering regimes

In the upcoming years, a new residential area is planned for construction in Stansvikinkallio. Many streets within this development will feature new linden trees planted beneath paved surfaces, and to avoid soil compaction, a structural soil will be introduced around the tree roots. To enable testing an adaptation of the so-called Stockholm recipe in Helsinki and to investigate the overall impact of biochar in comparison to a business-as usual recipe, an experimental setup and maintenance procedure was planned with the Helsinki biochar project. The local recipe features 70% stones and 30% biochar-compost mixture (1:1) while in Stockholm, the share of stones is 5 % more. In addition, three trees will be planted without biochar, which will be replaced by a typical soil mix suitable for broad-leaved trees (table 5).

Further, to elucidate the role of a strict fertigation regime deployed in Stockholm, an experimental maintenance plan was devised. Some of these trees will receive fertigation for the initial two years, which is the time for maintenance guaranteed by the park-building contractor. Control trees will only be watered with pure water, aligning more with the current approach in Helsinki. In the first year, trees will be watered once a week and in the second year, every other week.

A significant part of the planning process was to formulate the basis for a model specification that the city can use in the future when employing nutrient-charged biochar in structural soils. The specification addresses aspects such as the recommended duration of nutrient loading, mixing ratios, and potential compost alternatives. The model serves as an adaptable foundation intended for updates as knowledge and experience grow. In the future, it will be necessary to specify the selection of different biochars and preferred particle size distributions for trees as to date, no clear preference could be given due to lack of experience and reliable knowledge.

The construction schedule remains flexible and will be coordinated with the overall planning progress for the area.

Growing medium	Watering
A) 70+15+15 % gravel, biochar, compost	fertigation
A) 70+15+15 % gravel, biochar, compost	water irrigation
B) 70+30 % gravel, recycled soil	fertigation

Table 5 Planned growing medium treatments and watering treatments for the future experimental setup with Stansvikinkallio street trees

Meadow on recycled sandy soil

The suitability of biochar for establishing meadows was considered several times during the project. There were speculations about both the benefits and drawbacks of biochar for meadow vegetation, depending especially on the timeframe of the analysis. In various discussions, it was considered that in the short term, biochar might help in reducing excessive nutrient richness in the growing medium. However, there were concerns about the possibility of biochar becoming a nutrient source in the long term. One of the few references was a Swedish rather unsuccessful experience with agrobiopellet biochar on transforming lawns into urban meadows (Fransson et al. 2020). However, there were indications that biochar might increase species richness (Ann-Mari Fransson, personal communication 3.3.2023) and practical experiences especially with woodchip biochar were lacking. This lead to the search for a location to experiment with this.

As part of the redevelopment of the Vähätupa playground area, the old rock dust field with 1500 m^2 in size was transformed into a meadow, utilizing materials from the site. The recipe for a 10 cm thick medium layer consisted of 1/3 rock dust and 1/3 of soil. Half of the meadow area was then also treated with raw biochar, with 10%v/v of HSY woodchip biochar added into the growing medium. The HSY woodchip biochar in this case was the same as in the park lawn project, which was screened to remove larger particles. Long-term monitoring is planned for the site, observing the development of plant diversity and soil nutrient levels over time.

Lessons learned – Key insights from using biochars in urban green areas

While the research surrounding biochar supports its large-scale use, challenges arise from the lack of established guidelines for soil recipes, working methods, and maintenance practices. Moreover, the visible benefits of biochar in local contexts have not yet been fully demonstrated, making it challenging to justify the associated costs for an individual construction project.

The key lessons learned for designing and constructing urban green infrastuctures can be summarised in the following way

· Throughout the network of stakeholders, there was a strong positive and enthusiastic attitude towards testing biochars sometimes despite even negative presumptions.

· Generally, designers would prefer products that have known and predictable effects on soil, water, and plants. Simple, fast, and ready- to use specifications on biochar use that lead to positive results are needed, but in their absence, biochar use remained rather careful and expert advice and discussions were needed.

· Key questions related to asking how much biochar should and could be used to have positive and no negative effects and what kind of nutrient charging- or fertilising regimes are needed or necessary.

· It is challenging to determine the best biochar type from the market supply for a given design. Detailed information is available when requested, but advanced knowledge is required to assess how to use the information of given attributes. These attributes include eg. parent materials, pore size and particle size distributions, bulk density, and the relevance of declared nutrient contents in biochars.

· Biochar handling proved to be easier in most cases than expected. Most worries concerned its dusting behaviour, which was an issue only when sufficient moisture and/ or proper application methods were not ensured. The need for sufficient moisture in biochar, working safety documents and personal protection should be highlighted.

· On large-scale field conditions it is hard to ensure accurate measurement of soil components which may lead to inaccurate biochar mixing ratios.

· Nutrient charging was logistically successful when done at composting stations in 1:1 ratio with biochar and compost. In some cases, also lower compost ratio would have been desired to avoid excess nutrients to plants when using higher biochar percentages in soil recipes, or to avoid overly high organic matter content in eg. sports turfs. The waiting time required for nutrient charging needs to be anticipated when scheduling construction projects. No pre-charged biochars in high volumes were available on the Finnish market during the project, which would ease their use. However, in 2024, several growing medium and soil companies were able to provide a nutrient-charging service upon request. A pre-charged product is not equal to biochars sold as a mixture with fertiliser products

Future steps – Supporting the expansion of biochar use

Practical experiences regarding the use of biochar in green structures are still emerging, and an understanding of biochar's practical benefits is not yet well-established. Also, due to limited availability and its relatively high price in comparison to conventional soil products in Finland, its application is mainly based on special occasions where biochar is applied in small volumes. However, it is important to support this development and help biochar reach an economy of scale, which would impact both the pricing of biochar and its availability. Therefore, motivation for driving more widespread use could be supported through the city's carbon neutrality goals.

For this purpose, the city should soon develop a system for the management and quantification of its carbon stocks and integrate carbon storage into its emission calculations. Subsequently, biochar should be added as one of the city's strategic climate tools, for instance, by setting an annual carbon sequestration target created through its use. Biochar production is still emerging, and it is currently produced in small and pilot scales. It is also important to note, that biochar's carbon storage (or carbon removal) can be certified into carbon credits and sold separately to the physical product. Therefore, if the city wants to gain climate benefits from the application of biochar, the city should ensure the ownership of the carbon credit. On the other hand, it might be feasible for the city to purchase biochar without carbon credits at lower costs and apply it for its practical co-benefits.

