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Climate benefits and environmental challenges related to urban food systems

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Contents

1 Climate benefits

In a short literature review, we have collected available knowledge on the potential benefits of urban agriculture, as part of local food systems, on climate change mitigation and adaptation. The effects of urban agriculture on climate change mitigation and adaptation depend on the type of agricultural practice (e.g. in greenhouses, in soil, in artificial substrates used resources) and the difference with previous land use (e.g. leading to an increase or decrease of sealed soil surface and green areas). Specific types of urban agriculture can alter the urban environment and in this way influence climate adaptation, or contribute to mitigation in case the production can be realized with lower energy inputs due to opportunities offered by the urban system.

1.1 Mitigation to climate change

The contribution to mitigation of climate change is assessed for two potential mechanisms:

- A reduction in energy use for the production of food, compared to production in rural areas;
- Reduced use of energy as a result of reduced transport kilometers between production and consumption location.

The climate benefits and business opportunities generated by these mechanisms are summarized in the text box below, and discussed in the text.

Climate benefits

- The use of local resources leads to reduced energy demand
- Locally produced food does not automatically lead to a decrease of 'food-kilometers', and transport results only in a small contribution to the total CO2-emission of food production

Business opportunities

- Renewable energy production in/for greenhouses
- Employing local sources of heat and nutrients
- Reduce food kilometres of consumers through new logistic models, like foodlogica.com (e-trikes)
- Stimulate the production of specific food, requiring less energy input

1.1.1 Sharing wastewater

In a city many different activities take place; some produce heat, waste or by-products that can be useful for agricultural production. Introducing agriculture as a new activity in urban areas gives opportunities to close or decrease energy, water and/or nutrient cycles.

Urban waste water is in European cities collected in the sewerage system and transported to a wastewater treatment plant. Human excrements and urine contain a lot of nutrients

that can be used to improve crop harvest as a substitute for mineral fertilizers (Wahab et. al, 2010). Substantial amounts of plant nutrients and organic matter are present in sewage, household waste and waste from food processing industries (Skjelhaugen, 1999). However, culture, regulations and especially health concerns prevent the reuse of human excrements in agriculture (Refsgaard et.al, 2005). Besides these barriers, the household waste water is contaminated in the sewerage system with other pollutants (organic materials and heavy metals) from, for example, rain water run-off and drainage. However, at least in the Netherlands, many municipalities are separating rainwater drainage and waste water transport. Closing the nutrient cycle by reuse for e.g. agricultural production systems in urban areas requires different systems for wastewater collection, distribution and treatment than currently available in most western cities. Only on a small scale and with an experimental status this might be realistic on the short term.

Fresh water for urban agriculture can be withdrawn from multiple sources in the city: ground water, drainage water, surface water, drinking water, rain water and/or (treated) waste water (Van Oostrom et.al., 2010). Many of these sources are also available in rural areas. Small water amounts for high value crops can be withdrawn from rain water collected at roofs or even drinking water (relatively expensive). A study in South-Korea showed that collected rainwater from roofs can meet drinking water standards, especially when the first flush was diverted (Lee et.al., 2012). A small scale study showed that there were no alarming concentrations of nutrients and/or micro- and macroparameters in the drainage water from roofs in several residential areas in the city of Utrecht, although some water quality norms were exceeded (Buma and Garming, 2007).

1.1.2 Organic waste management

Using organic waste streams resulting from urban agriculture can generate climate benefits, e.g. through biodigestion. Through the biodigestion of waste streams from urban agriculture (manure and crop residues), biogas, electricity and heat can be produced for residential areas and office buildings. An example is the Polderwijk in the town Zeewolde in The Netherlands, where manure from an urban farm is co-digested with waste streams from a food processing industry and with residues from roadside clearing. The biogas is used to supply 3000 houses in the Polderwijk with heat and electricty, reducing 50% of the CO2 emissions compared to a conventional energy provision from fuel fossils (Veen, Breman, & Jansma, 2012).

Source: www.essent.nl

As a resource for urban agriculture, organic waste can be used for soil fertilization, animal feeding and energy production (Van Veenhuizen, 2006) (Anastasiou, 2014). Urban areas

generate large quantities of organic residuals that can be used as soil amendments or independent substrates. The local food enterprise 'RotterZwam' (www.rotterzwam.nl) grows fungi on substrates of coffee grounds. After the use of the substrate, enzyms are extracted from the fungi, and the residue is composted. Land application of soil amendments derived from organic waste can accelerate C storage (see also 2.1) and can replace synthetic fertilizers (Brown, Miltner, & Cogger, 2012).

The EU-funded FertiPlus project (www.fertiplus.eu) developed technologies and strategies to convert urban and farm waste into compost, biochar and combinations of organic amendments with biochar. Experiments on peri-urban vineyards in Italy showed that compost blended with biochar reduced greenhouse gas emissions, and increased the supply of nitrogen (FertiPlus, 2014). It should be noted however that the organic waste streams available in urban areas are mostly rich in nitrogen (N) and phosporus (P), but may lack potassium (K) or certain micronutrients (e.g. (Wang et al., 2008)).

Climate benefits

- Organic waste streams from cities and from UA can be used for biogas production, thus reducing GHG emissions from fossil fuels.
- Compost and biochar from urban and farm waste may reduce GHG emissions from urban agriculture.

Business opportunities

- Organic waste streams from cities can be reused as a resource for urban agriculture in the form of organic fertilizer, animal feedstock or soil amendment.
- Advisory services for the blending of organic waste components for the applications mentioned in the previous point. An example is 'Tacoma Grow (TAGRO)', an environmental service of the City of Tacoma, US, selling blended biosolids and gardening components for landscaping and vegetable gardens*.

