RUAF Foundation
RESOURCE CENTRES ON URBAN AGRICULTURE & FOOD SECURITY

Project IFQ1-1036
Monitoring impacts of urban and peri-urban agriculture and forestry on climate change

Report 1.1 Report on the (most relevant) potential impacts of Urban and Peri-urban Agriculture and Forestry (UPA/F) on climate change adaptation, mitigation and other co-developmental benefits

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This report summarizes contributions made by project partners on the interactive Huddle project discussion forum setup for this project as well as builds on an analysis of submitted literature and references.

Contributions were made by – or in consultation with- the following project partners:

- The Institute of Geographic Sciences and Natural Resources Research (IGSNRR)/ Chinese Academy of Science, China;
- Ministry of Agriculture, Agrarian Development, Minor Irrigation, Industries and Environment, Western Province, Sri Lanka;
- Municipality of Rosario, Argentina;
- Ministry of Water, Public Services and Environment, Santa Fe Province, Argentina;
- The International Water Management Institute (IWMI) India , Ghana and Sri Lanka;
- The National University of Rosario, Argentina;
- Institute of Physics –CONICET Rosario, Argentina;
- Applied Plant Research International (PPO/PRI) of the Wageningen University and Research Centre, The Netherlands;
- Adaptify, the Netherlands;
- The School of Forestry of the University of Florida, USA;
- RUAF Foundation, The Netherlands;
- World Bank, USA;
- UN-HABITAT, Kenya.

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1. Introduction

Cities have an important role to play in climate change mitigation and adaptation and enhancing climate resilience of their slum and vulnerable residents. Climate change adds to existing challenges faced by cities. Climate change, together with a decrease in absorption capacity of greenhouse gasses due reduction in the amount of green cover, parks, trees and agricultural surfaces in urban areas, poses serious threats to urban infrastructure, access to basic services and quality of life in cities and negatively affect the urban economy (World Bank, 2010a). At the same time, rapid urban growth, growing urban poverty and increasing food prices raise concerns about urban food security, especially for the poor. Cities are highly vulnerable to disruption in critical (food) supplies and climate change exacerbates this vulnerability. The IPCC (2007) projects that agriculture will be severely affected by a combination of changes in rainfall pattern, extreme events and high temperatures. For the current urbanization to be sustainable there is a need for "de-coupling" (enhancing the quality of life while minimizing resource extraction, energy consumption and waste generation and simultaneously safeguarding ecosystem services). Decoupling will depend on how city-based energy, transportation, food, water and sanitation systems are planned and/or reconfigured. In this regard, there could be a role for Urban and Peri-urban Agriculture and Forestry (UPAF). UPAF was recognized by the World Bank as a potential strategy for recycling of organic waste and waste water; having potential energy saving benefits as local production reduces the need for transportation and refrigeration and having social benefits including better health and nutrition and livelihood opportunities (World Bank, 2010a).

Urban and Peri-urban Agriculture and Forestry (UPAF) can be defined as the growing of trees, food and other agricultural products (herbs, pot plants, fuel, fodder) within the urban build-up area and in the peri-urban areas. UPAF includes urban horticulture, livestock, (agro-)forestry and aquaculture as well as related processing and marketing activities. Urban and peri-urban agriculture form part of the overall food system within a given city-region. Depending on urban development patterns, local cultural, political and socio-economic context, and agro-environmental conditions, UPAF has taken different shapes and forms in different cities. It takes place in a wide variety of areas (rooftops, backyards, public open spaces, flood-zones and peri-urban agricultural areas) and in different forms (backyard gardening for home production; commercial livestock production in peri-urban areas; agroforestry on steep slopes; rice production in lower-lying valley bottoms etc.). Its location may change with urban growth over time. It is expected that the various forms of UPAF contribute to a varying degree to climate change adaptation and mitigation. However, little to no analysis has yet taken place in order to better understand which specific UPAF models are best suited for which city configurations and which UPAF models have more or less potential climate change impacts. As there is lack of such specific data, UPAF is therefore first grouped and available general statements are given. Analysing the role of specific forms of UPAF is one of the challenges that remain and that the report tries to answer to the extent possible.

Urban and Peri-urban Agriculture and Forestry is often credited with providing the following benefits: Reducing "food miles" by producing fresh food close to urban markets; reducing fertilizer use and energy consumption by productive re-use of urban organic wastes; recycling wastewater and freeing up water for other uses; enhancing rainwater infiltration and storm water drainage; reducing the urban heat island effect and enhancing carbon sequestration by increasing the surface of green/ forested areas; providing better diets, urban food security, jobs and income, etcetera.

However are these mentioned impacts myths or reality? Which of the impacts are most significant/ relevant- also if compared to other climate change intervention measures? Which types of UPAF (e.g. urban forestry, community gardens, green roofs, commercial peri-urban agriculture and others) can contribute to a (more) significant extent to climate change adaptation, mitigation and overall city development and under what conditions/ situations?

Questions that may be posed include: "How many food miles and related GHG emissions/ energy use can be saved by producing food more locally; offsetting this against possibly higher consumer emissions and transport? For which food items would this be most relevant? Under which conditions?"

Or “How much food (or specific types of food) can UPAF produce, how much household or farm income can be generated through UPAF and to what extent does this actually reduce vulnerability of certain groups of the population- especially the poor and vulnerable?”

On a Huddle electronic discussion platform, project partners embarked on a critical reflection on the different UPAF impacts. This report provides a short summary of the main discussions and responses.

2. Identifying potential impacts of UPAF on climate change adaptation, mitigation and other (co)developmental benefits

In order to analyse UPAF impacts on climate change adaptation and mitigation an initial analytical framework was proposed by the Sukkel and Jansma from the Wageningen University and Research Centre. This framework –modified with inputs from other partners- is used below as a basis for analysing potential impact categories for different UPAF types and measures.

First however a general overview is given of the potential mitigation, adaptation and (co)developmental impacts of different UPAF types and measures. Where available some quantification of potential benefits is given, though these data are generally hard to find or only refer to certain geographic locations and climates.

Overall, UPAF may be more cost-effective than many engineered technologies. However the biggest advantages of UPAF, compared to other intervention measures and to non-edible/ornamental green infrastructure, are its overall co-benefits such as its contribution to urban food security- especially in the face of climate-induced disruptions to rural food supply- and the food price hike, its contribution to income generation and to improved city liveability. Proper planning and management is however needed to maximise these benefits- as also illustrated below. This report first discusses these co-developmental benefits in more detail, before looking at specific UPAF systems and measures and their potential climate change adaptation and mitigation impacts.

2.1 Localised food production through UPAF

UPAF types such as *home-gardens, community, institutional gardens and rooftop gardens* mainly contribute to household food production with potentially some produce sold to or bartered with neighbours, rural relatives or urban consumers. *Commercial –and larger scale- vegetable and animal production including aquaculture and agroforestry*, taking place on open spaces in the city and in the peri-urban fringes and areas may provide larger amounts of (certain types of) food to urban markets, as well as generate income and jobs. For example, and as might be expected, in the inner urban area in Lima (Peru) with very high population density, built up area and lack of agricultural space, only 7% of producer household heads claimed agriculture as their primary occupation. On the other hand, in the peri-urban area with relatively lower population density, sparsely build up and which enjoys wide tracts of agricultural land, a modest 20% of producer households reported agriculture as their main activity. The urban area around the airport with intensive horticultural production and the similarly intensive horticultural areas in the transition zone (peri-urban area subject to high advancement of urban growth), both recorded around a third of producer households with agriculture as main activity (Prain and Dubbeling, 2011).

Overall, potential developmental benefits of different types of UPAF include their contribution to:

Enhancing household and urban food security: Strategies to bolster food security in urban centres will take on increasing urgency as climate change and rapid urbanization play out over the next decades. According to OXFAM, climate change is already having a more serious effect on the food security situation than has been previously assumed, as the impact of extreme weather has not been included in the predictions (OXFAM 2012). A number of problems are associated with the current urban food system. First, the dependency of poor developing cities on food imports is a major source of vulnerability and risk, because of the volatility of international food prices and the loss of local agro-biological diversity. The urban poor are particularly vulnerable to variations in food and fuel prices and in income since food (often over 60%) and fuel (often more than 10%) make up a large part of their household expenses. Variations in food prices and income directly translate into diminished purchasing power and rising rates of food insecurity, compromising dietary quantity and quality. It is estimated that the rise in food prices between 2007 and 2008 increased the number of people living in extreme poverty in urban areas in East and South Asia, the Middle East and Sub-Saharan Africa (SSA) by at least 1.5% (Baker, 2008). Although prices of food and fuel have declined in the latter half of 2008 and early 2009, in 2011 price levels increased again to those of 2007. According to OXFAM, who modelled the effects of climate change and extreme weather events on food prices by 2030, their baseline modelling indicates that the average price of staple foods could more than double in the next 20 years compared with 2010 trend prices – with up to half of the increase caused by climate change (changing mean temperatures and rainfall patterns) (OXFAM , 2012).

