Food and crisis: the role of Controlled Environment Agriculture in building urban food system resilience

Insights from the scoping work of the Urban Food Futures programme in Nairobi, Cape Town, and Ouagadougou

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Abstract

The resilience of urban agriculture systems to climate change impacts has been little explored. It is known that urban and peri-urban agriculture (UPA) faces multiple challenges and constraints in the urban space ranging from soil and water contamination, exposure to climate-related risks and competition over space and resources often putting marginalized and poor population groups at a disadvantage. This part of the urban food futures programme (UFFP) aims to research UPA and controlled environment agriculture (CEA) as a potential adaption option for urban agriculture, protecting crops, livestock, and fish from extreme weather events or pest and disease outbreak. In this context we explored the role of UPA and CEA in building local food system resilience during a six-month scoping phase. We explored the soil health and soil quality in urban gardens in informal settlements in Cape Town (South Africa); conducted a feasibility study and cost benefit analysis on a selection of CEA systems in Kenya; conducted key informant interviews (KII) and focus group discussions (FGD) in Nairobi (Kenya) and in Ouagadougou (Burkina Faso) to better understand the role UPA can play in local food system resilience.

Still an issue even today is land ownership, affordable water access and quality, socio-cultural dynamics and unclear regulations of resource use, lack of regionwide knowledge and skill development, impact on dietary diversity, and market-oriented approaches. There are suitable CEA technologies available In Kenia and Burkina Faso from simple crop protection in the field to medium end facilities (hydroponics, plastic-/greenhouses). We find that UPA and CEA can create income opportunities, complement income, but it can also cause financial indebtedness. There are cost-efficient CEA systems available but need technical expertise, a continuous water and energy supply and enabling financial institutional support for farmers investments. Using CEA requires the provision of training and skill development by private and public institutions, rights to land usage or land ownership to enable long-term planning and investments, an enabling legal framework, access to agricultural equipment and inputs and a healthy biosphere in terms of a healthy soil and clean irrigation and wash water. Some schools in Nairobi practice UPA on their properties and use to some extend CEA. The school gardens help to produce at a noticeable quantity nutritious and more diverse school meals while also having a pedagogical impact. Overall, preliminary data suggests that UPA can complement local diets and diversify the food basket. At what quantity, needs to be explored further. UPA in Nairobi and Ouagadougou bears great potential to be multifunctional and could serve as a nature-based solution e.g., in the Greenbelt of Ouagadougou. To better deal with climate related issues such as flooding, water scarcity and energy lacks, some farmers practice agroecological techniques known from the rural areas now in Ouagadougou but also use micro gardens to save production during flooding and use solar energy to pump water up from boreholes.

We conclude that UPA and CEA can play a minor but important role in building local resilient food systems if adapted to the local needs and conditions while strengthening a local inclusive and enabling framework.

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List of Acronyms

CUA	Commune Urbaine d'Antananarivo
BMZ	German Federal Ministry for Economic Cooperation and Development
UPA	Urban and Peri-Urban Agriculture
UFFP	Urban Food Futures Programme
CEA	Controlled Environment Agriculture
FGD	Focus group discussions
KII	Key informant interviews
IPCC	Intergovernmental Panel on Climate Change
SCS	Safe Climate Space
HLZ	Holdridge life zone
KALRO	Kenya Agriculture and Livestock Research Organization
NEFSALF	Nairobi and Environs Food Security, Agriculture and Livestock Forum
PHA	Phillipi Horticulture Area
CNAbio	National Council of Organic Agriculture
MIF	Miramar International Foundation
MIC	Miramar International College
SUN	Sustainable Urban Neighbourhood Development
ABNA	Association Béo-Neeré Agroécologie
IDPs	Internally Displaced People's
FGD	Focus Group Discussions
NFT	Nutrient Film Technique
DFS	Drip Fertigation System
DWC	Deep Water Culture
KMALF	Kenyan Ministry of Agriculture, Livestock and Fisheries
VAS	Volumetric Aggregate Stability

BioSPG	Organic Participative Guarantee System
GHG	Greenhouse Gas
HSM	Homegrown School Meal

This paper was produced as part of the programme Urban Food Futures, which is a transdisciplinary action-research programme conducted in cooperation with TMG's partners from local governments, academia, and civil society. Our work is centred in Nairobi and Cape Town, where we focus on informal settlements and low-income areas with a high prevalence of hunger and poverty. In Ouagadougou we conduct selected research in the urban and peri-urban area. Our action research approach involves an ongoing process of joint reflection to arrive at a shared knowledge and understanding of challenges faced, possible solutions and future perspectives. A key element in this is the acknowledgement of different forms of knowledge, as well as of the lived experience of the communities with whom we work.