The current climate program in Helsinki does not allow compensation through carbon sinks that take place its geographical limits. For needs of transparency and accountability of Helsinki's climate policy, biochar use needs to delineated through a political process in conjunction with other sink options. For biochar, the sink may, and for commercial biochars would, take place through forest growth beyond the borders of the City. However, the storage of carbon would take place and accumulate in the soils within the City borders.

To promote biochar use, two layered approaches are proposed. The first involves setting an internal city goal or pledge to incorporate a small and safe percentage of biochar in all soils within green structures. This contributes to the practice for carbon storage, and can potentially contribute to large volumes of use. However, there is a risk of underutilizing biochar's potential benefits, and overlooking risks as not all plants or soils benefit equally from its addition.

Bearing on the above, a second more structured and detailed approach may be more advantageous. This would include

· Setting a volumetric goal for biochar use and assigning this as a task to selected divisions of the City.

· Selecting specific green structures as primary targets based on expected added benefits.

· Prioritizing adaptations that facilitate the addition of large quantities of biochar, especially in environments with risk of drying out such as restricted soil spaces or those using sand/gravel-based growing media.

· Creating specific guidelines for these structures, including biochar specifications, soil recipes, working instructions, and maintenance guidelines.

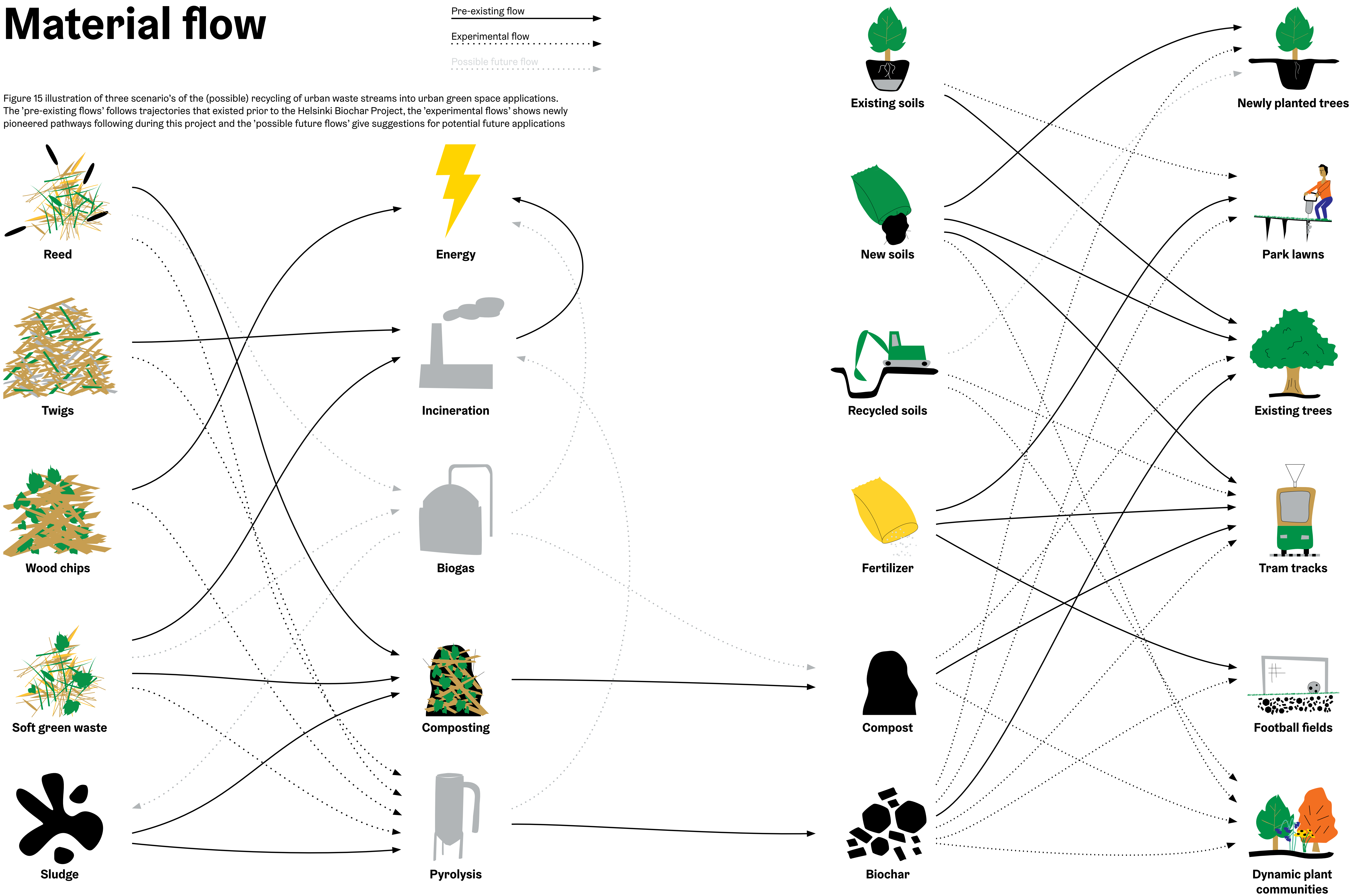
A concrete target could be to strive for a minimum of 100 m^3 in the launch year and 200m^3 in the following year through the city's Land Use and Structure-division. Attention should be paid to the detailed documentation of realized projects. Selection of green structures could involve those that have a sandy or stony growing medium but contain plants that do not prefer dry or nutrient-poor conditions, such as stormwater basins, green stone pavements, and trees in restricted root spaces where the tree species are known to tolerate potential winter sogginess. Along such design processes, and as knowledge based on the pilot experiments and other information sources build up, models for required working documents need to be complemented.

Further ahead, the future scenario should encompass the opportunity to use low-quality biochars for carbon sequestration. This could drive the manufacture of biochar from various materials, hygienized through pyrolysis, suitable for applications beyond urban vegetation, such as in construction work, including roads (Lehtinen, 2023).