In addition, high dependence on food imports, especially for lower income countries with limited foreign exchange reserves, means that any increase in import prices or decline in export earnings could force a decline in food imports, causing their food security to deteriorate further, hitting first and foremost the urban poor.

Maxwell et al. (2008) argue that with growing urban populations more urban consumers are exposed to the fluctuations in world market prices, and question who will safeguard their food security: *"Economies such as Mozambique's or Cambodia's may be growing, but they are not doing so at a rate that sustains buffers for their poorest inhabitants, and the rural- (peri-) urban shift can put many more people in potential harm without a functioning government safety net. This has implications for future humanitarian interventions; is the international community sufficiently able to assess urban needs and able to intervene to protect food insecurity in non-agrarian settings?"* (Maxwell et al, 2008, p. 16).

Own production of food in urban areas not only contributes to food consumption but also generates savings on costs of buying food. Production of food (e.g. green vegetables, eggs, milk, and meat from small animals) by poor urban households can supply 20-60% of their total food consumption (Baker, 2008; UN-FAO, 2008). The positive value of urban agriculture is not limited to urban households involved in production. Urban and peri-urban agriculture increases the availability of fresh, healthy and affordable food for a large number of other urban consumers, as much of the food produced by urban farmers is bartered or sold locally. In many cities UPAF meets a substantial part of the urban demand for vegetables (especially fresh leafy vegetables) as well as for fresh milk, poultry, eggs and – to a minor extent- pork, fruits and fuel. According to earlier data from the 1990's, the volume of crops and animal products produced in UPAF often represents a substantial part of the urban annual food requirement, e.g. in Nakuru 8%, Dakar 10%, Kampala 40%, and Hanoi 44% percent (data cited in: De Zeeuw and Dubbeling, 2009). More and current research is needed to demonstrate if these trends have held with urban growth and development and for which types of cities (capital cities, small and medium –sized cities, cities located in different agro-ecological zones, cities in developing and developed countries). Some of the more recent (but scarce) research is referred to below.

In 2007, IWMI quantified the amounts of food and nutrient flows for 4 cities in Africa. Urban agriculture contributed about 5-9%. This was based on what was found in markets, but also when including home production, the total amount reached about 10% of what is consumed. When adding peri-urban farming the total percentage went significantly up in one of four cites to 40% (Kumasi, Ghana), otherwise it was around 15-20%. The additional percentage of food grown in the peri-urban area was about 30%[1]. The study also showed that that in a country like Ghana a large amount of food is imported, while this may be reduced to a certain extent if local production takes over. However, the types of commodities involved are often those produced in rural areas (replacing international production by national production) and have little to do with the few commodities produced in urban and peri-urban areas. The study shows that UPAF can play a role for perishable produce (fresh vegetables, milk, eggs), but not necessarily for grains and staples or processed food- depending also on local climatic and agronomic conditions.

The amount of food that can actually be produced in urban and peri-urban areas was more recently subject of study in Almere (the Netherlands) and Toronto (Canada). A recent scenario study done in

1 Two notes on the methodology: 1. Data depend very much on the extent of the peri-urban area which has to be clearly defined if we want to compare cities; 2. Data also depend on the way how we compare tomatoes with bananas: piece wise, or based on volume or weight. IWMI used weight which gives e.g. onions and yam/cassava a big role.

Almere (the Netherlands) found that 20% of total food demand (*in terms of potatoes, vegetables, fruits, milk and eggs*) -projected for a future population of 350,000 inhabitants can be produced locally, that is to say in a radius of 20 km. around the city. More than 50% of the needed area has to be destined to animal production (grass and fodder) (Sukkel, Stilma and Jansma, 2010; 2012).

For Toronto (Canada) to produce 10% of its *fresh vegetable requirements* within its' own boundaries, it was determined that Toronto required 2317 ha of food production area if all production was organic to fulfil other municipal environmental objectives. Of this, 1073.5 ha of land could be available from existing Census farms producing vegetables, lands currently zoned for food production, certain areas zoned for industrial uses and over 200 small plots (0.4-2 ha) dotted throughout the NE and NW of the City. 1243.5 ha of rooftop space would also be required (MacRae et al 2010).

Improving nutrition: A second problem related to our current food system is that reliance on globalized food chains supplying lower nutrient dense foods creates a global challenge regarding nutrition. Poor urban families have had to shift to monotonous, micronutrient poor diets as more diverse diets became unaffordable for them. Disease patterns are shifting from nutrition deficiency diseases to higher rates of diabetes and obesity (Ambrose-Oji, 2009).

In addition, and in many cities, development of dependable food infrastructure (production, transport, markets, industry) is not keeping pace with the rapid urban growth. The lack of infrastructure is especially a problem in terms of keeping cities supplied with perishable and fresh produce. Urban (poor) consumers are in need of access to cheap, micro-nutrient rich foods such as fruits and vegetables. Home and locally produced food is often fresher- especially when sold directly from producer to the consumer- more nutritious and varied than the food stuffs bought in shops, markets or in fast food chains and street restaurants (Zezza and Tasciotti, 2008, Yeudall, 2007).

However, urban agriculture, if not properly managed, may also have some negative impacts on the human health and urban environment. Soil erosion and pollution of ground water may occur, if chemical fertilisers and pesticides are intensively used over an extended period of time. Contamination of produce may result from soil and water pollution or wastewater use. Ecological farming practices are highly recommended in urban and peri-urban agriculture to prevent such negative effects. Also urban livestock has to be managed well (limit free roaming; good feed and manure management; control of slaughtering) to prevent zoonosis (the transfer of diseases from animals to human beings).

Local food production may also help restore the relation between food production (producers) and consumption (consumer) and contribute to social cohesion.

Urban and peri-urban food production, processing and marketing also contributes to generating income and employment for many urban households. Accessing global value chains is difficult for small farmers; whilst improving their access to local markets could result in the development of local food production and processing industries, which create employment and benefit the poor by improving access to fresh food (Olivier de Schutter, UN Special Rapporteur on the Right to Food, December 2011). According to the World Bank (2007), intensive peri-urban horticultural and livestock rearing are extremely fast-growing sectors that employ many workers and produce high value-added products that yield reasonable incomes and returns. Income and employment are not only generated in production, but also in processing, marketing and agricultural input supply. Although the production levels and turnover of individual urban producers or vendors in many cases will be small, their high number in each city may make their overall contribution to the urban economy highly relevant. In 1997, in Dar es Salaam urban agriculture formed at least 60% of the informal sector and was the second largest urban employer (20%). In Kenya, it was estimated that urban agriculture produces 25.2 million kg of crops worth 4 million USD and 1.4 million livestock worth 17 million USD in 1985 (IDRC, 1994, cited by Mireri, 2006). Again, more recent research to check these data against the current situation is lacking. A study done in 2001 by RUAF showed that households engaged in (small-scale) commercial urban and peri-urban agriculture in Nairobi can generate monthly incomes that are equivalent too higher than the minimum wage of US$ 79/month. Commercial peri-urban farmers, with larger areas of land, generate most revenues, with dairy farming and leafy vegetable production, being the most profitable (mean earnings US$ 1000/year). Total production values were however not estimated (Prain and Dubbeling, 2011).

In addition, UPAF also provides opportunities for income generation and job creation in related input supply, processing and marketing. For example in Havana 26,000 people are involved in indirect jobs related with UPAF, next to the 117,000 people involved in UPAF production directly (Gonzalez and Murphy, 2000).