* http://www.cityoftacoma.org/cms/One.aspx?portalId=169&pageId=16884

1.1.3 Connecting energy streams

Urban areas offer potential for various forms of renewable energy technology, like solar energy (PV and heat panels), cold-heat storage and biomass. These technologies may offer alternative energy supplies for heating, lighting and machinery in greenhouses and farms in office buildings, and therefore reduce the need to produce energy from fossil fuels. Industrial waste heat can be used to warm buildings in urban areas, but usually there is no demand for this heat in summer time. Absorption heat pumps and absorption coolers can utilise this heat to heat and cool buildings or greenhouses (Salcedo-Rahola, Baldiri, Van Oppen, Peter, Mulder, 2009). The technology would offer possibilities to warm greenhouses in urban areas, or other closed environments used for urban farming, like offices (e.g. the urban farming project 'De Schilde' in The Hague, The Netherlands; www.stadslandbouwdenhaag.nl).

Figure 1 Impression of urban farming in office building: De Schilde, The Hague, The Netherlands. Sources: http://stadslandbouwdenhaag.nl and Tycho Vermeulen, Wageningen University.

Climate benefits

- The urban environment offers opportunities to use Renewable Energy Technology for energy supply to urban farms, reducing GHG emissions from the use of fossil fuel

Business opportunities

- The use of renewable energy and residual heat for urban agriculture may reduce production costs and increase margins.

1.1.4 Reducing transport distances between food production and consumption

Urban agriculture offers possibilities to reduce the transport distances between production and consumption. Shorter pathways between producer and consumer might reduce greenhouse gas emissions related to transport (Sukkel et al., 2010). Scheer et al. (2011) divided the agro-logistic chain in 3 parts: producer -processing company – retail/distribution centre – shop. A fourth part could be added to this list, the transport way from shops to consumers (households or public facilities such as restaurants or cantines).
The literature shows both positive (e.g. Demmeler & Heißenhuber 2004, Blanke & Burdick 2005) and negative outcomes on the impacts of transportation and energy efficiency in shortened food chains. The latter refer to shortcomings in structural logistics optimization (i.e. small vehicles, low volumes, many individual routes, points of sale) (Schlich & Fleissner 2005, Coley et al. 2009, in:(Zasada et al., 2014). Scheer et al. (2011) explain that locally produced food is not automatically leading to a decrease of 'food-kilometers'. Finally, Scheer et.al. conclude with the notion that transport results only in a small contribution to the total CO_2-emission of food production. In two other studies the contribution of transport was only 1,49% (European pigs) or 0,98% (Dutch tomatoes) to the total CO_2-emission. Seasonal outdoor products and glasshouse products can be complementary in time, which results in

opposing transport directions between markets during the year. Also, season differences between the northern and southern hemisphere result in complementary harvests during the year. However, transport of these products costs less energy than storing (and cooling) local products during longer periods (Scheer et.al., 2011).

The EU-funded FOODMETRES project sought strategies to shorten food supply chains in metropolitan areas, amongst others by reducing the actual distance that food travels (www.foodmetres.eu). In an expert survey, the impacts on environment, economy and society and culture were assessed for eight types of regional and short food chains providing food for urban populations (Figure 2). Food chains of the type 'urban gardening' (both for private consumption and for commercial purposes) performed best in the reduction of transport distance according to the experts. Efficient resource use and reduction of GHG emissions scored best for chains of the type 'Agroparks and Metropolitan Food Clusters', in accordance with their design to obtain an overall chain sustainability (Zasada et al., 2014).

a) Urban gardening for self-supply / private consumption (subsistence): food production in the urban setting for own consumption.
Relation type: Consumer as (co)-producer
Subtypes: allotments, community gardens, self-harvesting gardens (offered by a farmer).

b) Urban gardening for commercial purposes: profit-oriented food production in the urban setting.
Relation type: business-to-business.

c) Consumer-producer-partnerships/cooperatives: network or association of individual consumers who have decided to support one or more local farms and/or food producers/processors.
Relation type: Consumer-producer-partnerships/cooperatives
Subtypes: Community Supported Agriculture (CSA), Ethical Purchasing Groups (EPG), Solidarity Purchasing Groups (SPG), and food-coops.

d) Direct sales/marketing on-farm to the private consumer: farmers sell directly their products on their farm.
Relation type: business-to-consumer.
Subtypes: farm shops and stands, pick-your-own.

e) Direct sales/marketing off-farm to the private consumer: direct selling of products from a farm on the market in the urban area.
Relation type: business-to-consumer.
Subtypes: farmers and weekly markets, market halls, home delivery….

f) Sale to regional enterprises like retail or hospitality industry (e.g. restaurants, hotels, pubs), which provide food for urban population.
Relation type: business-to-business

g) Sale to public procurement and public catering: Preparation and delivery of meals for collective consumers in the urban area. Include intermediaries like wholesale.
Relation type: business-to-business

h) AgroParks / Metropolitan Food Clusters (MFC): "spatially clustered agro-food systems in which several primary producers and suppliers, processors and/or distributors cooperate to achieve high-quality sustainable agro-food production…" MFC are oriented towards the markets in the Metropolitan Region providing food for the urban population, but also to the world market.
Relation type: business-to-business

Figure 2 Food chain types examined in the FOODMETRES project. Source: (Zasada et al., 2014)

Climate benefits

- Urban agriculture does not necessarily reduce transport distances in food supply chains, although it can for specific types of food supply chains.
- GHG emissions from transport represent a small share of total GHG emissions from food production.

Business opportunities

- The energy efficiency of local food systems can be improved by resolving shortcomings in structural logistics optimization (small vehicles, low volumes, many individual routes, points of sale and storage, cooling).

1.1.5 Influencing consumers' diet

The availability of refined, processed and energy-dense foods in urban areas with the 'nutrition transition' in recent decades has stimulated the consumption of food high in sugar and fat (McMichael, Powles, Butler, & Uauy, 2007). Health problems are often reported in poorer areas of the city due to inadequate diets (Born & Purcell, 2006). In response to these developments, urban agriculture is reported in the literature to empower citizens to influence sources of food production and to encourage healthier lifestyle choices (www.cbobook.org). Such encouragement would come from a larger diversity in food products that respect the local food culture, characteristics of the place of origin reflected in the food products, and personal interactions between producer and consumer ('face to face') (Zasada et al., 2014). 'Buy local' campaigns promote local food a.o. for its better taste and increased health effects (Born & Purcell, 2006).