Additionally, the development of rewarding systems for contractors, inspired by successful models in countries like Sweden, could incentivize the use of low-emission techniques and materials in urban projects. By navigating these strategies, cities can not only enhance their sustainability goals but also contribute significantly to the broader understanding and implementation of biochar in urban environments, which can also have a substantial effect on the new and developing biochar market

Material flow

Figure 15 illustration of three scenario's of the (possible) recycling of urban waste streams into urban green space applications. The 'pre-existing flows' follows trajectories that existed prior to the Helsinki Biochar Project, the 'experimental flows' shows newly pioneered pathways following during this project and the 'possible future flows' give suggestions for potential future applications



5 Citizen engagement experiments

Because biochar is still a relatively unknown material, the Helsinki Biochar Project aimed to increase the awareness of citizens on the potential of biochar. In order to do so, the project set up a series of trials in the Helsinki metropolitan for that included direct citizen participation. The goal was to demonstrate that converting local waste streams into responses to climate change can be an engaging activity for citizens.

More specifically, the objectives for the citizen engegament part of the Helsinki Biochar Project were formulated as follows:

- to make carbon sequestration and storing visible and to engage biochar as one means for doing that.

- to demonstrate citizens that carbon sequestration is also for them and not only a job for decision-makers

- to raise awareness about the need to close the loop of recycling organic materials back into the soil and to link biochar to this cycle

To meet the objectives of this part of the project, three citizen gardener groups and one housing community were selected to experiment with using biochar. The site selection process was based on prior knowledge about existing interests and ongoing activities as feasible easy to reach sites, the ability to work within a group setting, but also included deliberate attempts to broaden the range of potential citizen participants. In addition to (gardener) groups, other forms of citizen engagement were considered, such as schools, individually or the creation of water filtering floating islands.

The citizen engagement trials did not primarily focus on the technical properties of biochar, such as the effects on plant growth or water retention, but rather on how citizens make use of biochar, experiment with the materials, how they mobilize and organize themself and what motivates them to use it. Information on these aspects was gathered through attending and co-organizing events, making field notes, photo documentation and 3 semi-structured interviews with key people involved in coordinating the (gardener) groups.

The lessons learned from the citizen engagement experiments were categorized into four overall themes: Biochar use in community gardening, Community Engagement, Urban Green/climate adaptation potential, and Nutrient (re)cycling. Based on the findings in these categories, recommendations for future steps were made.

Experimental Citizen Engagement sites

Jätkäsaari community garden

The Jätkäsaari community garden is a mobile garden group consisting of around 15-20 gardeners. This gardening community makes use of the many derelict urban spaces in the local area waiting for development. Once development starts on the lot, the garden moves to a nearby available location. The concept arose from seeing opportunity for using derelict spaces in the neighborhood and because the initiators made use of a temporary lot at the Lapinlahden lähde garden from which they had to move.

The infrastructure of the garden community is adapted to these temporal situations. The gardeners only make use of $1m^2$ garden boxes placed on pallets so they can easily be moved. Gardeners can rent rights for a garden box for 7€ a year. This arrangement was negotiated with the City of Helsinki with the help of Dodo, a local urban environmental association.

One mayor challenge for this community is access to water: which is now tapped in the waste recycling room of a residential building located a couple hundred meters from the site. Another related challenge is the water retention capability of the garden boxes: as they are positioned on top of pallets, the soil dries out easily. Therefore, a key motivation for participating in the biochar project was to gain insight if biochar helps to reduce the irrigation needs of the Jätkäsaari community garden

Lapinlahden Lähde community garden

The Lapinlahti garden community is located in the Lapinlahti bay area in Western Helsinki and is part of the pro-Lapinlahti mental health association, that rents the land from the City of Helsinki. The garden consists of two parts: a larger part where gardeners rent individual plots of various sizes, and a part that is collectively maintained by a group of gardeners.

The individual plot rental side of has a waiting list of interested farmers. Every year, if there are vacancies, new tenants are selected via a lottery system. Tenants of individual plots can also participate in voluntary group activities such as talkoot, a Whatsapp groups for discussions or collective purchasing of garden materials. Garden activities are coordinated by a small team. The communal side of the garden started as a means for people with mental challenges to provide wellbeing and relations to nature and teach gardening principles to beginners as a hobby. Participation in the communal garden is free of charge.

Like the Jätkäsaari Community Gardens, water retention of one of the larger issues in the Lapinlahti Garden Community, as it is not possible for most of them to visit the garden frequently enough to water the plants sufficiently. The gardeners were already aware of biochar as a potential solution for this challenge, but partly due to its high price it was never considered a viable option. In total 1250L of biochar was delivered to these garden communities, which was activated and applied during 'talkoots' (collective works) in the spring.

Rinnekodit housing association

Rinnekodit is a housing association that is conducting a pilot project in which it is creating a community setting providing support to help formerly homeless people to reintegrate into society. This pilot project takes place in a housing block in Eastern Helsinki. Gardening in the inner courtyard is part of the reintegration program. Small adjustments to the inner courtyard have been made to facilitate communal activities and enable community gardening. The coordinators working for Rinnekodit did not have much experience with gardening prior to the project and are learning through trial and error.

Applying biochar was part of a larger event to kick-off Rinnekodit's project to convert the inner courtyard into a therapeutic garden. Adding biochar to 6 pre-existing garden boxes, installing a new garden box with annual flowers, amending soil around already present berry bushes, adding biochar to a planting area next to a sidewalk, and donating and constructing a planter box filled with compost and biochar to a neighboring elderly home.

Kaapelitehdas (Cable Factory) rooftop gardens

On top of the roof of Kaapelitehdas, an arts and culture centre in Western Helsinki, a group of 40 raised garden boxes belong to a community of gardeners who also rent studios in the building.

250L of dry biochar was delivered to the rooftop garden of the Kaapelitehdas. The gardeners were free to decide how they wished to apply the biochar and for what purposes. In addition, one of the garden boxes was reserved to do a comparative test with a selection of native plants that attract pollinators. 10L of activated biochar (with nettle tea) was mixed in one half of the soil, while the other half did not receive any biochar.