1. INTRODUCTION

This report synthesizes the six-month scoping work for the thematic entry point of Controlled Environment Agriculture and urban and peri-urban agriculture (UPA) guided in cooperation between Welthungerhilfe and TMG between October 2021 and March 2022. We explored the potential of UPA and CEA to increase the resilience of urban food systems in Sub-Saharan Africa to climate change. Case studies in three cities, Nairobi in Kenya, Ouagadougou in Burkina Faso, and Cape Town in South Africa, were analysed to better understand the potential of UPA and CEA and identify benefits, barriers, and enablers in cities in Sub-Saharan Africa.

Cities in Sub-Saharan Africa face multiple challenges including high rates of food insecurity, the fastest urban growth in the world and negative impacts of climate change such as rising temperatures and increase in the frequency and intensity of events such as droughts and floods (Vidal Merino et al., 2021). Urbanisation trends, climate change impacts and food security are linked. Cities have an important role to play in climate change mitigation and adaptation, while at the same time they need to ensure adequate access to basic services such as water, food, and energy as well as jobs and economic opportunities to their growing populations. Urban food consumption is a large source of these anthropogenic greenhouse gas emissions (IPCC, 2019). In the next 30 years, an additional 950 million people will be living in cities in Africa (OECD, 2020) with the need for affordable and nutritious foods.

The Intergovernmental Panel on Climate Change (IPCC) predicts that food production in some regions will become impossible if current emission rates continue. Consequently, competition over arable land will increase (IPCC, 2022). Climate change not only affects food production. Extreme weather events are disrupting transport ways and rising temperatures will make the transportation of perishable fruits, vegetables, and meat costlier to maintain quality (IPCC, 2022). The urban poor, already paying a large part of their income on food, will be most affected by disruptions in food supply and rising food prices (Vidal Merino et al., 2021).

Urban and peri-urban agriculture (UPA) is being promoted to enhance urban resilience through improving access to nutritious food, diversifying food sources, reducing the impacts of disturbances in food supply from rural areas or imports and reducing shocks of food prices (Lwasa et al., 2015; Palmer et al., 2017; Schipanski et al., 2016). The IPCC Special Report on Land and Climate Change states that "Urban and peri-urban agriculture and, more generally, the implementation of urban green infrastructure, can contribute to climate change mitigation (medium confidence) as well as to adaptation (high confidence), including co-benefits for food security and reduced soil-water-air pollution" (IPCC, 2019: 188).

We understand urban and peri-urban agriculture as the growing of food and other agricultural products (e.g., ornamental flowers, fodder) and raising of livestock (including aquaculture and apiculture) within the urban area and its periphery (Cilliers et al., 2020; Mougeot, 2000) including related input supply, processing, storage, transportation, and marketing activities (Tefft et al., 2018; FAO, 2007). The types of UPA are diverse and range from activities in marginal spaces, to small family plots, medium-sized farms, to larger-scale commercial operations (Tefft et al., 2018). The purpose of UPA varies from private gardens and rooftop gardens for own consumption to community-, allotment-, educational-, easement-, therapeutic-, health clinic gardens, urban consumer farms and edible walls to mention a few (Cilliers et al., 2020). UPA can be integrated in green belts, multifunctional parks, and forests as agroforestry (FAO, 2007).

Urban and peri-urban agriculture faces multiple challenges and constraints in the urban space ranging from soil and water contamination, exposure to climate-related risks and competition over space and resources often putting marginalized and poor population groups at a disadvantage leading to critique for its marginal contribution to food security in lower-income urban households (Crush et al., 2011; Frayne et al., 2016; Paganini and Lemke, 2020; FAO 2007). UPA is not new and has always been in conflict with city planners, developers and city authorities on land use (FAO, 2007). However, for a long time UPA was overlooked or dismissed by planners and policymakers in cities around the globe, resulting in UPA being often considered illegal by city officials (Hovorka et al., 2009). Impacts of UPA cannot be generalized and differ among the UPA types and management techniques applied, the crops/species used, the geographical location and local context (RUAF, 2014).