Climate benefits/impacts

- The availability of local food is not convincingly reported to influence the diet of city inhabitants or to encourage healthier lifestyle choices, that would empower citizens to create climate-friendly (green-blue) urban environments.
- Therefore climate benefits from presumed effects on consumers' diets cannot be inferred.

Business opportunities

- Health concerns may encourage urban inhabitants to regreen their living environment. This motivation may be used in business models for local food enterprises.

1.1.6 Carbon cycling

Green spaces in urban areas managed for urban agriculture can be used to increase the overall carbon budget for urban ecosystems (Lal, 2012). Crops, agroforestry systems, peri-urban forestry and wetlands in urban agricultural systems may be used to sequester carbon (e.g. (Tratalos, Fuller, Warren, Davies, & Gaston, 2007) (RUAF Foundation, 2013), but

quantitative findings on the effects in the literature are sparse. The contributions that are reported are small (e.g. 0.2% of total city emissions in Manila, Lebel et al., 2007, in: (Pearson, Pearson, & Pearson, 2010), and other forms of urban agriculture may be net emitters due to methane emissions from livestock and manure (Pearson et al., 2010). Yet there are also reports on significant contributions. Kulak et al. (2013) assessed the potential reduction in greenhouse gas emissions related to the production and supply of food. An assessment focused on an urban farm project of 2.83 ha study in Sutton (UK) showed that greenhouse gas emissions could be reduced up to 34 t CO_2eq per ha per year; which exceeds carbon sequestration rates for conventional urban green space projects, such as parks and forests. Long-term experiments in Tacoma, Washington showed that 19-81% of added C through soil amendments derived from organic residuals persisted 3-18 years after addition. Inferred from these findings, the application of residuals to pervious surfaces in the city would result in an annual C sequestration of 0.22 Mg C ha-1 y-1 (Brown et al., 2012), corresponding to 0.81 t CO_2eq per ha per year.

Climate benefits

- Land-based urban agriculture in the open air can be used to increase the overall carbon budget for urban ecosystems, but reports on net effects are ambiguous.

Business opportunities

- Urban agro-ecosystems with proven impacts on climate mitigation may be used in carbon-offset schemes.

1.2 Adaptation to climate change

The contribution of urban agriculture to climate adaptation is assessed for two potential mechanisms:

- Effects of land use change to agriculture on soil and soil surface properties that alter water regulation;
- Effects of land use change to agriculture on soil and soil surface properties that influence urban local temperature.

New urban agricultural activities can change land cover depending on the type of urban agriculture. For example, a vacant plot or park can be transformed into an agricultural field ('green to green') or glasshouse ('green to grey'). Roofs or paved surfaces can be transformed to green roofs or agricultural fields ('grey to green') or be replaced by a glasshouse ('grey to grey'). Such conversions may be considered against the background of climate adaptation strategies for European cities, which are currently promoted by the European Commission through various policy instruments. The main instruments are the Research and Innovation policy on Nature-Based Solutions, the 7th Environmental Action Plan, the Communication on Green Infrastructure, and the Thematic Strategy on the Urban Environment.

Climate benefits

- 'Open air' forms of urban agriculture increase the area of green and blue spaces in the urban environment, thereby reducing its vulnerability to flooding, water and heat stress.

Business opportunities

- A pool of various local, small-scale measures is recommended for climate-proofing cities (Rovers et al., 2014). Urban agriculture could be one of these.
- The conversion of sealed spaces in urban areas to green and blue spaces will be encouraged by EU strategies aimed at regreening and renaturing cities, and increasing green infrastructure. This offers opportunities to urban enterprises providing green and blue spaces.
- The economic value of green and blue spaces in urban areas in use for residential and commercial purposes will increase due to the expected increases of heat stress under climate change.

1.2.1 Increasing water infiltration and retention

Paved soils generate higher water runoff during intensive rainfall than unpaved soils. For example, Levy (2009) calculated that community gardens have a 19% lower runoff rate than vacant lots in Philadelphia. Knizhnik (2012) assumes the runoff coefficients to be 0,55 for vacant lots and 0,08 for urban agriculture. This means an average yearly reduction of rainfall runoff of 85% when vacant lots are turned into community gardens.

Urban unpaved soils are usually more compacted than rural soils because of building and/or demolition activities and (heavy) vehicles. Often, the top layer is the most compacted layer (EPA, 2011). For both retaining rainfall and to support urban agriculture compacted soils should be amended. Gregory et.al. (2006) measured the difference in infiltration capacity of sandy soils in Florida. They found that compaction treatments and/or construction activities reduced the infiltration capacity between 70 to 99% (although there was a wide variability). Kelling and Peterson (1975) have measured the infiltration at nine urban lawns. Their results of the infiltration measurements show that the presence of textural and compaction discontinuities within the soil profile, formed during building and lawn construction, was probably the greatest factor affecting infiltration. Where these discontinuities were distinct, water intake was reduced to about 35% of that for a lawn with an undisturbed profile.

Unsealed soils in urban areas can be used to temporarily store water and to reduce peak discharges from surface runoff to the urban drainage system (Illgen, 2011). Dirven et al. (2011) propose a series of technical measures to increase the retention and storage capacity in towns in The Netherlands. Some of these measures can be combined with the use of space in urban areas for agriculture, like rain barrels or cisterns for fresh water supply, retention basins, subsoil drainage systems and artificial infiltration in injection holes. Ideally, smart-drains would be included in such systems to separate the first flush of stormflow, that

has the largest loads of pollutants. Other practices to increase the retention and reuse of water in urban areas for the benefit of urban agrculture include bioretention, the reduction of impervious area, permeable pavement, wetlands and green roofs (Claessens, Schram-Bijkerk, Dirven-van Breemen, Otte, & van Wijnen, 2014), and the disconnection of contributing area from sealed surfaces from the sewage system. Composting green spaces in urban areas is an example of bioretention. Plots with amended soil with compost turned out to infiltrate 1,5 to 10,5 times more rainwater than plots that were not amended (Pit et.al, 1999). Cogger (2013) concludes that in the literature the positive effect of organic components on improvement of the infiltration capacity is clear. The effect of organic amendments on plant available water is less clear, this means that much of the infiltrated water is not available to the plants.