Figure 16 the four locations of the citizen engagement trials

Timeline citizen engagement events

28-3-23
Information evening/
presentation at Dodo

23-4-23
Biochar activation talkoot in the
Lapinlahti community garden

7/8-5-23
Biochar application talkoots in the
Lapinlahti community garden

25-5-23
Biochar distribution at Kaapeli-
tehdas rooftop garden

29-5-23
Biochar distribution at Jätkä-
saari community gardens

30-5-23
Biochar application talkoot
Rinnekodit inner courtyard

6-9-23
Biochar tour at the Lapin-
lahdi community garden

12/26-10-23
Exhibition of biochar modules
at Aalto University campus

Figure 17
the citizen engagement
activities presented in
chronological order

Additional, potential ideas for citizen engagement experiments that were considered and explored

For wide dissemination of biochar knowledge, participation with schools would have been an option. Examples of such approaches can be found e.g. in Helsinborg in Sweden and Sandnäes in Norway, two other cities financed in the Bloomberg Philantrophies initiative. In Helsinki, an initial meeting with staff from two elementary schools took place after a suggestion from one of the City of Helsinki employees working on citizen engagement on creating green spaces in schools. However, the trial was too complicated in the short time frame and the overlap with school summer holidays. The school personnel were also looking for more concrete proposals, which at the time (the start of the project), we could not yet provide. However, in the future, biochar use could be integrated into school curricula.

In addition, we approached one activist in Helsinki who previously built floating islands together with school students, but did not receive a response. This idea was later dropped as other forms of citizen engagement looked more promising. An additional reason was that a floated raft with biochar would not include any form of carbon sequestration (one of the main objectives of the citizen engagement part of the project), but instead only focuses on the filtration capabilities of biochar.

At the start of the project, the idea of trialing a predesigned planter box module using similar plant species, recycled soil and biochar was pitched to several gardener groups and at the NGO Dodo ry. However, the idea did not gain enough traction amongst possible participant to find continuation. Because we did not want to force an experiment upon citizens, the idea was dropped.

Accomplishments and lessons learned

Biochar use in community gardening

The key lesson learned regarding biochar use by citizens was that no common knowledge exists yet on how to use biochar. While some gardeners knew about the product, and some even had prior experience with it, there was no common practice on how much biochar too apply and the ratios for activation. Whereas factors such as compost ratio is, the effect of nitrogen of calcium, soil aeration are part of most gardener's common knowledge, the presumed effects of biochar or how to activate it were mostly hearsay. For example, in the Lapinlahti gardens, the dosage of activation liquid was very low. At the same time, some gardeners wondered if the biochar should be crushed before mixing it in the soil.

Related to the absence of common knowledge on how to use biochar there is a lack of knowledge and experience on the effects of biochar in the soil. While some of the plants seemed to have benefited from the addition of biochar in the soil, on others it seemed to have a negative effect. It was also hard to determine if biochar was the only cause of the plants suffering, biochar ratios, weather conditions, prior condition of the soil or the quality of other soil amendments such as compost etc could also play a role in how well the plants grew. To measure these effects was not part of the trials, but a measured positive effect on plant health could help to convince citizens to apply biochar. In addition, due to the scope of the project, the long-term effects of biochar on e.g., water and nutrient retention are also unclear.

To further develop common knowledge on biochar's use and its effect, further long-lasting experimentation is needed. However, a lack of availability of biochar might prevent its future use.

Gardeners who already knew about biochar wanted to use it before they got connected to the Helsinki Biochar Project, but due to the cost of biochar in combination with its unclear effect, it was never a viable option/high enough priority to purchase it before. The fact that the biochar was distributed for free played a large role in motivating citizens to join the project. As such, it remains to be seen if the gardeners will keep using biochar in the future if they are expected to pay for a biochar product.

Community Engagement

Citizen engagement can happen on various levels. For participation in the trials, citizens were not addressed on an individual level, but rather through associations (garden groups, housing association)

Figure 18 an impression of several of the activities that took place at the citizen engagement sites and through collective works (talkoot). The advantage of addressing citizens in groups made distribution of the biochar easier. Initially it was the aim to distribute biochar in small bags to individual citizens, however due to production problems (high content of heavy metals) this plan was no longer an option.

The gardeners mentioned the positive aspects of collective gardening, such as co-learning, bringing people together, and the equalizing effect gardening activities. The availability of biochar in bulk bags suited this type of working. For one, it was a lightweight material, making it easy to participate for people with various levels of strength. In addition, it started conversations on soil quality. In the specific case of working with formerly homeless people, it was mentioned that they gained a sense of pride in being trusted to work with such expensive material, making them feel part of something bigger.

At the same time, collective gardening activities also contain certain challenges. During the interviews, shared challenges included: having to manage various levels of commitment; finding a balance between keeping gardeners welcome, but also making them understand they are not buying a service; having to deal with cultural differences. Suggestions to overcome such challenges included having a clear vision and goals; knowing one's target group and the need for a core of committed people to keep projects going. In doing so, the gardener groups depend heavily on the coordination and leadership of a few key individuals that were referd to in the steering group as local champions.

These local champions also played a key role in getting the biochar experiments of the ground. They were instrumental in getting the biochar delivered to the garden, coordinating, and initiating various experiments and events, and community management. For example, in Lapinlahti the coordinators play a key role in managing the garden community, planning events, and doing different trials. Even taking an organizational role in the biochar tour we had organized. While at Rinnekodit workers lobbied to their superiors to buy extra plants to fill more biochar boxes and organized an additional talkoot to include a neighboring elderly home. In Jätkäsaari, a local couple had a leading role in initiating the garden, organizing events, and conducting biochar experiments and communicating about the availability of the material.

From our perspective as project coordinators, finding a balance between giving instructions on how to use biochar and having citizens experiment without instructions was challenging. When the biochar was implemented at the various experimental sites, a member of the steering group was present to promote its use and give elementary instructions on how to apply the material. Alternative strategies could have been providing biochar without any promotion/instructions or organizing workshops on how to use it, with specific instructions. We chose not to do so, particularly because we wanted to understand how the participants would use the materials themselves and what infrastructure would be needed to expand biochar use for citizens.

In this regard, the participants did call for additional support in the form of locally available equipment, accessible knowledge and expertise. Some expertise was available at Dodo, but the participants did not make use of their knowledge. In addition, they also mentioned that by experimenting themselves, valuable lessons were learned.