This report which formed part of a series of reports from the Urban Food Futures Programme (UFFP) aims to research controlled environment agriculture (CEA) as a potential adaption option for urban agriculture, protecting crops, livestock, and fish from extreme weather events or pest and disease outbreak (Mohareb et al., 2017). Innovative vertical systems such as hydroponics can be highly productive with a lower environmental footprint compared to conventional systems owing to the reduction in land, water, and fertilizer use (O'Sullivan et al., 2019). However, such systems can be capital and energy intensive, especially in the Northern Hemisphere where heating to produce vegetables indoors consumes considerable amounts of energy (Goldstein et al., 2016; Mohareb et al., 2017).

2. Background

2.1 Climate Change Impacts on Food Systems in Africa

Human-induced climate change causes widespread adverse impacts on nature and people. The increasing frequency and intensity of climate and weather extremes beyond natural climate variability exposes millions of people to acute food insecurity and reduced water security. The largest impacts are observed in Africa, Asia, Central and South America, Small Islands, and the Arctic (IPCC, 2022). Across many regions in Africa temperatures are rising more rapidly than the global average. Frequency of heat waves and drought on land have increased and the probability of marine heatwaves around most of Africa has doubled (Trisos et al., 2022). Multi-year droughts have become more frequent in West Africa, and the 2015–2017 Cape Town drought was three times more likely due to anthropogenic climate change (Trisos et al., 2022). The growth of agricultural productivity has been reduced in Africa by 34% since 1961, more than in any other region of the world (Ortiz-Bobea et al., 2021). Between 1974 and 2008 crop-dependent yield changes occurred, where maize and wheat yield for example decreased in sub-Saharan Africa on average 5.8% and 2.3% respectively, while other crops remained more or less stable or showed a yield increase (Ray et al., 2019). Farmers in Africa perceive many climate threats to crop production including droughts, precipitation variability, a delayed onset and overall reductions in early growing season rainfall and excess heat (Trisos et al., 2022). Callo-Concha (2018) finds that over half of farmers surveyed in West Africa perceive increases in crop pests and diseases as due to climate change as the range and seasonality of many pests and diseases change under warming. Pests and diseases contribute between 10–35% yield losses for wheat, rice, maize, potato and soybean in sub-Saharan Africa (Savary et al., 2019). Recent locust outbreaks in 2019 in East Africa have been linked to climate conditions caused in part by ocean warming (Wang et al., 2020). Future warming will enhance negative effects on food systems in Africa by shortening growing seasons and increasing water stress (Trisos et al., 2022). Kummu et al. (2021) find that global warming beyond 2°C (high emission scenario) will place nearly all of Sub-Saharan Africa cropland outside of its historical Safe Climate Space. The Safe Climate Space (SCS) is here defined as the climate conditions to which current food production systems are accustomed (Kummu et al., 2021). The model looks at three decisive factors for agricultural production: precipitation, temperature, and aridity based on the Holdridge life zone (HLZ) concept. The model then combines change in the life zones with current production of major food crops and livestock types and the resilience of human societies to cope with these changes (Kummu et al., 2021). Results show that under a low-emissions scenario, the areas under most critical risk (i.e., lowest 25th percentile of resilience and top 25th percentile of climatic change) lie in the Sahel and the Middle East, covering around 1% of global crop and livestock production (Figure 1) (Kummu et al., 2021). If nations are not able to halt the growth in greenhouse gas emissions and the global community ends up following the path of the most extreme climate change scenario, 32% of crop production and 34% of livestock production areas would fall outside the SCS (Kummu et al., 2021). The most critical areas would then cover most of the Middle East, large parts of South Asia and sub-Saharan Africa and Central America (Figure 1). In Africa, particularly Benin, Burkina Faso, Chad, Côte d'Ivoire, Guinea-Bissau, Niger, and Sierra Leone, would face severe challenges in producing their food if the world community fails to reduce emissions and their resilience remains low (Kummu et al., 2021).