A recent RUAF/ World Bank study (Prain and Dubbeling, 2011) implemented in the cities of Lima (Peru), Accra (Ghana), Nairobi (Kenya) and Bangalore (India):

- Indicate a positive relation between age, education and migration of urban household and the presence of urban agriculture and show that urban agriculture provides a stable occupation and income strategy for a vulnerable sector of the population, that is, the old and less well educated poor households, especially women-headed households and in general households that settled earlier than non-producers. They do not support commonly expressed ideas that urban producers are recent migrants who are still transitioning towards integration into (non-agricultural) urban society.
- Seem to indicate that agriculture is highly compatible with other kinds of work, such as petty trading, salaried employment or even casual labouring. Producer households are more often found to have a second job as compared to non-producer households. This apparent adaptability of agriculture to combine with other occupations also facilitates access to <u>multiple income sources</u>. For 58% of the Bangalore producers, urban agriculture constitutes an important source of additional income. Especially, livestock is a major supplementary income for producers, where nearly 46 percent earn up to 50 percent of their total annual income from livestock raising. Such diversification of income sources is very important as a risk-reduction and adaptation strategy.
- Suggest that, partly due to this reason, income generation is considered of greater importance than access to additional food as a reason for cultivation, although this differs for individual households or locations.
- Highlight another important aspect of income generation from agricultural production, namely <u>cash savings from producing own food</u> that otherwise would have to be purchased. Although the foods purchased with savings depend on local food cultures to some extent, there are commonalities, primarily in the important use of savings to purchase staple foods. The vast majority of staple foods are typically produced in rural areas and facilitating their purchase through savings from own production is a key contribution. Savings are also important for covering higher value items in the diet, such as micro-nutrient and protein rich animal foods and supplementary vegetables.

Alongside the economic and employment aspects, UPAF can also play a role in the <u>social inclusion</u> of marginalised groups (the aged without a pension, unemployed youth, persons with disabilities, those afflicted by HIV-AIDS and those impacted by war or disasters, female-headed households etc.) by providing them with an opportunity to feed their families and raise an income, while enhancing self-management and entrepreneurial capacities. For example, community urban and peri- forestry is promoted in Durban, South Africa to restore degraded forest and water catchment systems, protect water supplies and create "green jobs". Groups of urban poor are trained to grow and trade indigenous trees (www.durban.gov.za/services/).

Urban and peri-urban food production is in many cities a part of urban infrastructure. However, its recognition can be improved when better understanding –next to its developmental benefits- its *adaptation and mitigation benefits* for other priorities like climate change. The RUAF/ World Bank study (Prain and Dubbeling, 2011) discusses that the <u>diversification of income and food sources reduces the vulnerability</u> of producer (and non-producer) households and enhances their coping capacity by increasing the stability of household food consumption against seasonality, disturbances in food supply from rural areas or imports, increases in food prices and (temporary) losses of income. As food prices are expected to continue to rise in the coming decades, leading to a further deterioration of food security in cities, the role of UPAF in this respect may become much more important than is currently considered.

In addition, urban and peri-urban agriculture and forestry can also contribute to <u>energy savings and GHG reductions</u> through recycling of organic wastes through composting, encouraging wastewater reuse (see further below); and -by producing fresh food close to the city – reducing related energy needs for transport and refrigeration (World Bank, 2010a).

Transport, processing, packaging, cooling and storage of food contribute to energy use and GHG emissions. Large amounts of food are brought into the city from distant production centres and sold in large whole-sale markets. Larger transporting distances and storage also require refrigeration and air conditioning, which involve higher energy expenditures. In addition, refrigeration equipment contributes to emissions of hydrochlorofluorocarbons (HCFCs). In several European countries, including the Netherlands, 30% of all GHG emissions are related to food consumption (personal comment Sukkel, 18-06-2012).Similar trends can be expected for rapidly growing cities in the global South, especially in those countries where a growing middle class increased demand for more animal products and processed foods.

Can increased local production and food distribution through UPAF in this regard contribute to mitigation efforts? Transport, processing of food items, storage and cooling, all contribute to related energy use and GHG emissions. Replacing food imports by local production, thereby reducing so-called "food-miles" may thus contribute to reduction in energy use and GHG emissions, though reductions are dependent on:

- The type of transport used (their condition and mileage) and the distance travelled; especially the degree to which foreign imports by air and "heavy transport" (trucks) for bringing food into the city can be reduced. Depending on the type and distance of transport, energy use for imported products can total 80-90% of the total energy use in the food chain (Millstone and Lang, 2003). When comparing use of heavy sea-ships, heavy trucks and airplanes, energy use per kilometer and per ton of food transported stands to about 1:20: 100 (Dutilh and Kramer, 2000).
- The degree to which "consumer transport" for buying food can be reduced (can "food be brought to the consumers, instead of consumers to the food"?) and developing new food distribution networks such as close-by located neighbourhood shops; farmers markets-and at same time also avoiding "food deserts").
- The amount of time food needs to be stored and cooled. Reduction in use of cold rooms helps reduce energy consumption and HCFCs. Shorter market chains also reduce the need for use of preservatives and packaging. However, in some cases it is much more efficient to process food centrally then to process (cook) it in every household. Also sterilising food in the factory can be much more efficient than storing the fresh product in a refrigerator for a longer period.
- The replacement of processed foods and animal products by fresh and seasonally produced products and non-animal foods (this may require a chance in food consumption patterns).

The total energy reduction by promoting local food production may however be small compared to the overall energy use of the city. When replacing 20% of the food basket by local production in Almere, The Netherlands, while at the same time promoting fossil fuel reduction in production, processing and cooling by renewable energy sources, energy savings (363 TJ) would add up to the equivalent of the energy use of 11,000 Dutch households. Savings in GHG emissions (27.1 Kt CO2 equivalent) would equal carbon sequestration of about 1,360 ha of forest or the emission of 2,000 Dutch households. The largest savings are due to: (a) reduction in transport and (b) replacing fossil fuel use by renewable energy sources (solar, wind energy; use of excess heat from greenhouses) and (c) replacing conventional by organic production ((Sukkel, Stilma and Jansma, 2010; Jansma et al 2012).

Localised food production however also has another set of (co)developmental and sustainability benefits as reduction in (heavy) transport helps reducing air pollution ("fine dust"), noise, traffic jams and accidents, and potentially the spreading of diseases. Other benefits may include lower losses of food and improved food quality (less storage, use of preservation; more fresh food).

It also has to be taken into account that food items that are imported or transported from rural areas can however not always be produced locally or seasonally or can only be produced under energy-intensive systems (e.g. heated greenhouses), depending on local climatic conditions; soil characteristics; surface areas and water needed and available (Abalone, Terrile and Piacentini, 2012).

2.2 UPAF as a form of productive green infrastructure

UPAF, *especially specific types of UPAF such as urban and peri-urban forestry; agricultural and tree production in flood zones; the integration of edible plants in urban parks;* can also be considered as a form of productive green infrastructure, bringing positive impacts on cities' liveability, aesthetics and the environment. Such UPAF types can make productive use of land that is not fit for construction (flood or earthquake-prone areas, land under power lines and in buffer zones) and adds value to land that might not otherwise have an economic output. It can generate income from temporarily idle land through urban and peri-urban infill, and is compatible with public parks and open space planning.

However, questions are still raised regarding the sustainability of UPAF in the context of a dynamic urban market with high competition for land, soaring land prices and largely uncontrolled urban growth, if not protected by Municipal laws and programmes and combined with other functions like recreation, water management, urban greening, lowering urban temperature and adaptation to climate change. Adapting urban brownfields and built-up surfaces for agricultural or green space use may for example have much higher mitigation potential than leaving disturbed areas as vacant open space. Specifically urban and peri-urban forestry and their soils in particular also act as a carbon sink (immobilising carbon in trunks, leaves and soil organic matter) and thus contribute to enhancing carbon sequestration.

Most cities will experience more heat waves, leading to an increase in the amount of energy used for cooling and refrigeration purposes, and increases pollution and smog. Other mitigation benefits may result from UPAF contributing to reducing the urban heat island effect (the increase of mean day temperatures in built up areas due to human and industrial activities and decreased evapotranspiration of buildings and road), by providing shade and enhanced evapotranspiration, thus reducing cooling and heating requirements and emissions from energy (Zaunberger, 2011). Again, impacts will be highest for specific types of UPAF, such as urban and peri-urban forestry, but also permanent green productive rooftops can have impacts on reducing home and office temperatures.

In many cities increasing land sealing, and excess of storm water, has become a serious concern, especially in areas experiencing more or more intense rainfall. Flash floods occur more and more frequently as a result of overloaded drainage systems and lack of infiltration areas. Compared to undisturbed catchment areas, measured peak flow may increase up to 50 times and relative increases in runoff volume up to 30 times (Zimmerman, Bracalenti and Montico, 2012). The presence of green infrastructure (forests, grasslands, water bodies and parks), more permeable surfaces and water-storage ponds will significantly slow the storm water runoff. This makes it relevant to increase vegetative cover on vacant spaces, especially flooding areas, to protect them from encroachment and occupation.