Urban Green/climate adaptation potential

Participating citizens had an eagerness to understand more on how biochar is behaving, particularly in the context of gaining a deeper understanding of their gardens' overall soil conditions. A proper amount of scientific support might be useful to increase engagement and/or confidence in applying biochar. On the other hand, it is difficult to monitor and quantify the specific effects of biochar has on the soils of gardens managed by citizens, due to the many variables and unpredictable conditions. Although the collective knowledge on biochar gained from the experiences of the gardeners could be archived, which could contribute to the establishment of common local biochar knowledge. Scientific support could be deployed to increase gardeners' general knowledge of their soil, by increasing their capabilities to conduct, read and interpret small scale tests. In addition, the amount of carbon sequestered by applying biochar would be one data point that would be easy to monitor, as the amount of carbon present in each batch of biochar would be known in advance.

At the same time, citizens also engaged in low-tech self-testing based on more subjective means. One clear example is such a practice was the 'underwear test' in which two pairs of underwear were buried in the soil and dug up towards the end of the season. As the underwear decomposes, this indicates the activity of soil life and decomposition in the soil. Along those lines, other intuitive or situated methods exist that help to gain a better understanding of the properties of soil, such as, looking at indicator plants, mixing a handful of soil in a jar of water and letting it settle, using tullgren funnels to count small insects, or infiltrometers to get a rough indication of the water infiltration capacity of the soil. In addition,

Figure 19 various biochar activation methods used in the citizen engagement trials the observations made by gardening itself on, for example, plant growth or microclimates, also contribute to gaining more understanding of how the soil and garden behave.

Gardeners gaining a deeper understanding in their soils' behaviors could help the future design of urban soil compositions suitable for the specific needs of urban gardeners. Because most community gardeners are not able to visit their garden (plots) daily and because they garden as a spare-time activity, plants need to survive with little attention. In addition, gardeners expressed the wish to reduce the amount of water needed in the garden. These specific factors call for a soil composition designed for nutrient and water retention capacity, in which biochar could be one component.
The latter aspect especially was one of the major motivations for gardeners to participate in the project. In the Lapinlahti gardens had suffered from drought in the past and the gardeners did not always have the means to sufficiently water their plants, as for most of them they must commute to the garden from elsewhere in the city. The garden boxes in both Jätkäsaari and the Cable Factory are susceptible to drought as there is not much soil space available and they are raised from the ground. Especially in the Jätkäsaari garden this was a challenge as there was no source of water nearby for the gardeners to use.

In addition, some gardeners mentioned that the use of biochar to sequester carbon might be enough of a motivation to use it. These comments were made in the context of the possibility of biochar not having any apparent beneficial effects on the soil. However, gardeners also indicated that they would not pay for biochar if there were no obvious benefits.

Nutrient (re)cycling

In both the Lapinlahti and the Jätkäsaari community gardens, the gardeners were quite aware to use frugal means to obtain nutritial imputs for their gardens. For example, by using materials such as nearby park leaves, old coffee grounds to make compost. More experienced gardeners tried to reduce inputs of peat and try to minimize the use of plastic or commercial products containing peat. However, in practice alternative options were not always feasible: either because they were not available or due to logistical challenges which made it hard to get such materials on site. Garden coordinators from different communities expressed the wish to make wood chips on site from, for example, locally pruned park trees. Composting and waste separation were happening at all sites. In addition, several gardeners expressed the wish to compost additional materials, such as household or restaurant waste, on site but were not allowed to do so because of regulations.

To activate the biochar, the participating gardeners were using different media based on resources directly available to them. Several individual gardeners mentioned how they already made bokashi at home and used it in their gardens. The liquid produced in this process was used as one of the activation media on several separate occasions. A year-old nettle tea was used in one instance, but at the same time it was not possible to use fresh nettle tea, as at the time of the year during which nettles grow in Helsinki did not correspond with the start of the growing season (this is when the biochar was activated). In addition, gardeners used free left-over materials sourced from local companies and farms, such as composted coffee grounds from a mushroom producer, or liquid manure from a nearby farm to activate their biochar.

In addition to using locally available resources for gardening activities, the gardeners were also interested in using locally made biochars. Because it was not possible to use most of the biochars produced from the experimental feedstocks, due to them containing too many harmful metals, surpassing national legal thresholds. Woodchip biochar would have been an option in terms of the finnish law, but due to the amount of PAH 16 exceeding the threshold set for food plants by the european biochar certificate, the decision to use commercial biochar was made instead. Various gardeners expressed disappointment in not being able to use locally produced biochar. Reed char was mentioned as interesting in the Lapinlahti Community Garden because reed was going nearby that is mowed every year. The gardeners were interested in using it on their plots but did not know what to do with it. Biochar made from locally harvested reed sounded promising to them.

In this regard, collaboration between citizen groups and waste management services could be strengthened to further promote and facilitate local re-use of resources. The citizen gardeners mentioned informal collaboration with Stara about using park waste, or the potential for collaboration with HSY in setting up a decentralized and local biowaste handling system to avoid unnecessary transport (to Espoo). As well as potential to compost biowaste from local offices and/or restaurants.

Suggested next steps in citizen engagement

The key suggested next step in relation to citizen engagement is to continue to facilitate the development of a local 'common language' for biochar. This could be done by setting up structured trials and strengthening local networks by further mapping local practices and expertise. The municipality could take a leading role by developing citizen engagement programs that link biochar distribution into climate adaptation, develop stimulating regulations and campaigns, and by incorporating biochar use in a broader soil recycling strategy.

Due to time restraints of the overall project, and time it took to set up initial contact of trial sites, the scope of experimentation was limited. As a result, participating citizens mentioned their need to know more about the effects of biochar in the soil. Having more knowledge of its effects could potentially convince citizens to use biochar in their gardens. This could be done via structured trials that facilitate direct collaboration between citizens and researchers and other experts. For example, by providing scientific support in measuring the effects of various applications of biochar on pH, nutrient holding, water retention, plant growth and/or long-term effects.

The activation of biochar also offers opportunity for further citizen engagement. For example, the long winter period offers an opportunity to organize workshops in which biochar is charged by applying various media. Measuring dissolved nutrients and microbial activity together with researchers could serve as one way to spread information and strengthen ties between practitioners with different forms of knowledge. Findings could be documented by developing an (online) database with recipes for ratios, local plant information, available activation media.

There is also potential for the City of Helsinki to develop climate adapatation strategies that involve citizens. In other cities worldwide forms of citizen participation in climate adaptation already exist, from which inspiration can be taken. The City of Helsinki could take a leading role in setting guidelines for citizens and providing (financial) support, for example, by making climate adaptation subsidies available. The production, distribution and use of biochar could become an integral of such a strategy.