Green roofs can be used to control storm water runoff in urban areas by attenuating peak flow and reducing runoff volumes. Carson et.al. (2013) examined three different kinds of green roofs in New York City. These roofs have a substrate depth between 32 and 100 mm. Between June 2011 and June 2012 these roofs retained between 36% and 61% of the total rainfall. Rainfall attenuation during individual storm events have a broad range for each roof, because the relative attenuation is dependent on the storm size, see figure 1.

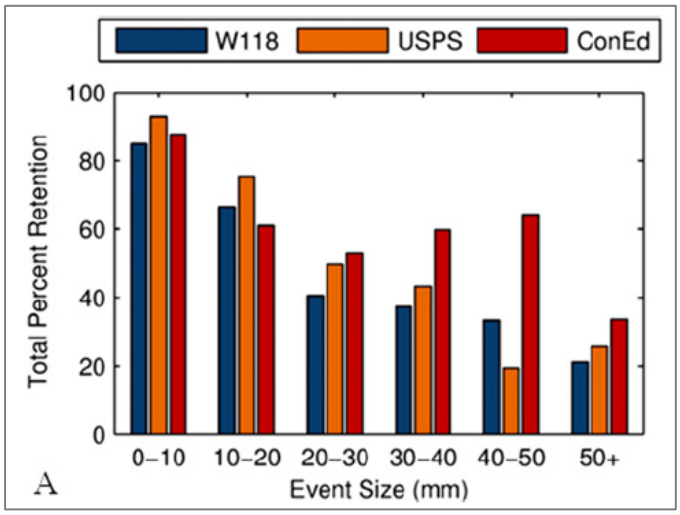

Figure 3 Retention rate (vertical axis) for three green roofs (W118, USPS and ConEd) in New York City depending on the amount of rainfall during a storm event size (horizontal axis) (Carson et.al. 2013). The percentage retention is calculated as (rain fall during the event – roof discharge) / rain fall.

Berndtsson (2006) has done a review on experiments with rain fall run off from green roofs. The table below shows the results for long term averages as well for peak run off reduction.

Table 1. Overview of the retention of green roofs during the study period (long term average) and during rain fall events (short term reduction). (Berndtsson, 2010)

Reference	Rainfall retained in green roofs, average during study period (%)	Rainfall retained in green roofs, range for studied events (%)	Length of study period
Bengtsson et al. (2005)	46	–	17 months
VanWoert et al. (2005)	60.6	–	15 months
DeNardo et al. (2005)	45	19–98	2 months
Moran et al. (2005)	63 (roof 1)	–	18 months
	55 (roof 2)	–	15 months
Carter and Rasmussen (2006)	78	39–100	13 months
Monterusso et al. (2004)	49	–	4 rainfall events
Bliss et al. (2009)	–	5–70	6 months

Khnizek (2013) cites from a study of Dunnett et al. (2008) in which they point out that there aren't many studies on green roofs that take into account the difference in the vegetation characteristics. The results of their study showed a relation between the vegetation type and the runoff reduction. "The results suggested that plant structure, such as size, leaf size and angle of branch would be more important for capture of water rather than how much they grow". Khnizek (2013) adds that "it can therefore be theorized that since most plants used in UA are much larger with broader leaf sizes than sedum species, there would be a strong advantage to UA on vegetated roofs as an alternative to largely non-native sedums."

In the review study of Berndtsson (2010) the main conclusions about the effect of the vegetation on runoff are "that many studies agree that it is the depth and type of substrate that has the major influence on green roof water retention capacity and not the vegetation type and cover (Dunnett et al., 2008b; Monterusso et al., 2004; VanWoert et al., 2005). However, it is also found that the vegetation plays a role in water retention and it is mostly pronounced in periods with low water availability and higher temperatures and negligible in winter (when the water availability is high) (Dunnett et al., 2008b; Steusloff, 1998; Wolf and Lundholm, 2008)."

Compost filter socks are mesh tubes filled with composted material that is placed perpendicular to sheet-flow runoff from paved surfaces in urban areas. The compost filter sock provides a three-dimensional filter that retains sediment and pollutants while allowing the cleaned water to flow through (US-EPA, Sormwater Best Management Practices[1]). Studies from (L. B. Faucette et al., 2009) and (L. Faucette & Risse, 2004) showed that compost filter socks can filter pollutants in urban runoff, like coliform bacteria, metals (but not Cr) and petroleum hydrocarbons. Removal efficiencies were found of 75% for coliform bacteria, 37-72% for heavy metals, and 43-99% for petroleum hydrocarbons. Compost filter socks were shown to perform similarly to or better than grass filter strips and bioretention systems, and therefore could replace the latter where constraints on land area exist.

[1] http://water.epa.gov/polwaste/npdes/swbmp/Compost-Filter-Socks.cfm

Figure 4 Installation of filter socks in a road ditch, Indiana, US. Source: Filtrexx International, LLC.

Climate benefits

- Urban agriculture in non-sealed spaces and on roofs contributes to climate adaptation by improving the capacity of the urban surface to infiltrate, buffer and retain rainfall and surface runoff.