Increasing vegetation cover will increase water interception (water intercepted by leaf canopies and returning into the atmosphere as transpiration directly from the leaf surface), depending on the type of vegetation and the distribution of rainfall (less intense rainfall (cm/hour) and more rainfall received during leaf-on growing season) enhances the quantity of water that is intercepted). To quantify the capacity for interception by vegetation the Leaf Area Index (LAI) may be used. So depending on the type of vegetation (forests, crops), the LAI and the area occupied by them, the interception potential of UPAF may be assessed as an indicator of storm-water reduction. To this the capacity of green roofs and green walls may be added to this list.

Green areas also contribute to increased storage capacity and water infiltration into the soil. Infiltration capacity depends on soil moisture, soil types and degree of compaction. The absorption and water retention capacity of different soils could be compared for different UPAF production systems and during different stages of production (bare soil, full vegetation cover), while comparing this to the capacity prior to UPAF (vacant soils or soils with debris) or to other land uses (paved areas) (Feldman, Coronel and Piacentini, 2012). Also the water run-off volume and speed are indicators of measurement. Reduced storm water runoff may also extend the lifetime of the city's drainage system, whose infrastructure is expensive to maintain.

By contributing to maintaining green open spaces in the city and enhancing vegetation cover, UPAF may thus have important adaptation benefits including:

- Reduction of floods and impacts of high rainfall by storage of excess water, increased water interception and infiltration and keeping flood zones free from construction
- Improving water quality through natural cleaning in low lying agricultural areas (e.g. natural or constructed wetlands, aquaculture in maturation ponds etc.)
- Improving air quality
- Curbing erosion and (the impacts of) landslides
- Enhancing urban biodiversity, protecting a wider base of plant (and animal) genetic diversity.

In addition, urban productive green spaces create opportunities for recreation and leisure, for income generation, and enhance the well- being of citizens. Costs and energy are however involved in the conversion of paved areas into green spaces; recycling of debris and maintenance.

The degree to which UPAF actually contributes to the various impacts mentioned above (e.g. food security, income generation, flood reduction; reducing urban temperatures etcetera) depends to a large extent on the type of UPAF that is promoted. It is therefore necessary to look into more detail at specific UPAF systems and their impacts. For example, and depending on the local context, the reduction of flood and impacts of high rainfall may be best achieved by promoting –in order of importance-: the protection and agricultural use of floodplains, promoting green roofs for increased water storage capacity and reduction of water flows, and promoting urban forestry to increase capacity for rainfall interception by increasing vegetation cover (Zimmerman, Bracalenti and Montico, 2012).

In order to advance with such analysis of different UPAF types, the following main types are distinguished:

1. Backyard and community gardening
2. Urban and peri-urban forestry
3. Green and productive rooftops
4. Urban and peri-urban agriculture in flood zones
5. Agriculture in city fringes and peri-urban areas.

Below the numbers 2-4 will be further described in more detail, as no studies on the impacts of type 1 and 5 are yet identified.

Next to the role that can be played by different UPAF systems, there are several management and policy measures that may specifically contribute to enhancing its climate change impacts. Three of these measures are identified by the project partners: the recycling and productive use of organic waste in UPAF; the recycling and use of wastewater in UPAF and the influencing of consumer behaviour on food preferences and dietary changes. If consumption patterns would change towards eating less animal products, less processed foods and more (local) vegetables and seasonal products, a much larger percentage of the urban food basket could potentially be produced locally. Such shifts in consumption patterns will also have a large influence on potential savings in energy use and GHG emissions (Sukkel, Stilma and Jansma, 2010; 2012). It is for this reason that these three so-called "UPAF measures" area also described below.

2.3 Urban and peri-urban forestry

Urban and peri-urban forestry (including parks, gardens, avenue trees, fruits, agroforestry and forested areas) can be considered (as temporal[2]) carbon sinks by storing and sequestrating carbon in trunks branches, leaves and roots of plants and trees, especially at time of their full growth[3]. Although urban and peri-urban forestry does not represent a major sink for global GHG, it can help offset a city's GHG emission to a certain extent (World Bank, 2010b).

Carbon storage (the total current carbon stocks as a function of plant biomass) can be around 30 and 80 metric tons of carbon per hectare of forest, depending on the tree species, tree size, climate and planting area. Existing trees in Toronto are estimated to store about 61.1 metric tons of carbon per hectare, that is 1.1 million metric tons of carbon. If these trees were to be removed (by converting forest areas into housing or industry), the loss or emission of carbon that was stored by these trees would be equivalent to the:

- Amount of carbon emitted in the city in 29 days
- Annual carbon emissions from 733,000 automobiles
- Annual carbon emissions from 367,900 single family houses (Nowak et al, 2010).

Carbon sequestration is defined as the assimilation of carbon by trees in one year as a function of net primary production (the balance between the light energy fixed through photosynthesis -gross primary productivity- and the portion lost through respiration and mortality). Carbon sequestration by urban

[2] All vegetation will decompose at one point in time and release CO2 back in the atmosphere.

[3] At times of afforestation or reforestation we may actually find negative carbon balances (more carbon is used to plant trees than what trees can actually take up when they are young. It is not until planted trees are grown that they can capture carbon at full potential and be considered real carbon sinks (personal comment F. Escobedo, 28-03-2012).

forests in Hangzhou (China) is calculated to add up 1.66 metric tons of carbon per hectare per year. This offsets 18.57% of the amount of carbon emitted by industrial enterprises.

Based on field data from 10 USA cities and national urban tree cover data, it is estimated that urban trees in the coterminous USA currently store 700 million tonnes of carbon ($14,300 million value) with a gross carbon sequestration rate of 22.8 million tC/yr ($460 million/year). Carbon storage within cities ranges from 1.2 million tC in New York, NY, to 19,300 tC in Jersey City, NJ. The national average urban forest carbon storage density is 25.1 tC/ha, compared with 53.5 tC/ha in forest stands (Nowak and Crane, 2002).

Integration forestry in urban areas also contributes to reducing the urban heat island effect and providing shade, with lower demands for heating and cooling and related reductions in emissions and energy use. This may also lead to reduced investments in new power utilities which release huge amounts of GHGs into the atmosphere. Lower ambient and building temperatures increase working and living comforts. Protection from direct solar and UV radiation and temperature may also impact incidences of heat strokes and skin cancer (van der Leun, Piacentini and de Gruijl, 2008).

Again most data available cover northern and temperate climates only. A study in Manchester City (United Kingdom) illustrated the relationship between maximum surface temperature and evapotranspiration (Gill S.E., 2006).. Woodlands showed to have higher effects on evaporation and temperature as compared to roads, offices and allotments or open spaces for example.

During summer, trees provide shade, insulation of buildings, and air cooling. According to the USDA Forest Service, the net cooling effect of a young, healthy tree is equivalent to ten room sized air conditioners operating 20 hours a day. Trees situated around buildings can reduce air conditioning needs by 30%.

In winter, trees contribute to wind sheltering and insulation. Wind-speed reduction by trees decreases the movement of outside air into interior spaces through walls which have a high thermal conductivity (glass windows) (Nowak et al, 2010). According to Heisler from USDA Forest Service (1986), trees around buildings can save 25% of energy used in heating. Toronto's urban forest is estimated to reduce energy use from heating and cooling of residential buildings by 41,200 MWH ($9.7 million/year).

Urban and peri-urban forestry contribute to rainfall infiltration and storm water drainage, possibly reducing flood incidences and contributing to replenishment of ground water. The city of Milwaukee (USA), with a 16% canopy cover, has reduced the storm water flow to 22%. This represents a saving in city taxes of $15,4 million by not having to build additional storm water retention capacity. Washington DC has a 35% urban tree canopy. According to The Urban Ecosystem Analysis, it reduces storm water storage costs by $4.7 billion. However, ground covers and soils are just as important as vegetation. Trees intercept and store less rainfall than do litter and un-compacted soils (F. Escobedo, 28-03-2012).

Dense urban and peri-urban forests may even protect homes during storms and hurricanes, though trees may also present risks in extreme weather events (falling branches or trunks).
In some cities, applying (agro-) forestry and peri-urban forest conservation on steep slopes is sued in order to prevent building on risk prone slopes; improve water-holding capacity and soil – water infiltration and reduce (the impacts of) erosion and landslides. Sustainable management of slopes in and surrounding cities may have a major influence on water management and flooding. Where quality of soil is poor, forests have a better soil regeneration capacity as compared to annual crops.