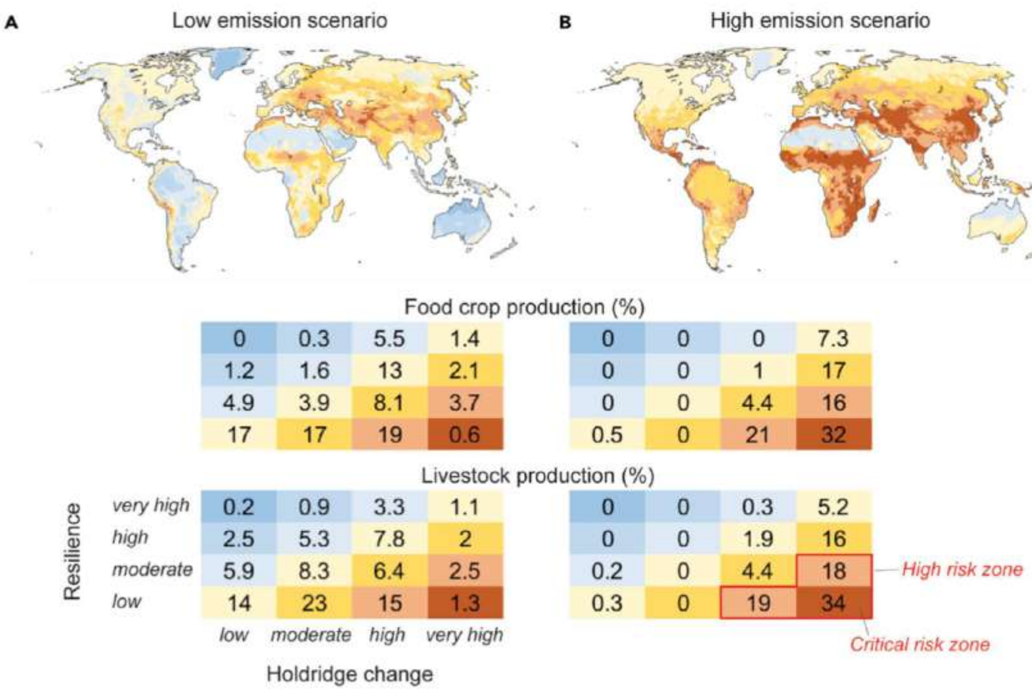

Figure 1: Future climate changes based on the Holdrige Life Zone concept for 2081-2100 combined with the resilience of human societies to cope with these changes under a low (A) and high (B) emission scenario (Kummu et al., 2021).

In many areas highly affected by climate change the resilience to cope with the change is currently low. Exposure and vulnerability to climate change in Africa are multi-dimensional with socioeconomic, political and environmental factors intersecting (Trisos et al., 2022). Many people in Africa are employed in climate-exposed sectors. In Sub-Saharan Africa 55–62% of the workforce is employed in agriculture and 90-95% of cropland is rainfed, making agricultural systems sensitive to water stress (Trisos et al., 2022). Production will not be the only aspect of food systems in Africa impacted by climate change. Processing, storage, distribution, and consumption will also be affected. However, most studies on climate change impacts on food in Africa focus only on production (Trisos et al., 2022). A significant knowledge gap exists around the complex ways in which climate change will interact with broader components of African food systems, and strategies for making these systems more resilient, particularly in a context of rapid population growth and urbanisation across the continent (Adenle et al., 2017; Schmitt Olabisi et al., 2018).

2.2 Literature Review on CEA

Controlled environment agriculture (CEA) is a broad field; however, it is being promoted to have the potential to produce more food with fewer resources on less land with less exposure to climate variability. In this chapter we review the meaning of CEA, key benefits and challenges of CEA in urban areas and identify current research gaps. Controlled environment agriculture is known since a long time (Dalrymple, 1973). As the term implies, Controlled Environment Agriculture (CEA) allows farmers to control different variables of the growing environment such as temperature, humidity, carbon dioxide, nutrient concentration, and light to a more or lesser extent (Agrilyst, 2017; Gómez et al., 2019; Dalrymple, 1973) but also root zone, growth media and the atmosphere (Dalrymple, 1973). A controlled environment (CE) can be defined in a broad range from minimum protection of crops from e.g., wind, rain and snow (protected cropping in the field) to partially controlled in greenhouses and up to high end facilities with complete CE (light, atmosphere, root medium) (Dalrymple, 1973). The term indoor farming refers to CEA implemented in various types of enclosed spaces (Agrilyst, 2017). Thus, the growing systems and structures can range from small-scale farms to commercial high-tech fully controlled and semi-automated greenhouses to everything in between (Agrilyst, 2017). For an overview of the most prominent growing systems and facility types see Annex Figure A1. CEA is not synonymous with urban farming (Agrilyst, 2017) but often controlled environment farms are located on the urban fringe to take advantage of shortened supply chains (O'Sullivan et al., 2019).