Based on the experience from the citizen engagement experiments for this project, the municipality could make use of existing associations. The urban garden groups that participated in this project demonstrated they consist of thriving communities. Their forms of organizing themselves could be replicated in other (vacant) areas of Helsinki. Inner courtyards (managed by housing associations) and mobile urban gardens are promising potential spaces to incorporate in such a strategy.

Stimulating regulations and campaigns could also stimulate local recycling practices. For example, gardeners from different communities pointed out the wish for possibilities to compost kitchen waste from either households or restaurants, but current regulations make it difficult or even illegal to engage in such activities.

Currently, the City of Helsinki is already conducting experiments with locally recycled soil mixes for urban green maintenance. These experiments could be expanded by developing predesigned soil mix suitable for citizen gardening activities. This could be made from HSY compost, biochar and gravel. Different ratios or source materials could be linked to specific uses, for example a biodiversity soil mix or a mix for edible plants. By providing a platform for structured trials, citizens could participate in the development of locally produced soil mixes. Composted urban green waste, wood chips, biochar, gravel could be redistributed to citizens in future scenarios as most gardeners expressed a desire to make more use of locally sources materials, but these are currently hard to find or due to regulations or logistics impossible to use.

5 Conclusion

During the project, a wide range of waste materials were mapped out in search of potential feedstocks for pyrolysis. In the process, the overall discussion about how waste is currently handled and how the alternative could look like, was increased. Several materials were pyrolyzed in HSYs large-scale pilot facility, which offered valuable information for the scientific community and to HSY, who were interested in exploring other materials beyond sewage sludge and the potential of the facility. In conclusion, light and fast-degrading green plant materials were not so suitable as such for the facility, and would need further prehandling and process development. Biochar made from narrow woody twigs was easily processed, but the level of harmful substances was too high in the resulting biochar and the carbon content and water holding capacity in it was surprisingly low. The best quality was obtained with woodchips and in the future this material could be redirected from the city to HSY to be pyrolyzed as such, or preferably with another material of lower calorific value to better suit the facility's lower heat tolerance.

The project was overall able to promote biochar awareness throughout the public sector and experts within the green infrastructure professionals. During a brief timeframe, the project directly expanded the number of realized public biochar use sites from three to ten and facilitated the planning also beyond these projects. The wide collaboration network spanning across commercial biochar producers, landscape designers, contractors and academics generated relevant conversations and new connections to further facilitate biochar use and knowledge sharing also in the future.

The production of biochar and the planning and implementation processes of green structures raised numerous questions. The quantity of questions and the lack of ready answers indicated several clear areas for development, addressing of which would clearly promote the use of biochar by providing support for working with this new material. The most critically, know-how would be needed in specifying the accurate ratios of biochars in soils and biochar types that will most likely have the desired or undesired impact on the green structure. Also, equally important would be to resolve and state clearly in which cases biochar would be best to be pre-charged with compost or manure, when co-application with compost or fertilizer is enough and when it can be applied raw. Optimally, there would be a service provider to do the charging when required, or a ready product on the market. However, when the charging is to be done, the question remains on the best- and sufficient practices for each available material. The community involved in the planning of green areas would greatly benefit from clear and tailored educational materials, as well as from established and proven model designs that can be implemented with biochar. The fear of failing in large-scale construction and renovation projects due to biochar is currently slowing down its use in a situation where carbon stocks should be fast accumulated.

The concrete potential of increasing carbon stocks and carbon sequestration through biochar in Helsinki remains to be determined. To make an assessment, it is necessary to first define in which structures and at what concentrations biochar can realistically and feasibly be maximally used. This ensures that resources are directed sensibly, considering both economic considerations and potential multi-benefits and drawbacks for plant growth. The approach differs from a theoretical calculation, where the assumption is that 10-15% of biochar is added to all new city growing media, achieving an estimated 3,5-5% of the annual target for negative emissions (Soronen et al. 2019). Making a comprehensive guideline for maximizing the use of biochar still requires experience with the effectiveness of growing media recipes. However, practices could already be established for safe biochar quantities to structures where it is generally considered to be safe. Further, the city's own carbon balance calculations are crucial to be developed in this regard, as they currently do not consider carbon sinks or sequestration at all to motivate the use of biochar for climate ambitions. Ultimately, to determine the potential beyond growing media use, other possible applications of biochar should be considered, such as water filtration structures, as well as various construction projects unrelated to urban green. The latter ones could potentially include use of lower-quality biochars made from a variety of materials beyond woodchips which would not have relevant market value or meet the quality standards for nature-based solutions, but would neither increase the demand for forestry-derived materials.

In terms of the citizen engagement part of the Helsinki Biochar Project the following objectives were formulated: to make carbon sequestration and storing visible and to engage biochar as one means for doing that; to demonstrate citizens that carbon sequestration is also for them and not only a job for decision-makers; to raise awareness about the need to close the loop of recycling organic materials back into the soil and to link biochar to this cycle.

To meet the objectives of this part of the project, three citizen gardener groups and one housing community active in Helsinki were selected to experiment with using biochar. The lessons learned from the citizen engagement experiments were categorized into four overall themes: biochar use in community gardening, community engagement, urban green/climate adaptation potential, and nutrient (re)cycling. The key suggested next step in relation to citizen engagement is to continue to facilitate the development of a local "common language" for biochar use, continue to strengthen ties between local stakeholders and develop an integral climate adaption strategy and soil recycling strategy for which the City of Helsinki could take a leading role.

6 References

Budai, A., Zimmerman, A. R., Cowie, A. L., Webber, J. B. W., Singh, B. P., Glaser, B., ... & Joseph, S. 2013. Biochar Carbon Stability Test Method: An assessment of methods to determine biochar carbon stability. International biochar initiative, 20.

EBC (European Biochar certification). 2023. Analytical methods. Accessed 21.12.2023. Available at: https://www.european-biochar.org/en/ct/8-Analytical-Methods

ELY- centre, Centres for Economic Development, Transport and the Environment. 2022. Ruoko, Järviruo'on tietopankki. Available at: https://www.ely-keskus.fi/web/ruoko/maanparannus Accessed 29.12.2023

Fransson, A., Gustafsson, M., Malmberg, J., Paulsson, M., 2020. The Biochar Handbook for users. Available at: https://biokol.org/english

Lehtinen, K. 2023. Utilizing Biochar in Street Structures. [Bachelor's thesis]. Tampere University of Applied Sciences

Liu Z., Dugan B., Masiello C. & Gonnermann, H. 2017 Biochar particle size, shape, and porosity act together to influence soil water properties. PLoS ONE 12: e0179079.