Business opportunities

- Economic benefits may be generated from allocating open spaces in urban areas with soils suitable to grow high-value crops to urban agriculture, instead of other types of green or blue surface cover.
- Construction services for green roofs and compost filter socks

1.2.2 Reducing urban heat island effect

Due to absorption of solar radiation by building materials, reduced evapo(transpi)ration and the emission of heat related to the use of energy ('anthropogenic heat'), the temperature in cities is higher than the surrounding environment.: the 'Urban Heat Island (UHI)' effect. Increased temperatures in cities can inhibit photosynthesis and decrease crop yields. Also, vapour pressure deficits can be high in urban areas, causing plants to use more water. This could lead to increased moisture stress and decreased photosynthesis (Arnfield, 2003), (Schneider, 2013). Maximum temperature differences between cities and surrounding areas up till 12 °C are reported in the international literature, mentioning the largest differences during the night (Rovers, Bosch, & Albers, 2014). The recent study Climate Proof Cities for The Netherlands (Rovers et al., 2014) reports maximum UHI intensities of Dutch cities between 3 and more than 7 °C. The emission of heat by industry, households, buildings, traffic, humans and animals represents an important share of the UHI effect: ca 10% was reported for the city of Rotterdam (Rovers et al., 2014).

Giridharan and Kolokotroni (2009) studied the UHI-effect in London during the winter period. The maximum UHI effect was 9 degrees Celsius in the core area. Their findings of

summer and winter research suggest that winter UHI is largely a macro level or regional level phenomenon while summer UHI is largely a micro level phenomenon. Klok et al (2012) found that, during a hot period in 2006, in the 73 largest cities in the Netherlands, the surface day-temperature is on average 2.9 °C higher than in the surrounding rural area and during the night the difference is 2.4 °C.

The fractions of builit-up and paved surfaces and the fraction of green, evapotranspiring surfaces are the most determining factors for the spatial variation of the UHI effect within urban areas (Rovers et al., 2014). Klok et al (2012) report that a decrease of sealed urban surface leads to a reduction of the surface heat-island effect of 1.2 °C during the night and 2.0 °C during the day. A study in Rotterdam showed that an increase of 10% in greenery results in a temperature reduction of 1 °C (Klok et al., 2010, in (Claessens et al., 2014). Zhou and Shepherd (2009) modeled possible UHI mitigation measures (greening and/or increasing surface albedo) in Atlanta. Doubling the shade factor and evapotranspiration resulted in a reduction of the maximum temperature with 7 degrees Celsius. Increasing albedo with a factor 3 resulted only in a reduction of 1 to 2 degrees Celsius. Corburn (2009) studied three measures to mitigate the urban heat island effect: planting trees in open spaces or along streets, blanketing rooftops with vegetation (living roofs/green roofs) and increasing the reflectivity of built surfaces. The input from local planners was used to determine which measures could fit in different areas in the city. According to local stakeholders, the planting of street trees was more favorable option than increasing the albedo.

Figure 5 Green, evapotranspiring surfaces around urban areas.

Urban farming increases the vegetation cover in and around cities (e.g. Figure 5), and can provide a cooling mechanism by increasing the evapotranspiration. It can therefore help to reduce the urban heat island effect in the growing season, and the need for energy-intensive

air-conditioning and ventilation. An important requirement for the cooling effect from green spaces provided by urban agriculture is the availability of water (Eriksen-Hamel & Danso, 2010) (Rovers et al., 2014).

Climate benefits

- 'Open air' forms of urban agriculture can reduce the Urban Heat Island effect by reducing the area of paved surface, and by providing a cooling mechanism through increased evpotranspiration.
- As a result, GHG emissions from fossil fuel use for air conditioning and ventilation can be reduced.

Business opportunities

- Smart siting of farms in urban centres can be used in city planning to generate economic benefits from avoided costs for health damage from heat stress.

2 Some environmental challenges related to urban agriculture

> *"Planning to grow urban food places leads to essential questions about soil, water, terrain, and climate. How does nature work here? What will enhance the health of the soil? How might the built environment become productive and photosynthetic, harvesting more water, energy and nutrients than it consumes?"*
>
> William McDonough, theguardian.com, Wednesday 23 April 2014

The abiotic urban environment offers various resources for urban agriculture in the form of soils, water, space, atmosphere and energy, carried by radiative heat and solar radiation (
Figure 5). At the same time, there are environmental growth-limiting or reducing factors that affect production in urban and peri-urban agriculture, such as the pollution of soil, water and atmosphere or shade from buildings or even trees (e.g. (Wortman & Lovell, 2013) (Eriksen-Hamel & Danso, 2010)). The availability of water for urban agriculture, nutrients from organic waste streams and wastewater, and residual heat were already briefly discussed in chapter 1. Below, some further issues are presented that may be relevant to identify business models for Community Food Enterprises. There is a huge literature on each of these topics. We do not pretend to give a complete overview of available knowledge and ongoing initiatives. Websites with more in-depth information on the topic are listed at the end of the report.

Figure 6 Overview of environmental resources, opportunities and barriers for urban agriculture.

2.1 Soil health

The capacity of urban soils to provide sustainable and safe food production can be judged from the soil health condition in urban areas. Soil health is defined here as a state of composite quality of biological, chemical and physical properties of the soil as they relate to crop productivity, following (Knight et al., 2013). Studies in the US have shown that urban development is taking place on the most fertile and productive land (e.g. (Imhoff, 2004; Nizeyiamana G. Peterson, M. Imhoff, H. Sinclair, S. Waltman, D. Reed-Margetan, E. Levine, and J. & Russo, 2001). Yet, there are often concerns about the poor conditions of urban soils for food production. The reasons are lower plant nutrient and organic matter content, a lack of structural and functional complexity of the food web, potential contamination due to previous commercial and industrial use, and low aeration, porosity and drainage due to compaction by heavy construction equipment (Cheng & Grewal, 2009) (US-EPA, 2011). Based on field experiments in vacant lots in Cleveland, Ohio, (Knight et al., 2013) concluded that properties like active carbon, microbial biomass N, various nematode community parameters, clay content and soil organic matter have potential for predicting the quality of urban soils for crop productivity.