A key benefit of CEA is the ability to modify production environments to maximize plant quality and yield, extend growing seasons, and enable crop production in unfavourable climatic conditions (e.g., wind, rain, extreme temperature, and limited light). Amid climate change this will be an important feature as the increasing variability in temperatures and rainfall will make it more difficult for outdoor growers to predict and plan for coming growing seasons (Koundinya et al., 2018; O'Sullivan et al., 2019). Several authors have noted the role of controlled environment farms acting as an alternative food supply providing a cushion to external commodity price shocks due to weather or natural disasters (Ismail, 2015; Sioen et al., 2017). It has further been argued that farming in urban areas can increase the resilience of urban neighborhoods to shocks from natural disasters by providing alternative food sources not reliant on long, complex supply chains (Sioen et al., 2018). By controlling and thereby optimizing the growing environment for lettuce and leafy greens, CEA can be even more productive per m² than open field production (O'Sullivan et al., 2019). The productivity per m² of traditional greenhouses can further be increased by growing plants in vertical stacks or towers (Agrilyst, 2017; O'Sullivan et al., 2019). Urban farms can also enhance productivity of land by making use of space that is not used otherwise for example by growing in abandoned buildings, on rooftops, or walls (O'Sullivan et al., 2019).

Farming in an enclosed environment reduces the leakage of resources such as water and nutrients. For example, hydroponic systems have a significantly lower water demand than soil-based production. It has been calculated that water demand in a hydroponic lettuce production in southwestern Arizona, USA has on average 13 ± 2.7 (± standard deviation) times less water demand compared to conventional production (Barbosa et al., 2015). These efficiencies are driven by control of humidity and temperature to optimize transpiration, by on-site recycling of water, including condensation of transpired and evaporated water vapor from humid air, and on-site collection of rainwater (Astee and Kishnani, 2010; Thomaier et al., 2015). However, it needs to be noted that not all controlled environment farming systems are as water efficient, aquaponic systems for example have a higher water demand (Annex Figure A2). It is generally recognized that CEA systems restrict the entry of pests and diseases thereby reducing the use of pesticides and insecticides (Roberts et al., 2020). However, occurrence of pests and diseases cannot entirely be prevented (Goodman and Minner, 2019). The often warm and humid conditions in CEA structures even can be favorable for pests to propagate once introduced (Roberts et al., 2020). Integrated Pest Management (IPM = combination of durable, environmentally, toxicologically, economically justifiable farming practices to prevent pest damage primarily through the use of natural factors limiting pest population growth and disease development, and which resort only if needed to other, preferably non-chemical, measures) in greenhouses is well developed and applied in many countries worldwide (van Lenteren and Nicot, 2020). However, Roberts et al., (2020) note that little rigorous research has been conducted on pest and disease control in more novel vertical farming systems.

Energy use is a key cost of controlled environment farms (O'Sullivan et al., 2019).

Research on energy consumption found that the hydroponic production of lettuce in Arizona requires 82 ± 11 more energy per kilogram produced than the conventional production of lettuce in Arizona (Barbosa et al., 2015). Dominating the hydroponic energy use are the heating and cooling loads followed by the energy used for the supplemental artificial lighting (Annex Figure A2). This is primarily due to the fact that the greenhouse was sited in Yuma, Arizona, an area which can have average temperatures of 34.7 °C in the summer and 14.1 °C in the winter. Due to the high energy demands, Barbosa et al. (2015) find that commercial hydroponics is not a suitable alternative to conventional lettuce production in Yuma, Arizona. However, greenhouses located in more moderate climates (i.e., climates closer to the greenhouse set point temperature) experience a lower energy demand. In fact, in certain climates heating and cooling systems may not be required, but instead replaced by a passive ventilation system, thus reducing the overall energy demand considerably. The feasibility of hydroponic systems is hence heavily reliant on the climate of the farming location (Barbosa et al., 2015). The cost-benefit might change especially with the current crisis and increasing energy costs.