The intensified use of *agro-forestry*, or the combination of trees and shrubs in agricultural crop and/or animal production and land management systems (including improved fallows, multipurpose trees and shrubs, boundary planting, farm woodlots, orchards, plantation/crop combinations, shelterbelts, windbreaks, conservation, hedges, fodder banks, live fences, trees on pasture and tree apiculture) helps to reduce emissions and enhance food security and resilience of the local production system. Agroforestry systems tend to sequester much greater quantities of carbon than agricultural systems without trees. Planting trees in agricultural lands is relatively efficient and cost effective compared to other mitigation strategies, and provides a range of co-benefits important for improved farm family livelihoods and climate change adaptation. Although generally applied to rural areas, opportunites exist for its application in peri-urban areas and in doing so, reintegration of trees in crop or animal production systems can help diversify production, allows recycling of animal and crop by-products and thus the efficiency of the production whilst lowering/spreading the risk against production or market failures. Agroforestry systems are also important sources of fodder, timber and fuel wood. There are several examples of private companies supporting agroforestry in exchange for carbon benefits. This will be increasingly important as impacts of climate change become more pronounced.

Forested areas may also contribute to preservation of natural habitats and conservation of biodiversity. Trees provide an important ecological habitat for birds and insects. Moreover, (undisturbed) forest soil has a high level of soil biodiversity.

Urban and peri-urban forestry also has multiple co-benefits such improvement in air quality; reduced noise pollution; production of food, wood and fuel (food production, income and renewable energy production). Air quality is improved through absorption of gaseous pollutants (ozone, nitrogen dioxide) through leaf surfaces, intercepting particulate matter (dust, ash, dirt, pollen, smoke), and releasing oxygen through photosynthesis. According to The Urban Ecosystem Analysis of the Washington DC, Washington DC tree cover (35%) generates annual air quality savings of $49.8 million; while the Toronto urban forest intercepts 1,430 metric tonnes of air pollution (CO, NO2, O3, PM10, SO2) annually, representing an equivalent value of $16.1 million per year in ecological services (Nowak, 2010).

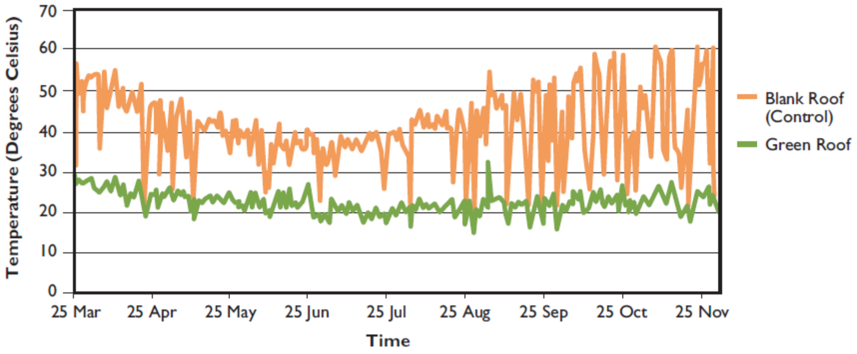
However not all urban and peri-urban forest systems (including street trees, parks, urban or peri-urban forests) have the same impact. Impacts differ for different systems and in different locations. In tropical areas, fast growing trees contribute to CO2 sequestration, but may put higher demands on water use. Native species may demand less water but area generally more shrub-like and provide less shade (Zhao, Kong, Escobedo and Gao, 2010; F. Escobedo, 28-03-2012).

Carbon storage by urban forestry also depends on its management. Hard urban (growing) conditions, which stress trees, may not allow for a good health and growth of trees. Also the number of large trees may be low, limiting carbon storage. Moreover, this stress generates tree mortality or removal, as a result of which a large % of the stored carbon is again released (Konijnendijk, 2007). Growing younger trees provides higher rates of carbon sequestration while larger and older trees proportionately store more carbon. Ideally, a balance between is maintained between actively growing younger stock and healthy, mature trees to optimize urban forestry benefits (Nowak et al, 2010).

Next to its potential benefits, also costs have to be considered. Abundant, (ever)green, dense urban and peri-urban forestry can reduce urban temperatures, but needs to be maintained and watered. Urban and peri-urban forestry needs to be low maintenance, long-lived and require little energy (e.g. for maintenance; fertilisers etcetera) and water inputs.

2.4 Green and productive rooftops

Integrating food production with building infrastructure (rooftops; balcony gardening; growing walls; greenhouses) may contribute to reducing the urban heat island effect and regulating temperature (heating and cooling requirements), depending on the type of production system and local climatic conditions. Large scale roof planting can help reduce the "urban heat island effect" in the inner city through shading, absorption of heat in plant thermal mass and evaporational cooling. Green roofs reduce the air temperature above the rooftops as a result of solar reflection and evapotranspiration. Indeed, Durban (South Africa) studies showed that the air temperature above a blank roof is higher than above a green roof (shown in green). The average ambient air temperature above the green roof and blank roof was 22°C and 41°C respectively from 24 March 2009 to 24 November 2009. On average, there was an 18°C temperature difference between the green roof and the blank roof. The daily temperature fluctuations are also smaller: 2,7°C fluctuation above the green roof as against 9,8°C fluctuation above the blank roof (Van Niekerk et al 2011). Similarly, and according to the city's Department for Environment, on summer days in Chicago, "temperatures atop the green-roofed City Hall are typically 14 to 44°C cooler than the adjacent county office building, which has a black tar roof" ((Kisner, 2008).



Average air temperature readings taken on blank and green roofs in Durban (Van Niekerk et al 2011)

Studies in Germany have shown that "a green roof habitat can decrease the ambient temperature in underlying rooms by 3-4°C". Canadian researchers found that "green roof reduces the daily energy demand for cooling by 95% under a conventional roof". During the winter, green roofs diminish energy heating use by absorbing solar radiation and diminish heat loss through the roof by providing insulation. The Canadian study found that green roofs reduce the heat loss from a building by approximately 26% (Liu and Baskaran 2003). The question remains to which similar effects are also found in more tropical climates.

Reductions in energy savings and emissions may also be off-set against energy use and GHG emissions related to maintenance, production and transport of needed materials and inputs and on the extent to which combining UPAF with urban infrastructure also enables synergic and cyclical processes between urban domestic and industrial sectors and agriculture (e.g. use of excess heat, use of cooling water or CO2 from industry in green houses). Effects on heating and cooling will also depend on degree of (permanent) cover of the rooftop, local climatic conditions, building insulation, building types and heating and cooling behaviour of the owners(are homes or buildings cooled/heated using energy intensive equipment?). More research is needed to understand effects on urban temperature and the urban heat island for different types of agricultural green roofs in different localities.

Green rooftops may contribute to storm water drainage and reducing run-off, depending on the depth of soil or type of substrate used and type of vegetation cover. Experiences in the USA have shown that green roofs may capture between 50-95% of summer rainfall, while peak runoff flows can be reduced with approximately 50% (EPA, 2009). Other research has shown that three to five inches (7,5 to 12,5 cm) of soil or growing medium can absorb 75% of rain showers that are one-half inch or less (Kisner, 2008).

According to eThekwini Municipality’s Environmental Planning and Climate Protection Department studies on Durban, the amount of the storm water run-off from green roofs is eight times less as the amount from blank roofs. The storage capacity of different types of green roofs could be measured and multiplied with the existing and potential area under green roofs in a certain city (Van Niekerk et al, 2011).

The efficiency to reduce rainwater run-off however depends on several factors:
- soil depth: deeper soil retains more water
- the type of plants grown : plants with high leaf surface area intercept more rainwater, plants with a large roof mass absorb more water, seasonal crops are less efficient at times of the year when plants are absent or in the development stage (the leaf area is reduced).
- green roof surface area and cover: a greater surface area retains more rainwater; year-round coverage is more effective than seasonal coverage .

Canadian researchers estimate that each square metre of green roof habitat can remove ± 200g of Particulate Matter (PM) from the air each year. Based on this research, a green roof habitat of 6m2 can absorb roughly the amount of PM that one passenger vehicle will emit in a year (Liu and Baskaran, 2003). This estimate is based on a car that travels an average of 20,000km per year and emits on average 0.1g of particulate matter per km.

Similarly, a modelling exercise undertaken in Washington DC, examined the air quality benefits of establishing green roof habitats on 20% of the total roof surface of buildings with a roof surface of greater than 930m2. It was estimated that green roof habitats would cover about 2 million m2 and remove 6 tonnes of Ozone (O3) and almost 6 tonnes of PM annually. This is equivalent to what could be absorbed by about 25,000 to 33,000 street trees (Wong, 2008).

If the above findings were applied to Durban, the 550m2 green roof habitat would remove annually approximately 100kg of PM, which is roughly equivalent to that emitted by 92 passenger vehicles in a year and sequester approximately 209kg of carbon over a two year period. This is equivalent to the carbon that one passenger vehicle will emit in approximately four months (this estimate is based on a passenger car that travels an average of 20,000km per year or 1,666km per month, and emits on average 120g of CO2 or 33g of carbon per km) (Van Niekerk et al, 2011).