Soil organic matter is essential for land-based urban agriculture, since it provides nutrients to crops and feedstock, and enhances soil moisture retention. The amount of soil organic carbon (SOC) stored in urban soils is highly variable in space and time, and depends among others on soil parent material and land use (Lorenz & Lal, 2009). It will also vary based on the type of vegetative cover, maintenance history, and, for new developments, regulations and practices for topsoil restoration (Brown et al., 2012). Some studies on C stocks in urban soils use an environmental gradient approach from urban centers outwards, in the context of urban sprawl. In general, these studies found increased C pools in urban soils compared to rural areas, due to more intensive management (increased water and nutrient input) and direct impacts of proximity to urban areas, including higher temperatures and increased N deposition (Brown et al., 2012).

Lorenz & Lal (2009) report values for the SOC pool in urban soils ranging between 16 and 232 $Mg.ha^{-1}$ up to 0.3 m depth, and between 15 and 285 $Mg.ha^{-1}$ in 1-m depth. Edmondson et al. (2014) found an average SOC storage of 99 $Mg.ha^{-1}$ (to 20 cm depth) in greenspaces of domestic gardens and non-domestic greenspaces across a typical mid-sized U.K. city (Leicester, 73 km^2, 56% greenspace), a value comparable to the SOC storage of arable land around the city. The largest SOC stocks were found in domestic gardens with trees. For comparison, soil organic carbon stocks in European agricultural soils, as estimated from a recent pan-European assessment with the CENTURY model (Lugato et al., 2014, in: (Morari, Panagos, & Bampa, 2015)), range from lower than 40 $Mg.ha^{-1}$ in the Mediterranean region to between 80 and 250 Mg.ha-1 in north-eastern Europe. According to this model assessment, hotspot locations of SOC include agricultural peat soils in northern Europe, with values >250 $Mg.ha^{-1}$.

Improving soil health for agricultural use in urban areas may be more demanding than for other types of use in order to achieve the specific characteristics needed to grow certain crops. (US-EPA, 2011) distinguish physical, chemical and biological reconditioning, to be performed in that order. Physical reconditioning of urban soils aims at improving drainage

characteristics, soil structure, and mitigating compaction. An example is the raking out of debris often accumulated in urban soils (Figure 6). All are important for urban agriculture, e.g. for enabling root penetration and water holding capacity. Chemical and biological soil reconditioning techniques to make urban soils suitable for agriculture include adding compost and tilling, altering the soil chemistry to achive desired parameters (e.g. pH), and manipulating soil organism populations (US-EPA, 2011). The supply of organic waste (as compost) in urban agriculture can lead to surpluses in N and P (Khai et al., 2007, in (Eriksen-Hamel & Danso, 2010), (Wang et al., 2008). This can cause environmental problems to surface and groundwater in urban areas, but is usually not a constraint to crop production. However, as already mentioned in chapter 1, in case the organic waste is of a limited variety, amendments may lack potassium or micro-nutrients. In these cases there is a need for urban farmers to develop balanced nutrient management plans (Eriksen-Hamel & Danso, 2010).

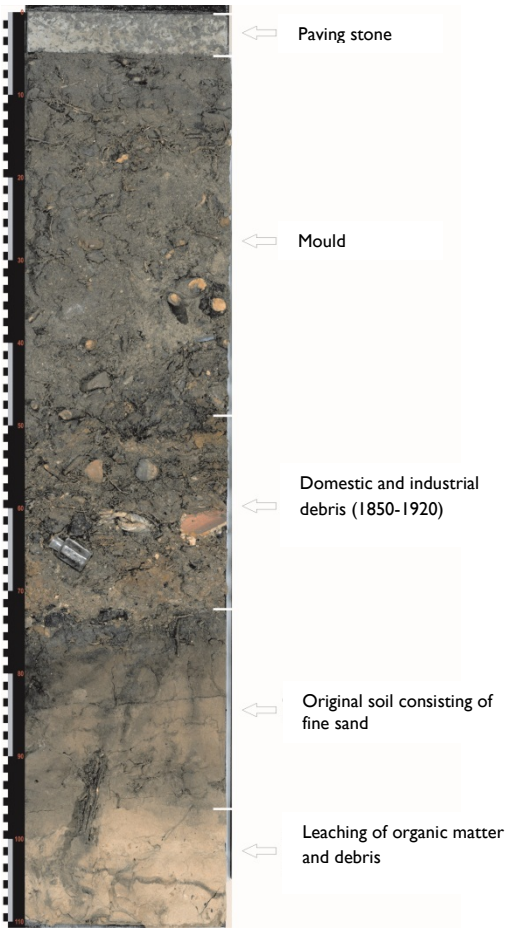

Figure 7 Soil profile in the Liebergen neighbourhood in the city of Hilversum, Netherlands. Source: Stephan Mantel, ISRIC World Soil Information.

Environmental challenges

- Identifying 'healthy soils' for agriculture in urban areas. Soil health for urban agriculture can be inferred from measurable soil properties, and improved by soil reconditioning techniques.
- Optimizing the spatial allocation of urban farms in places with high inherent soil nutrient stocks. Organic matter and carbon contents of urban soils are highly variable in space and time, and not necessarily lower than in surrounding rural land.

Business opportunities

- The urban environment may offer locally available moisture and soil amendments like composted food scraps, manure, approved biosolids, and lawn-based mulches that can be used to improve soil quality, fertility and tilth, and hence the agricultural production capacity of urban soils.
- The use of municipal waste products to improve soil health can reduce processing and transport costs associated with disposal. This may offer a value proposition to urban agriculturalists as buyers of municipal waste.