Advances in technology and by linking operations to renewable energy sources where possible are also improving the sustainability and energy efficiency of CEA. Cheaper, more efficient lights such as LEDs have been a critical factor in reducing production costs of indoor farming (Kozai et al., 2016). Other design factors, such as the use of geothermal or urban waste heat for heating and integration of solar photovoltaics to meet energy needs are also improving system economics (Togawa et al., 2014). A risk with the reliance on energy are power outages and/or system failure that might damage the system. Labor is the second largest cost in many controlled environment farms, following energy (O'Sullivan et al., 2019). There are two aspects that drive up labor costs. First the cost of living in urban areas is generally higher than in rural areas and accordingly staff costs are also higher. Second, the skill set required for controlled environmental farms tends to be more advanced than that of a field laborer and hence command a higher salary (O'Sullivan et al., 2019). CEs are perceived to have fewer potential food safety risks than field-grown produce due to their isolation from the soil and wild animals. However, human pathogens, heavy metals and chemicals can still be introduced into CE production systems from various sources including water, substrates, and human contact (Gomez et al., 2019). Currently, crops grown in CE systems are often limited to those with short growing seasons such as leafy vegetables. Vertically grown crops are more expensive than field-grown produce, and thus not accessible for low-income urban dwellers (Al-Kodmany, 2018). While urban farms are uniquely placed to take advantage of urban waste, energy, water, and nutrients further innovations are needed to use these resources (e.g., wastewater) safely and economically (O'Sullivan et al., 2019).

3. Urban and Peri-Urban Agriculture (UPA) in Nairobi, Ouagadougou and Cape Town

3.1 UPA in Nairobi

According to the 2019 Kenyan census, there are approximately 32,000 farming households (majorly women) in Nairobi City (KNBS, 2019). For much of the city's history, such farmers have operated under the constant threat of prosecution. That is because prior to the passage 2015 Urban Agriculture Promotion and Regulation Act, farming in Nairobi was illegal as local and national authorities entrenched a colonial policy which criminalized urban agriculture. The law brought up to date the long overdue inclusion of agriculture in urban planning regarding land use, food policy and market infrastructure. It sought to promote urban food security and job creation by enhancing urban farming, access to land and water, value addition, and value chain development (GoK, 2015). The law has been criticized as 'weak on promotion and heavy on regulation' by the former Food Advisor for the city seconded by the C40 Cities. This implies that while there is a legal framework regulating UPA, there is little institutional support, as illustrated by the low prioritization of agriculture in Nairobi's budgeting process. As of 2017, Nairobi City County Government employed 172 extension officers, with the intention of increasing the number to 248 by 2022 (GoK, 2018). Due to the limitations of the public sector's demand-driven and the NGOs' beneficiary-led extension approaches, primarily farmers often learn from each other. Urban farming provides only a limited proportion of the city's food, with GoK (2020) reporting that the greatest contribution coming from eggs (18% of the city's needs) and herbs and spices (10% of city's needs).

Production Patterns. Njiru, Kasarani and Dagoretti, three of Nairobi's 11 per-urban sub-counties, account for more than two thirds of its farming households (KNBS, 2019). Located on the outskirts of the city centre, arable land is more readily available in these locations. The 2019 Census also reveals that more that almost 70% of all urban farmers in Nairobi produce for own household consumption, with the excess going to the market. Typically, this entails small-scale vegetable growing, characterised by minimal use of inputs such as certified organic seeds and chemical and mineral fertilisers. Small-scale farmers improve soil fertility by using animal or compost manure, and they source their seeds from agro-veterinaries supply shops. On the other hand, pigs and poultry are the most commonly reared animals (JKUAT, 2020). Extension services are provided by the county government, parastatals, research, and training institutions, such as the Kenya Agriculture and Livestock Research Organization (KALRO). Non-profits such as the Ruben Centre, and non-government organisations such as Mazingira Institute (GoK, 2018) also play an active role. More recently, there has been an emergence of companies whose sole focus is provision of extension services to urban farmers (Waweru, 2022). The Covid-19 pandemic led to increased interest in urban agriculture in the informal areas as households sought to produce their own food to cope with the loss of incomes from jobs. Kitchen garden design services experienced high demand during this period. Some middle-class people started urban farming as they were staying at home and had ample time. One such group organized the ShambaJijini virtual summit in October 2021 with over 50 speakers discussing a variety of topics on regenerative urban agriculture such as organic farming, food security, permaculture, waste recycling, and markets among other subjects (ShambaJijini Summit, 2021). Unlike in rural areas, urban farmers are rarely involved in self-organisation for market access or collective action through social movements. In a survey sampling over 300 farmers in Nairobi, only 18% were organised in formal groups, with the most popular form of the organisation being self-help groups and community-based organisations (CBOs; JKUAT, 2020). While such organization is being promoted by organizations like the Nairobi and Environs Food Security, Agriculture and Livestock Forum (NEFSALF), participation is still low (RUAF, 2019).