Agricultural productive green roofs also make a modest contribution to food security by producing local fresh food. They provide an interesting opportunity to grow food in inner city and densely build-up areas, otherwise often lacking (open) space for food production. If half of the Vancouver's usable rooftop space was used for urban agriculture, it could generate around 4% of the food requirements of 10.000 people. While combining this with hydroponic greenhouses, this figure could be increased to 60% (Holland Barrs Planning Group et al. 2002). In 2003, the City of Toronto owned approximately 1.700 buildings. Researchers proposed to convert 20% of all City-owned rooftops into agricultural green roofs over three to five years. Assuming a modest average food garden surface of 465 m^2, it would further make approximately 16 hectares available for food-production and for moisture absorption (Nasr et al, 2010). However there often are significant barriers to using rooftop space (structural requirements, safety, building codes etcetera).

2.5 UPAF in flood zones

The protection of flood zones in urban and peri-urban areas is a common measure in sustainable urban planning. Flood zones are able to buffer or ameliorate the impacts of floods, and the loss of flood zones increases the risks of floods occurring. Inland wetlands, such as floodplains, lakes, and reservoirs, are the main providers of flood attenuation potential in inland water systems. Flood zones and wetlands are able to mitigate floods by storing potential floodwaters, reducing floodwater peaks, and ensuring that floodwaters from tributaries do not all reach the main river at the same time. During the dry season, subsurface flow from wetlands may replenish stream flow (UN FAO, 2008).

UPAF may be instrumental to protecting flood zones and wet lands from construction or land filling. Urban agriculture and forestry in Freetown (Sierra Leone) can be found on wetlands or on mountain slopes. However, any available plots in the area can only be cultivated sustainably if formally secured for urban agriculture in the long term. It is for this reason that all wetlands in Freetown were zoned and preserved for urban agriculture. Next to promoting local food production, this measure is also expected to help keep flood-zones free from construction and improve water infiltration, resulting in reduced flooding incidences and related damages caused (UN Habitat, no date). Other positive effects may be reduction of costs associated with maintenance of such areas.

Agricultural use of lowlands in Antananarivo has shown to help prevent flooding as the lowland rice and watercress systems can store large amounts of water. For example, a valley of 287 ha can store up to 850,000 m3 of water, corresponding to three successive days of heavy rains (Aubry et all, 2010).

2.6 Recycling and productive use of solid organic waste in UPAF

The productive reuse of wastewater and composted organic wastes UPAF might enable:

- To reduce the need for artificial fertilizers (and thus also lower the depletion of minerals like phosphorus and Nitrogen and as well as reduce the energy needed for producing the fertilizers (Prain et al, 2010).
- To reduce landfill volumes and thus methane emission from landfills.
- Reducing GHG emissions from water and wastewater treatment.

Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg of Municipal Solid Waste (MSW) per person per day (0.68 billion tons per year). Today this has increased to about 3.5

billion residents generating 1.47 kg per person per day (1.9 billion tons per year). By 2025 this will likely increase to 4.3 billion urban residents generating about 1.61 kg/capita/day of municipal solid waste (2.5 billion tons per year) (World Bank, 2011). In Low Income Countries (LIC), on average, less than 50% of the Municipal Solid Waste (MSW) is collected and less than 25% is properly disposed of. Uncollected MSW is usually the second largest source of air pollution in LIC cities (particulate emissions contribution). Uncollected, and collected, MSW, leads to methane generation through anaerobic decomposition (though this methane may be captured for energy use). GHG emissions from MSW have emerged as a major concern as post-consumer waste is estimated to account for almost 5% (1,460 mtCO2e) of total global greenhouse gas emissions. Encouraging waste minimization through MSW programs can therefore have significant up-stream GHG minimization benefits. Reduction of collection efforts will also contribute to reducing transport and related GHG emissions.

In most Low Income Countries, over 50% (up to 90% or more in some cases) of all municipal waste is organic matter. Composting (aerobe fermentation) is likely to arise in importance as an MSW options due to its ability to reduce methane and produce a useful soil conditioner (especially if MSW is linked to urban agriculture). The quality of waste however has to be considered –especially if waste is not segregated at the source and mixed with hazardous components. Waste separation and possible sieving -if done at larger scale- may however involve extra energy costs. Carbon finance may r be an important catalyst for waste management improvements in low-income cities (World Bank, 2011).

Organic waste use in agriculture in addition improves soil fertility and improves water holding capacity. It reduces the need for chemical fertilisers, the related use of energy emissions of GHGs (NO_2 and CO_2), reduces nitrate leaching and sequesters carbon in the soil. Composting can furthermore be combined with controlled fermentation and production of bio-gas as a renewable energy source.

Most studies on organic and conventional production, referring to CC mitigation, show that the main difference in GHG emissions in favour of organic production is the absence of the use of synthetic fertiliser and the larger carbon sequestration related to the use of organic fertilisers. In commercial agriculture this advantage of organic production is however off-set by lower yields and thus higher GHG emissions per weight unit of produce.

The extent to which UPAF fertiliser or nutrient needs can be replaced with waste-based nutrients is dependent on the extent to which UPAF farmers currently use chemical fertilisers (in most home production these are not used!) and the quantity the actual waste-related nutrients produced in a certain city (total amount of waste generated) or the amount currently collected. IWMI calculated for four African cities how much the collected waste could support food production if returned to urban and peri-urban areas (see http://www.ruaf.org/sites/default/files/UAM23%20pag11-12.pdf). For Kumasi, Ghana, this resulted in the following: In a “realistic” scenario, which only considered the waste currently collected (70-8-%of all waste produced), the entire N and P demand of (intra)urban farming could be covered, as well as 18 percent of the nitrogen and 25 percent of the phosphorus needs of peri-urban agriculture in a defined 40 km radius (Dreschel et al, 2007). So the collected organic waste can only support about 1/5 of the peri-urban derived production. When considering (see &2.1) that 9% of the urban food demand is produced in urban areas and 40% in the peri-urban area; only 8% (1/5 of 40%) on top of the 9% urban production can be covered. This would mean that in total 17% of the food the city needs could be supported by waste based nutrients in urban and peri-urban farming in Kumasi assuming full recovery of all what is collected. Could we say then that UPAF has the potential to reduce 17% of the fertilizer-energy needs? This is only possible if the UPAF production is fertilizer based. As indicated, in many UPAF, fertilizer is used, but only in small quantities. Actual GHG emission reductions by replacing chemical fertiliser by organic waste may thus be very small in these cases.

Life Cycle Analysis Studies also have shown that fertiliser transport itself has very limited impacts on fossil energy use. Mayor benefits will probably stem from reducing waste volumes at landfill and disposal sites and reducing related waste transport needs.

2.7 Recycling and productive use of wastewater in UPAF

Cities that need to transport water over long distances to their urban residents require considerable amounts of energy to do so. Solid waste and wastewater treatment combined contribute to about 3% of global GHG emissions (IPCC, 2007). In many LIC cities wastewater treatment facilities are insufficient and untreated wastewater is discharged into open water bodies, with negative impacts on health, local ecosystems and downstream water quality. Integrated water management practices such as rainwater harvesting, grey water re-use and localised treatment can lead to energy savings and GHG reductions, though again energy needed for operating larger treatment plants can be high. When sewage and grey water are mixed, simple sedimentation techniques may already help to remove pathogenic agents to a large extent (Amerasinghe, 01-05-2012). Using rainwater and recycling (partially) treated wastewater in UPAF (while carefully managing potential health risks) also contributes to freeing up water sources for other uses (domestic and industrial consumption). It might be interesting to carry out some simulation studies and calculate adverted GHG emissions of waste and wastewater are used for UPAF.

Rainfall harvesting from roof and road run-off has been promoted in Beijing since 2000. Harvested water is collected in water ponds for primary treatment (sedimentation) and later used for irrigation of parks and gardens, aquifer recharge, maintaining water levels in small ponds and lakes in the city and fire fighting. Capacity for collecting rainwater can reach up to 40 million cubic meters. Capturing rainwater from greenhouses is propagated since 2005. On average 200-300 m3 of rainwater can be annually collected from greenhouses with roofs covering 667 m2, allowing to irrigate 2-3 times this area of crops if efficient irrigation methods (drip irrigation) is used (Yang, 26-04-2012).