2.2 Solar radiation

Some urban areas are reported in the literature to receive less solar radiation than rural areas due to the increased reflectance of radiation away from the ground, as a result of increases in air pollutants and aerosols over urban areas (Alpert and Kishcha, 2008, in: (Eriksen-Hamel & Danso, 2010). However, the impacts of solar dimming on the potential production of crops in urban areas are difficult to predict. The reflection of short-wave radiation from buildings and paved surfaces creates heat loads, hindering the photosynthesis of plants (Schneider, 2013), and depletes soil moisture compared to situations where only direct incoming irradiance is measured (Eriksen-Hamel & Danso, 2010).
Shade from buildings (causing decreased solar radiations on plants) is likely to reduce plant productivity if radiative heat load is also low, like in wet humid climates (Wang et al., 1994, in (Eriksen-Hamel & Danso, 2010)). Possible remedies to reduced direct solar radiation in cities include shade-adapted plants, sunny locations or locations with artificial light (e.g. office buildings), or targeted nutrition. Solutions to decrease the requirement of artificial lightning in vertical farming include adapted building designs to optimize solar irradiation, or VertiCrop systems, that use moving conveyors to expose plants to either natural or artificial light (www.verticrop.com). Examples include the VerticCrop System to grow lettuce crops for animals at Paignton Zoo in Devon, England[2]. Another example is Philips' City Farming, a technique to perform multilayer farming in closed climate controlled cells[3].

[2] http://www.biaza.org.uk/plant-care-management/awards-and-commendations/verticrop/
[3] http://www.lighting.philips.com/main/application_areas/horticultural/cityfarming/philips-city-farming.wpd

Figure 8 Sunny spaces in the city. Source: Hop & Hiemstra, 2013, PPO (c).

Environmental challenges

- Reduced direct solar radiation at locations in urban areas may reduce plant productivity
- Reflection of solar radiation from biuldings and paved surfaces also negatively influences plant growth due to increased heat loads.

Business opportunities

- Using climate-controlled multilayer cultivation and artificial lighting (e.g. LED lighting) offers the possibility to reduce costs, increase production and grow more efficiently.

2.3 Production space

One of the motives for urban and peri-urban agriculture is to provide sufficient food for the increasing human population in urban centers, realizing that the availability of suitable land for land-based agriculture outisde cities is decreasing (e.g. http://www.fao.org/urban-agriculture/en/), (McBratney, Field, & Koch, 2014), (Lin, 2014), (Germer et al., 2011). Urban areas offer space for food production on rooftops, in vacant lots, in vacant buildings and in the underground. Apart from the space provided, the proximity of technology and knowledge in cities supports hightech forms of urban agriculture, and the proximity to customers reduces the amount of food miles "from farm to floor". Another advantage is the proximity of water and energy sources (see chapter 1). An example of a commercial rooftop farm is the LokDepot aquaponics farm in Basel, Switzerland, where fish and

vegetables are grown, while the waste from the fish is used to feed the plants, and the plants are used to clean the water for the fish[4].

Vacant lots in urban areas often suffer from bad soil or climatic conditions as explained in previous sections. Skyfarming or vertical farming, i.e. farming in storeys in (existing or designed) buildings or greenhouses, is promoted as a solution to overcome constraints of environmental conditions in urban areas, since it would be largely environment independent (Despommier, 2011), (Germer et al., 2011). Hightech vertical farming includes the growth of crops (mostly horticultural), fish and cattle in multi-storey buildings in urban areas, using new technologies like rotating crop beds and Power LED lightning (Oskam, Lange, & Thissen, 2013). There are some examples of vertical farms (e.g. on www.verticalfarm.com), but most are in the conceptual stage. Examples from The Netherlands are the growth cabinets in office farm De Schilde (The Hague) and De Zuidkas, an imaginary office building of over 11,000 m² on the Zuidas tangent in Amsterdam (http://www.dezuidkas.nl/en/).

Underground farming is another option to exploit space in urban areas, by cultivating food in underground spaces or containers. The farm systems usually are hydroponics, aeroponics or air-ponics. Light is provided by growth lamps or daylighting systems (tubes) (wikipedia.org). An example is the Growing Underground project, a hydroponic farm beneath the London Underground's Northern Line, in a network of tunnels that were originally built as air-raid shelters during the Second World War (http://growing-underground.com/).

Environmental challenges

- Production space for agriculture in urban areas is small and scattered compared to peri-urban and rural areas, but becomes more interesting now that the latter are unlikely to meet the demand for agricultural products in the future.

Business opportunities

- The proximity of technology and knowledge to urban agricultural enterprises supports hightech forms of urban agriculture.

2.4 Soil contamination

Soils, water and atmosphere in urban areas may carry contaminants from past land uses, emissions from industry and traffic, or air deposition, that may be harmful to human health. There are many potential soil contaminants (e.g. lead, arsenic, mercury, cadmium, and polycyclic aromatic hydrocarbons). Lead (Pb) is the most often studied contaminant due to the elevated concentrations and its correlation to other urban contaminants (Wortman & Lovell, 2013). Soil concentrations of Pb in a natural soil are typically near 20 mg kg^{-1}, whereas a heavily contaminated urban soil may contain concentrations near 2000 mg kg^{-1}. The elevated concentrations of lead (Pb) and other contaminants are due to waste

[4] http://sustainablecitiescollective.com/david-thorpe/426096/worlds-first-commercial-rooftop-aquaponics-farm

incineration, coal and oil combustion, and the use of leaded gasoline and paints (Wortman & Lovell, 2013). Mitchell et al. (2014) analysed heavy metal concentrations in in soils from 54 community gardens in New York City, and found that in most gardens (78%), health-based guidelines were not exceeded. Experimental studies on soil contamination with lead and the uptake by vegetable crops in urban gardens in The Netherlands and the US showed that lead contents in the vegetable crops were below health-based thresholds for exposure (e.g. (Romkens & Rietra, 2010), Otte et al., 2012; (Anastasiou, 2014); (Wortman & Lovell, 2013)).