Barriers to UPA. Urban agriculture in Nairobi is mainly hindered by a lack of suitable land, insecure land tenure, and competition for urban space from other land uses in a rapidly growing city. Increasing demand for housing has pushed the urban poor to less habitable interstitial areas such as riparian land, road and railway sides, and power line reserves. Such informal settlements provide only limited space, often inadequate for farming. Even when they do farm, the urban poor who form 60% of the city's population, typically do not have title deeds for the land they cultivate (GoK, 2018). Water scarcity is a further hindrance to agriculture in Nairobi. Most city residents do not have an adequate supply of clean, safe drinking water. In this context water for irrigation is even scarcer. Most farmers therefore rely on rainfed agriculture, which is seasonal and unreliable (JKUAT, 2020). There are also cases where farmers use water from rivers that are heavily polluted with domestic and industrial waste. This is a major public health concern with produce grown using such water reported to contain high levels of contaminants, including faecal matter and heavy metals. Poor urban farmers also experience difficulties in accessing quality inputs like planting materials, seeds, or vaccinations for livestock. One group of farmers in an informal settlement described losing 300 pigs to African Swine Flu, while others explained they could not afford high-quality dairy goat breed (personal communication). Farmers are faced by the constant challenge of theft of produce, especially in informal settlements where urban farmers grow crops on communal or government land along rivers, roads, powerlines, and railway reserves.

Opportunities for the future of UPA. The 2018-2022 Nairobi County Integrated Development Plan developed flagship projects in schools to install greenhouses, multi-storey gardens, hydroponic systems, fishponds, and water tanks in schools to enhance crop productivity, incomes and promote food security (GoK, 2018). While the fact that a majority of these projects are yet to be implemented is problematic, it also opens an opportunity for a broad range of UPA interventions from non-governmental players through Controlled Environment Agricultural technologies. Although Kenya has a National School Meals Programme targeting vulnerable communities, it has not been widely rolled out in Nairobi, and schools have been forced to devise their own programmes. The recently launched '4-K' agriculture clubs ('Kuungana, Kufanya, Kusaidia Kenya', 'coming together to act, to help Kenya') could grow food to supplement schools' food requirements, or the government could support community members to grow food for schools. Thus, utilization of the public land held in schools could be an entry point in promoting UPA interventions. Furthermore, Nairobi has joined global platforms addressing food insecurity or received support in designing sustainable food systems. In 2015 Nairobi joined of the Milan Urban Food Policy Pact and in 2021 it was selected as one of six cities in which the FAO's Green Cities Initiative will be piloted (MUFPP, 2015; FAO, 2021). Between 2017 and 2020, FAO and the C40 Cities supported development the Nairobi City Food System Strategy (GoK, 2020). The inclusion of Nairobi in such forums makes it a suitable location to develop UPA interventions, particularly those inclined towards controlled environment agriculture.

3.2 UPA in Cape Town

Production Patterns. In Cape Town, an estimated 5000 small-scale and micro-farmers have been supported in backyard food production by local NGOs since years. Typically, a majority of the farmers are women aged 50 to 60 and grow crops for their own consumption with minimal economic impact (Paganini et al. 2018). Usually seed and seedlings are supplied by NGOs and most often include spinach, onions, carrots, peppers, lettuce, brinjals and others. While some producers keep small livestock, particularly chickens and goats. Likewise, the local government also supports urban gardening with training, input and infrastructure, with a reported 152 projects running in 2014 (Battersby et al., 2014). The