Saarela, K., Harju, L., Rajander, J., Lill, J., Heselius, S., Lindroos, A., & Mattsson, K. 2005. Elemental analyses of pine bark and wood in an environmental study. Science of the Total Environment, 343: 231-241.

Soronen, P., Riikonen, A., Salo, E., Koivunen, M., Tikka, S., Passi, S., Salonen, A., Jalas, M., Tammeorg, P. 2019. Design support for the carbon drawdown demonstration area in Jätkäsaari, Helsinki Report on principles of urban demonstration areas for carbon sequestration.

Terracottem. 2023. Terracottem Universal [Technical data sheet]. Available upon request at: https://www.terracottem.com/en/terracottem-universal

Project webpages

Carbon neutral cities alliance CNCA. 2024. Biochar-Urban Forestry Strategy Resource Library — Center for Regenerative Solutions (CRS) - Accelerating Nature-Based Climate Action (naturebasedclimate.solutions)

Carbon Lane- project. 2023. Hiilipuisto - Carbon Park | Aalto University

Carbon park. 2023. Hiilipuisto - Carbon Park | Aalto University

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7 Appendices

Appendix 1: biochar analysis

parameter	unit	reed BC	soft green waste BC	woodchip BC	twig crush BC	Value threshold (Finnish)	Value thershold (EBC Agro& Urban)
Total P	mg/kg	5450	4240	1027	1970		
Total K	mg/kg	26700	39600	5910	12600		
pH (CaCl2)		7,8	9	7,75	8,8		
Conductivity (EC)	mS/cm	<0,01	<0,01	<0,02	<0,01		
Moisture	w % H2O	18	21	49,4	38		
Ash content (550°C)	w % (dm)	54,6	54,8	6,7	53,4		
Harmful metals							
Arsenic (As)	mg/kg dm	8,9	3	<0,8	5,9	25*	13
Mercury (Hg)	mg/kg dm	<0,07	<0,07	<0,07	<0,07	1	1
Cadmium (Cd)	mg/kg dm	0,4	0,4	<0,2	1	1,5	1,5
Chromium (Cr)	mg/kg dm	130	174	76,5	202	300	90
Copper (Cu)	mg/kg dm	115	57	11	368	600	100
Lead (Pb)	mg/kg dm	28	29	2,5	123	100	120
Nickel (Ni)	mg/kg dm	88	111	43	103	100*	50
Zinc (Zn)	mg/kg dm	292	237	122	819	1500	400
Manufacture and feedstock							
Charring temperature	oC	550-600****	548	560			
Retention time	minutes	70-120****	70	70			
Feedstock main component		green lake reed (september)	weed- and mowing waste	spruce and broad lea-ved trees	twigs of mixed wood from home yards		
Origin of feedstocks	mg/kg dm	Helsinki	Helsinki	Helsinki	waste station		
Extra							
organic C	w % (kg/kg)dm	28	24,2	82,4	43,5		
inorganic C	w % (kg/kg) dm	0,1	0,3	0,3	0,6		
H/Corg		0,34	0,27	0,34	0,35		
Bulk density	kg/m³ dm	493	519	175	429		
EFSA 8 PAH	mg/kg	n.c.	n.c.	0,2	n.c.		
PAH 16	mg/kg	1,3	3,5	11,7	6,7	***	
salt content	g/kg	36,4	23,2	7,1			
water holding capacity in <2mm fraction **	% dm	179	167,4	301,8	142,9		

Analysis results of HSY biochars manufactured for the project, thresholds set by the Finnish fertilizer legislation and the European biochar certificate. Non-compliant values in the biochars are marked with the respective color of threshold column.

*Threshold values for harmful metals valid in Finnish legislation until October 2023 (MMM 24/11, attachment IV). After this, the thresholds according to the new regulations for As and Ni were 40 and 70 mg/kg, respectively (MMM 964/2023, attachment 1).

** the sample is crushed and sieved before sampling

*** no threshold was in place for PAH 16 in Finnish legislation in summer 2023. As of October 2023, the threshold value for biochars with an organic carbon content below 50% is set at 6 mg/kg dm (MMM 964/2023, attachment 2).

**** no exact values are given for pyrolysis conditions in soft green waste due to several process stops.

dm= in dry matter

n.c.= non-calculable

Appendix 2 Comparison of properties between biochar feedstocks and end products

parameter	unit	raw green reed	reed BC	raw green waste	soft green waste BC	raw wood chips	woodchip BC	raw twig crush	twig crush BC
Total P	mg/kg	1350	5450	2090	4240	223	1027	1000	1970
Total K	mg/kg	13600	26700	20400	39600	1340	5910	7870	12600
pH (CaCl2)			7,8		9		7,75		8,8
Conductivity (EC)	mS/cm		<0,01		<0,01		<0,02		<0,01
Moisture	w % H2O	3,2	18	4,3	21	2,9	49,4	54,3	38
Ash content (550°C)	w % (dm)	29,6	54,6	25	54,8	1,1	6,7	9,2	53,4
Metals									
Aluminium	mg/kg dm	3860	5260	1730	6920	81	1200	3290	6760
Arsenic		15,4	8,9	<0,8	3	<0,8	<0,8	1,7	5,9
Lead		9	28	6	29	<2	2,5	109	123
Cadmium		<0,2	0,4	0,4	0,4	<0,2	<0,2	0,3	1
Chromium		98	130	103	174	2	76	89	202
Iron		9530	19900	4650	14600	141	1590	3580	11900
Potassium		13600	26700	20400	39600	1340	5910	7870	12600
Copper		39	115	15	57	3	11	14	368
Nickel		34	88	40	111	1	43	43	103
Phosphorus		1350	5450	2090	4240	223	1027	1000	1970
Mercury		<0,05	<0,07	<0,05	<0,07	<0,05	<0,07	<0,05	<0,07
Zinc		108	292	113	237	37	122	143	819