The use of organic waste in urban crop production may also cause contamination of urban soils and water resources. Urban organic waste can reach soils used for agriculture in various forms (Cofie, Adam-Bradford, & Drechsel, 2009) (Meuser, 2010):

- By the use of fresh waste from vegetable markets, restaurants and hotels, as well as food processing industries as feed for urban livestock
- Direct application of solid waste on and into the soil
- Mining of old waste dumps for application as fertiliser on farmland
- Application of animal manure such as poultry/pig manure and cow dung
- Direct application or human excreta or bio-solids to the soil
- Organised composting of SW or co-composting of SW with animal manure or human excreta

In the study of (Mitchell et al., 2014), contaminants were associated with visible debris and a lack of raised beds. Metals in compost derived from municipal waste may come from many sources: batteries, consumer electronics, ceramics, light bulbs, house dust and paint chips, used motor oils, plastics, and some inks and glass. High concentrations of these elements may impede plant growth, but the greatest concern is through their potential to directly harm childeren and animals through direct ingestion, to harm soil organisms, or to enter the food chain (Cofie et al., 2009).

There are several practices to reduce the potential for gardening-related exposures to soil contaminants ('healthy gardening practices'), such as gardening in raised beds, importing clean soil and compost for bed establishment, phytoremediation[5], and maintaining the soil pH at levels that minimize the plant uptake of heavy metals (Romkens & Rietra, 2010) and EPA (2014)[6]. Sheltered production methods have been used in urban agriculture to avoid contact with the soil and air in contaminated areas (e.g., greenhouses, indoor production, hydroponic growing mediums, etc.) (UrbanDesignLab, 2012). Also, the growing of non-food crops in sites in cities that are heavily contaminated may relieve some of the concerns for exposure to contaminants from air, soil and water resources. Such crops may include e.g. aromatic and medicinal herbs, flowers, fiber crops and biomaterials, or biofuels (UrbanDesignLab, 2012).

[5] For cleaning up soils contamonated with cadmium, zinc and copper; of limited value for lead.
[6] http://www.clu-in.org/ecotools/urbangardens.cfm

Environmental challenges

- Soils in urban areas with a commercial or industrial history may contain contaminants that can pose health risks when the soils are used for agriculture. Yet in many cases health-based thresholds for human exposure are not exceeded.
- The use of organic waste in urban agriculture may be another source of contamination of water and soil resources in urban areas.

Business opportunities

- Non-food horticulture by CFEs in contaminated sites could offer a value proposition to city governments as part of phytoremediation strategies and solutions for the storage and buffering of contaminated storm-water runoff.

3 Conclusions

The effects of urban agriculture on climate change mitigation and adaptation depend on the type of agricultural practice (e.g. in greenhouses, in soil, in artificial substrates used resources) and the difference with previous land use (e.g. leading to an increase or decrease of sealed soil surface and green areas). Specific types of urban agriculture can either alter the urban environment and in this way influence climate adaptation, or contribute to mitigation in case the production can be realized with lower energy inputs as a result of the specific characteristics of the urban system.

Climate mitigation
Contributions from urban agriculture to the mitigation of climate change work through two mechanisms:

1. A reduction in energy use for the production of food, compared to production in rural areas. Introducing agriculture as a new activity in urban areas might provide opportunities to close or decrease energy, water and/or nutrient cycles. Urban waste water contains a lot of nutrients that can be used as a substitute for mineral fertilizers.

   In order to benefit from urban waste water resources, infrastructure has to be altered. On the short term, this means that only on a small scale and with an experimental status this might be realistic. On the long term, and in new to develop areas, the opportunities will be bigger.

   In order to quantify the potential for sharing resources in urban areas between food production and other sectors, additional and place-based research is needed. Based on this, an estimation of reduction of GHG-emissions could be made.

2. Reduced use of energy as a result of reduced transport kilometres between production and consumption location. Urban food systems can reduce the amount of kilometres food travels. The effect on climate mitigation is limited; literature shows that transport results only in a small contribution to the total CO_2-emission of food production. Transport of products over long distances costs less energy than storing (and cooling) local products during longer periods.

Climate adaptation
Urban agriculture can help societies to adapt to climate change through effects of the conversion of land on properties of soil and land cover that alter water regulation and influence urban local temperature. The conversion of land use to urban agricultural activities can be of various types. For example, a vacant plot or park can be transformed into an agricultural field (green to green) or glasshouse (green to grey). Roofs or paved surfaces can be transformed to green roofs or agricultural fields (grey to green) or be replaced by a glasshouse (grey to grey).

The abiotic urban environment offers various resources for urban agriculture in the form of soils, water, space, atmosphere and energy, carried by radiative heat and solar radiation. Some environmental challenges related to the use of these resources for urban agriculture were discussed.

Urban soil conditions

There are often concerns about the poor conditions of urban soils for food production due to reduced soil health with regard to physical, chemical and biological aspects, for example lower plant nutrient and organic matter contents, potential contamination due to previous commercial and industrial use, and low aeration, porosity and drainage due to compaction by heavy construction equipment. The literature shows that these aspects show a large spatial variability within urban areas. Hence, siting of soil-based agricultural enterprises could be optimised to locations with high inherent soil nutrient stocks and other favourable aspects of soil health. Soil reconditioning techniques can be used to improve inferior health conditions to a certain extent.

Other environmental production factors

Light, temperature and production space are other production factors that work out differently in urban areas compared to rural areas. Solar radiation may be reduced due to reflectance from air pollutants and aerosols, and shade from buildings. The reflection of short-wave radiation from buildings and paved surfaces creates heat loads. Both may decrease plant productivity, but solutions are available to adapt urban agriculture, like using shape-adapted crops or artificial lighting. Space limitations may be overcome through multilayer farming, using space in and on top of existing buildings and in the underground.

Business opportunities

Despite the environmental challenges to urban agriculture, several business opportunities for community food enterprises could be identified, including the availability of local water resources and soil amendments derived from municipal waste, the possibility to increase crop productivity per unit of surface, and the proximity of technology and knowledge to urban agricultural enterprises, supporting hightech forms of urban agriculture.

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