With the negative effects of climate change on rainfall patterns, UPAF irrigated with urban wastewater seems a possible strategy to increase agricultural productivity around urban areas and alternative to rain-fed rural agriculture. The urban demand for fresh water is also rising rapidly, due to population growth as well as increasing supply, coverage and overall urban economic growth, while availability of fresh water is becoming a serious problem. In water-scarce countries (especially in the Near East and North Africa, South Africa, Pakistan, and large parts of India and China) and in densely populated areas, growing competition between industrial, energy and domestic uses of water and agricultural use of water can be observed. Concurrently, water demand for food production is increasing due to rising populations as well as due to changes in urban food consumption patterns: as urban dwellers move towards richer and more varied diets (from tubers to rice; from cereals to meat, fish and high-value crops) that require more water to be produced (UN Water, 2007). Along with more efficient water use in agriculture, the productive reuse of (treated) urban wastewater and the collection and use of rainwater in UPAF have been identified as a sustainable way to produce food for the growing cities (IPCC, 2007; UNESCO, 2003). Such use of alternative sources of water in UPAF will help to:

- Adapt to drought by facilitating year-round production, making (safe) use of reliable waste water flow and nutrients in water and organic waste. Health risks related to reuse of untreated waste water for production can be reduced through complementary health risk reduction measures as explained in the new World Health Organisation (WHO) guidelines for safe use of excreta and wastewater (WHO, 2006).
- Reduce the competition for fresh water between agriculture, domestic and industrial uses;
- Reduce the discharge of wastewater into surface water sources and thus diminish their pollution.

Additionally, the use of water saving and harvesting technologies and of less water demanding (or more drought resistant) crops and species is key in UPAF to minimise water demand.

2.8 Influencing consumer behaviour

Food handling, diets and shopping behaviour all can have big impacts on energy use and GHG emissions. In the food chain of western countries about 30% of the food is wasted. Food waste is related to food quality, cooling, packaging and preparation. Also energy use for preparing food can be a substantial part of the energy use in the total food chain. Similarly, dietary choices have big impacts on emissions. Animal products have approximately a 4-10 fold higher GHG emission per calorie then vegetable products (Sukkel, 13-04-2012). A shift from animal to plant products can reduce emissions for food substantially (Jansma et al. 2012)

Finally food shopping behaviour should be taken into account. In most studies on food flows consumer transport is often not considered. However consumer transport in many countries substantially contributes to the total food transport and determines to a large extent energy use (fossil fuels) for transport. The strategy of many cities to centralise food availability in stores at the edges of town causes huge increases in consumer food miles. Consumer food miles and related energy use are in western cities much higher than professional food transports. Studies in the UK show that 48% of all food transport (per ton of food) was caused by consumer transport. This indicates also a need to look at changing and optimising distribution patterns and network, favouring more local distribution and stores.

Knowledge and awareness of consumers on how to reduce food waste and their energy use in food preparation and developing a food distribution network that reduces consumer food miles may lead up to 20-40% of GHG emission reduction according to various studies (Sukkel, 13-04-2012).

3 Summary of impacts of UPAF on climate change adaptation, mitigation and other (co)developmental benefits and needed arrangements for different UPAF types/measures in different city zones

Impact categories of UPAF –as described above- include climate mitigation, climate adaptation and co-developmental benefits (food production, income generation, sustainable resource management etcetera). Indicators that may be used to further analyse these different categories include:

- Mitigation: (fossil) energy use; carbon storage, carbon sequestration, GHG emissions (CO2, CH4, NO2, HCFC), food miles, heat island effect, (chemical) fertiliser use, landfill volumes and per capita waste generation
- Adaptation: diversification of food and income sources, amount of locally produced food versus imported food, food availability and food prices, amount of green spaces, water storage/infiltration capacity, storm water runoff, drought resistance, incidences of floods/erosion/landslides, biodiversity, competition for water/use of alternative water sources.

However, impacts of UPAF cannot be generalised as:

- They differ among different UPAF types (for example the carbon sequestration potential of urban and peri-urban forestry will be far higher than that of community gardens in which mainly annual crops are grown).
- They depend on the crops/species used in UPAF and the management techniques applied (e.g. individual street trees provide less shade and cooling effect as compared to larger areas of forests; UPAF systems using organic or agro-ecological production methods will have a different impact on overall GHG emissions as compared to production systems where large(r) amounts of chemical fertilisers and pesticides are used).
- They depend on a set of trade-offs and related factors, e.g. the emission benefits of localised and fresh food production (less transport, processing, storage and packaging) may be off-set against larger consumer transport for picking up –small amounts of- food.
- They depend on the geographic location and local context (e.g. rooftop gardens have a different relative effect on temperatures –and related heating/cooling requirements- in temperate climates as compared to tropical climates. Also in tropical climates more water may have to be pumped up to the roof for irrigation, its related energy costs then of-setting potential energy savings).

The type of UPAF systems to be promoted depends on local climatic and spatial conditions, with some systems being more suitable or relevant for certain urban areas then others. Spatial system boundaries also need to be introduced to allow for measurement of for example production areas and boundaries for specific UPAF systems. Three spatial categories are proposed by Sukkel and Jansma, including (A) the city centre; (B) the city fringes –up to 20 km from the city and (C) peri-urban areas (20-50 km from the city).

Important variable influencing the extent to which certain UPAF impacts can be achieved include total surface area; extent to which external inputs and materials are used; low or high maintenance; product choices (animal products have far higher GHH emissions per calorie than vegetable products); consumer food distribution networks; water and waste management (recycling of organic wastes; use of grey or rainwater; use of water-saving and irrigation technologies); use of organic versus conventional production techniques and seasonality of production.

Policy arrangements and interventions that can be put in place to promote certain UPAF systems/measures include the creation of local food hubs; preferential local food procurement;

preservation and promotion of productive green spaces; incentives for rainwater harvesting technologies and open plot cultivation etcetera.

The table below tries to summarize and provide an overview of all these aspects, also in order to facilitate further discussions on actual quantification of impacts and the measurement and collection of such quantitative data.

Some explanations to the columns of the table:

- City zone: A = Inner city; B= Sub urban (less densely built up); C:= Peri-urban (mainly open spaces)
- UPAF measures: certain types of urban and peri-urban agriculture and other food related measures with high potential for climate change programmes in city regions
- Mitigation benefits: The expected mitigation effects expected to be obtained from each UPAF measure.
- Adaptation benefits: The expected adaptation effects expected to be obtained from each UPAF measure.
- Developmental (co-)benefits: The expected developmental benefits of each UPAF measure (on food security, on income and employment creation, on city liveability etc.).

The number of plusses indicates the expectations –as judged by the project team- regarding the magnitude of these impacts at city level. One plus indicates expected low impacts; two plusses medium impacts and three plusses indicate expected high benefits. LE indicates that there is currently low evidence to substantiate these estimates; while ME indicates medium evidence towards this. The annotation High Evidence is not used as data presented are often only available for a small number of cities, data may be out-dated and data are not specified for specific situations (e.g. cities in specific stages of development or in specific agro-ecological zones). It is for this reasons that further collection of evidence is needed.

In two cases, data available refer to UPAF types (urban and peri-urban forestry and green rooftops) that often not include a food production component. Although this requires specific management practices, it is expected that similar impacts could be achieved in “productive forestry and agricultural rooftops systems”. Impacts will in all cases be dependent on climatic conditions; on production technologies and management practices used. Specific variables that determinate the extent to which the expected impacts can be achieved are indicated in the final column of the table.