*) This column is an average of two sample cases in woodchip char

BC= biochar

Appendix 3 List of communication events

General communication for the public was done via the project webpage https://www.aalto.fi/en/department-of-design/helsinki-biochar-project which also had a finnish translation. Imagery was shared through an instagram page https://www.instagram.com/helsinginbiohiilihanke/

Professional stakeholder events and communication

- Häme polytechnic school HAMK, webinar presentation 3/2023 (>20 attendants)

- Urban environment division KYMP, webinar presentations and biochar samples giveaway campaign 3/23 (>150 attendants)

- Nodus Talks, panel discussion in Helsinki Design museum 3/2023 (>20 attendants)

- Sustainability Science Days conference, presentation 5/2023 (>20 attendants)

- Participation to an excursion to Swedish biochar pilot sites, Stockholm 9/2023

- Ichar 7th School of Biochar, Italy, project presentation, 10/2023

- Helsinki Region Environmental Services HSY, internal biochar webinar 10/2023 (>45 attendants)

- Aalto Department of Design, internal meeting + presentation 25.10.2023

- Urban environment division KYMP, biochar education morning for the city project managers 11/2023

- Appearance on the newspaper "Helsingin sanomat", 26.10. Title "Itä-Helsingin uuteen pyöräbaanaan upotettiin mustaa ainetta, joka ratkaisee kerralla useampaa ilmasto-ongelmaa" https://www.hs.fi/talous/art-2000009897348.html

- Article on "Ylläri" - internal magazine of Helsinki construction services, Stara, 10/2023,

- Article on "Viherympäristö"- magazine 12/2023. Title "Helsingissä uusia biohiilipilotteja".

- Urban environment division, KYMP, webinar hosting and presentation 8.12.2023 (>170 attendants)

- Biochar in the city? exhibition in the lobby hall of KYMP- house 12 - 1/2023

Citizen events and communication

28-3-23 Information evening/presentation at Dodo

Given a presentation at Dodo, a local environmental activist organization in Helsinki, at one of their regular events 'Urban Dinner', in which an environmental topic is being discussed. The goal of presenting at this event was threefold: to raise awareness on the Helsinki Biochar Project amongst active citizens; have citizens brainstorm about potential citizen engagement experiments; and to activate small samples of biochar with bokashi for the attendants to take home with them.

(31.-6.3.23) Poster display and distribution of biochar bags at KYMP

After a professional webinar, a handout of 110 commercial biochar bags with an instruction leaflet was arranged with a small project poster exhibition in the lobby of the Urban Environment Building at Työpajankatu 8, Helsinki.

23-4-23: Biochar activation talkoot in the Lapinlahti community garden

As part of the garden season preparation event, a 1250L bag of biochar was delivered to the Lapinlahti garden. 6 200L barrels were filled with 100L biochar+100L each. 3 of them had home-made bokashi as a activation liquid and 2 of them were activated with liquid cow manure from a local biodynamic farm. One barrel was filled with water only. The rest of the biochar was made available for the adjacent garden group who

7 and 8-5-23: Biochar application talkoots in the Lapinlahti community garden

The first weekend of May was the official kick-off of the garden season for the Lapinlahti gardeners. Because this is one of the few events that most gardeners are present at the same time, it was chosen to make the biochar available for application on this date. On the 7th of May, the gardeners from the individual plots gathered, on the 8th of May the gardening group from the communal garden applied the biochar in different areas in their garden.

25-5-23: Biochar distribution at Kaapelitehdas rooftop garden

250L of dry biochar was delivered to the rooftop garden of the Kaapelitehdas. In advance a leaflet with information on how to activate and apply biochar was distributed to one of the coordinators of the rooftop garden, who forwarded it to the gardening community. The gardeners were free to decide how they wished to apply the biochar and for what purposes. In addition, one of the garden boxes was reserved to do a test on how native pollinators attract plant fair in soils with and without biochar. 10L of activated biochar (with nettle tea) was mixed in one half of the soil and the plants were sold from Hyötykasviyhdistys (the association for useful plants).

29-5-23 Biochar distribution at Jätkäsaari community gardens.

200L of biochar delivered to the Jätkäsaari community garden was free to use by the gardeners in their planter boxes. In addition, one comparative experiment using the same plants and compost, but with different ratios of biochar in each box was done, as well as a comparative experiment making a mushroom bed with and without biochar

30-5-23: Biochar application talkoot Rinnekodit inner courtyard

The biochar application was part of a larger event to kick-off Rinnekodit's project to convert the inner courtyard into a therapeutic garden. Adding biochar to 6 pre-existing garden boxes, installing a new garden box with annual flowers, amending soil around already present berry bushes, adding biochar to a planting area next to a sidewalk, and donating and constructing a planter box filled with compost and biochar to a neighboring elderly home. The biochar was not activated in this location.

6-9-23 Biochar tour

The Biochar Tour was organised together with one of the garden coordinators at the Lapinlahden Lähde community garden. The goal of the tour was twofold: 1) to inform the participating citizens of the citizen engagement trials on the larger scope of the project, and 2) to bring in members from the steering team to facilitate knowledge exchange between professional experts and citizens. The tour consisted of three parts: first a presentation on the trials together with the City of Helsinki/KYMP, the various citizen engagement trials, and on the specific trials in the Lapinlahden Lähde community garden; second an exhibition of 'biochar modules' showcasing conceptual respresentations of the project as a whole, as well distribution of 'Helsinki-hiili', biochar made from the wood chips experimental feedstock; and third a tour in the garden itself where the trials shown, the conductivity of the soil(?) was measured with a ...device, and an open discussion on the experience with biochar.

12/26-10-23 Exhibition of biochar modules

To promote the project in an engaging way amongst citizens and other stakeholders, a small-scale exhibition module was developed. These modules contain conceptual representations of some of the biochar experiments conducted in Helsinki, visualizations of the concept of the project, the potential of biochar in urban environments, the utility of biochar in soils, and samples of the feedstocks. In addition, the exhibition modules can be complimented with the distribution of biochar in the 3L bags containing woodchip biochar from one of the experimental feedstocks. From 12 to 26 October 2023, the 'Biochar Modules' were exhibited at Aalto University department of Design and from 8. December to 15. January at the Heelsinki Urban Environment building. Further action is being taken to also display them in public spaces, such as the Helsinki Oodi Library and the Helsinki Design Museum.

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