City zone	UPAF type/measure	Impacts on Climate Change				Co-development benefits	Variables that determine the extent to which such impacts on climate change can be achieved
		Mitigation benefits		Adaptation benefits			
A	Promotion of **backyard and community gardening**	++ LE	Less energy use and GHG emission due to reduced food miles Reduction of waste volumes due to on the spot composting / reuse Minor carbon storage and sequestration	+++ ME	Less vulnerability to an increase in food prices and disturbances in food imports to city due to enhanced local production and diversification of food (and income) sources; Positive effects on urban biodiversity (especially niche species)	Enhanced food security and nutrition (especially for the urban poor and women) due to improved access to nutritious food close to consumer Positive effect on urban biodiversity and liveability Educational and recreational opportunities	Total production areas and intensity/yield and diversity of (year-round) production. Consumer diets and consumer transport distances for buying food. Degree of external inputs and materials used in UPAF and related energy costs/ GHG emissions (ecological vs. conventional production; degree of recycling and use of organic waste, use of rainwater harvesting and water saving production techniques; crop choice: use of drought resistant species)
A	Promotion of **green productive rooftops**	++ ME	Less energy use and GHG emission due to reduced urban temperatures and insulation: Less energy use for acclimatization of homes and offices Minor carbon storage and sequestration	+++ ME	Minor: Less vulnerability due to enhanced local production and diversification of food (and income) sources Enhanced water retention capacity and reduced runoff Reduced urban heat island effect Positive effects on urban biodiversity (e.g. migratory stops)	Enhanced food security and nutrition due to improved access to nutritious food close to consumer Educational and recreational opportunities Multifunctional use of urban spaces Enhanced city liveability	Degree of external inputs and materials used in UPAF and related energy costs/ GHG emissions (degree of recycling and use of organic waste, use of rainwater harvesting and water saving production techniques; crop choice: use of drought resistant species; choice of production technologies and inputs required, (energy-costs of setting up the system) Degree of (permanent) cover and soil depth
A-B	Promoting food and biomass production (e.g. agro-forestry**) in flood zones** and other urban open spaces needing conservation	+++ LE	Less energy use and GHG emissions due to reduced transport, cooling, refrigeration, storage and packaging Carbon storage and sequestration	+++ LE	Less vulnerability due to enhanced local production and diversification of food (and income) sources Enhanced water storage and retention capacity Reduced flooding incidences/ lower water peaks; lower impacts of floods due to prevention of housing in flood plains;	Food production (volumes) Enhanced food security and nutrition due to improved access to nutritious food close to consumer Employment Positive effect on urban biodiversity and liveability	Seasonality of production Degree of external inputs and materials used in UPAF and related energy costs/ GHG emissions (ecological vs. conventional production; degree of recycling and use of organic waste, use of rainwater harvesting and water saving production techniques; crop choice: use of drought resistant species)

City zone	UPAF type/measure	Impacts on Climate Change				Co-development benefits	Variables that determine the extent to which such impacts on climate change can be achieved
		Mitigation benefits		Adaptation benefits			
					Positive effects on urban biodiversity	Multi-functional use	Intensity of rainfall/ storm water peaks Location of flood zones and current use State and overload of city drainage systems
B-C	Promoting **urban and peri-urban forestry and agro-forestry** (especially **on steep slopes** and other areas susceptible for erosion and landslides)	+++ ME	Carbon storage and sequestration Less energy use for cooling/refrigeration/acclimatization due to reduction of urban temperature (in warmer climates) Reduction of air pollution	+++ ME	Less incidence of floods and landslides due to reduced run off and enhanced water storage and retention capacity Positive effect on biodiversity conservation	Production of food (crops, fruit, nuts) /fuel /wood Liveability enhanced (shade, aesthetics, temperature, air quality) Less health problems due to less heat stress (heat stroke, skin diseases, and heart problems) and air pollution.	Total surface area under high / low density production Degree of combination with food production Choice of tree species (young or old trees, growth rate; water needs, maintenance requirements; retaining leaves year-round or not, long or short living, etc.) Degree of maintenance and maintenance techniques applied and related energy costs and GHG emissions Forest fires, urban stress and other causes of reduction of tree coverage
B-C	Protecting and promoting **agriculture in city fringes/peri-urban areas,** including wetlands (where appropriate)	+++ LE	Less energy and GHG emissions due to reduced food miles and more locally produced fresh food: Less transport, cooling / refrigeration, storage and packaging Less cost in maintaining infrastructure for transport, storage and cooling Carbon storage and sequestration	+++ LE	Improved biodiversity for appropriate habitats and species, especially in conjunction with organic, low-till agriculture Enhancing food resilience for city (especially during disasters and political/financial crisis periods); less vulnerability due to enhanced local production and diversification of food (and income) sources	Enhanced food security and nutrition due to improved access to nutritious food close to consumers Employment Positive effect on urban biodiversity and liveability	Seasonality, diversity and intensity of production Production per unit of energy Degree of external inputs and materials used in UPAF and related energy costs/ GHG emissions (ecological vs. conventional production; degree of recycling and use of organic waste, use of rainwater harvesting and water saving production techniques; crop choice: use of drought resistant species) Local food distribution systems
A-B-C	Promoting recycling and **re-use of organic wastes in UPAF** (from	++ LE	Reduction in energy use due to lower waste volumes and related transport	+ ME	Improved water holding capacity due to more organic matter in soils	Reduced air /water pollution Fertile agricultural land and/or	Transport and energy use in compost collection, production and distribution (sources, location of composting sites

City zone	UPAF type/measure	Impacts on Climate Change				Co-development benefits	Variables that determine the extent to which such impacts on climate change can be achieved
		Mitigation benefits		Adaptation benefits			
	households, agro-industry, vegetable markets, wood and crop biomass, etc.**)**		Reduced methane emissions due to less organic materials in landfills and less uncontrolled burning of wastes Less energy use and GHG emission due to reduced fabrication and use of chemical fertilisers Delayed emissions and carbon sequestration due to higher organic matter in soils OR: Additional energy production (biogas production through fermentation of organic wastes)			renewable energy (biogas) Reduced nitrate leaching Less smell and improved sanitation Less land needed for waste processing, Employment and income	and users, transport means used) Idem for treatment and distribution of wastewater (treatment technology used, location of plants and users, etc.) Degree of recuperation of methane at landfill
A-B	Promoting **Reuse of in UPAF of waste water and "harvested" rainwater**	++ LE	Less energy use and GHG emission due to reduced fabrication and use of chemical fertilisers and reduced secondary/tertiary wastewater treatment	++ LE	Less vulnerable to drought Reduced potable water use for irrigation and reduced competition for fresh water sources	Enables year round intensive food production Less pollution of open water sources Possible hygiene effects Potential health risks related to use of untreated wastewater in an improper way	Availability of other water sources Choice of waste-water treatment techniques Costs of infrastructure to transport and store wastewater to urban producers, or local treatment, and safety measures
A-B-C	Promoting **climate smart farming techniques** & **farm managemen**t in UPAF[4]	++ ME	Higher carbon sequestration due to higher organic matter in soils	++ ME	Higher water retention capacity due to higher organic matter in soils More resilient farming systems Positive effect on biodiversity Use of alternative sources of water	Better quality products (free of pesticides etcetera)	Degree in which the various climate smart management techniques are applied Lower production per unit of land or energy will off-set positive benefits

4 We refer here -amongst others- to: Transition to ecological production methods; Application of water saving techniques and rainwater harvesting; Use of drought or flood resistant species; Adapting the timing of cultural practices; Improved management of livestock (e.g. manure and urine management, feed production from organic wastes)

City zone	UPAF type/measure	Impacts on Climate Change				Co-development benefits	Variables that determine the extent to which such impacts on climate change can be achieved
		Mitigation benefits		Adaptation benefits			
					rather than potable water		
A	Enabling **resource flows between urban agriculture and other urban sectors** (especially greenhouses) [5]	++ LE	Less energy use and GHG emission due to reuse in UPAF of by-products, excess heat, (purified) CO2 or cooling/waste water from industry or block heating of residential areas	+ LE	Less vulnerability due to diversification of food and income sources Enhanced resource/energy use efficiency / more connectivity in the urban system	Enhanced food security and nutrition due to improved access to nutritious food close to consumer Employment and income	Technical arrangement for reuse Needed external inputs (e.g. fertilisers) Ecological vs. conventional production Degree of use of organic wastes, rainwater harvesting and water saving production techniques Needed external inputs/materials Use of drinking water?
A-B	**Improving the urban food distribution system[6]**	+ ME	Less energy use due to reduction of travel by car to buy food in super stores in city fringe	+ LE	Enhanced food security especially for the urban poor	Avoidance of " food deserts", Better accessibility of food by lower income groups Less fine dust, air pollution and traffic jams due to reduced traffic	Type of consumer transport used; More traffic to bring food to the local retailers or more consumer transport (going to different stores) will off-set benefits
A-B	**Changing dietary choices and food preparation /preservation habits of consumers; reduction of food wastes**	++ ME	Reduced GHG emissions and energy use due to consumption of less meat and imported products and more fresh seasonal local produce and due to lower amount of food wastes	+ LE	Less household expenditure on food and thus less effect of rising food prices or lower incomes	Positive effects on health: less obesity; better nutrition More cash available for other household needs	
A-B	**Transformation of existing non-green spaces** (brownfields, underused car parks and squares**) into green, multi-use spaces**					Improved local environment, More recreational and eco-educational opportunities Enhanced food security and nutrition due to improved access to nutritious food close to consumer	

5 We refer here to use of excess heat, cooling water, CO2 and by products from industry, offices and block heating of residential buildings in green houses, aquaculture, production of animal feed, etcetera

6 We refer here to facilitating the functioning of local markets and shops close to the consumer rather than large super markets at urban fringe and forms of direct selling from local producers to consumers (farmers' markets, box schemes, home delivery schemes)

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