City promotes and supports urban agriculture through two City policies – the Urban Agriculture Policy under the Urban Agriculture Unit within the Economic Development Directorate, and the Department of Social Development's Food Gardens Policy in Support of Poverty Alleviation and Reduction (2013). Besides food security and value chain development, these policies also seek to encourage climate change mitigation and adaptation, as well as urban greening initiatives (Haysom 2015). An important aspect of food production in the City of Cape Town is production on wetlands of the peri- urban Phillipi Horticulture Area (PHA). Water resources and natural defences against winds makes the PHA a valuable agricultural location supporting 34 farms which create more than 2800 direct jobs. There are hundreds of additional jobs created along the value chain including input provision and packaging and logistics. Of these farms, approximately five are large scale commercials, 20 commercials and 9 smallholders. At least 33 different crops are grown here, while intercropping and rotation means that three or four different crops can be grown per annum. The most popular crops include cabbage, carrots, lettuce, herbs, spinach and cauliflower. Much of this produce is sold to the city's main commercial fresh produce market – Epping Market - and to South Africa's five main retailers (Western Cape Government, 2018). The greater PHA comprises over 300 000 hectares, much of which is now mixed use, and is also home to nine informal settlements. This area, which is also zoned for sand/silica mining, is constantly being encroached upon by urban development needs. Just over 180 000 hectares currently remain for farming. Barriers to UPA. Access to land is a major challenge, with many farmers growing in school grounds and annexing whatever small, abandoned pieces of land are available and growing in containers and back yards. Land tenure is precarious, leading to an unwillingness among farmers to invest in long-term infrastructure or perennial crops such as trees. Access to water is also problematic and the intense drought of 2018/19 was fatal for many of these gardens. These problems are further worsened by poor soil fertility, pests, and harsh climactic conditions such as elevated temperatures, wind and flooding (Paganini et al., 2018). Urban farmers in Cape Town, especially the small-scale ones, experience a number of structural challenges. The policy environment is fragmented and inappropriate, primarily incentivizing a large-scale commercial, corporatized value chain approach. The policies are therefore unable to effectively accommodate the highly diverse scales of production, production methodologies and market approaches of small-scale and urban farmers (Greenberg and Drimie, 2021). Limited buying power on the part of local populations means that farmers sell their healthy produce to more distant affluent markets. Coupled with high levels of food waste, the selling of food to external markets means nutritional security in marginalized communities are not fully addressed by UPA (Haysom and Battersby, 2016). Furthermore, most of the market-oriented produce is sold through "box schemes" run by NGOs or private intermediaries, which further extracts resources from the communities (Paganini and Lemke, 2020).

Opportunities for the future of UPA. Despite the challenges mentioned above, there are a number of opportunities which present pathways to enhancing the impact of urban and peri-urban agriculture on the local communities of Cape Town. To begin with, farmers are organizing themselves to shift power relations in the local food system in their favour (Paganini and Lemke, 2018). Some self-organized farming collectives, which take more control and ownership of the process, are beginning to emerge. Farmers and other stakeholders in community food systems are beginning to embark upon a process of "community dialogues". These dialogues are meant to build hyper-local food systems, peer-to-peer learning systems, networks of care as well as solidarity and advocacy platforms. Farmers have identified urgent policy needs including simplified procedures to access land, infrastructure, and services to establish local markets. They also seek preferential government procurement policies, better government policy linkages between agriculture and nutrition, and consumer awareness campaigns regarding the social and ecological benefits of agroecology

(Paganini et al., 2019). The Covid pandemic led to more charged discussions on food sovereignty, climate change and the role of UA in future endeavours to ensure food and nutrition security in South Africa, a highly urbanized country. These discussions shone a light on the fault lines of South Africa's corporatized food systems and the dire need to devolve food production and access to local levels. Therefore, for the first time, South Africa's Ministry of Agriculture became aware of urban farmers and micro-farmers and acknowledged that this sector needs diverse kinds of support as given to commercial farmers. This acknowledgement hints at more governmental support for UPA the future.

3.3 UPA in Ouagadougou

This chapter is partly based on personal communication and experience, which to some extend could not be supported due to limited literature available. Ouagadougou, the capital of Burkina Faso, is experiencing exponential population growth. In 1960, the city had about 59,000 inhabitants, which is now estimated at 2.5 million, or 45.4% of the country's total urban population (RGPH, 2019 and INSD, Burkina Faso, 2020). Reasons are a decline in the mortality rate, particularly among infants, and internal migration (Ouattara, 2009; Delauney, 2009). Migrants from rural areas of Burkina Faso have sought employment in the capital's growing number of small industrial units and its service sector, while more recently the prevailing security crisis in the North, Sahel, North Central and East of the country is increasing the movement of internally displaced people towards urban centres, including Ouagadougou. The demographic explosion has been accompanied by significant food, economic and land challenges, in response to which urban and peri-urban agriculture has emerged as a partial solution. About 3,000 people, 52% of whom are women, earn their living from urban production in the urban and peri-urban area of Ouagadougou (Milan Urban Food Policy Pact Forum, 2021). Although it contributes to food security, job creation and the provision of livelihoods, and to the city's sanitation, urban agriculture is not yet acknowledged by the state and municipal authorities as an important component of the economy of Ouagadougou, due to its precarious nature. This brief document aims to look at urban and peri-urban agriculture in Ouagadougou in a holistic way, which includes discussion of its political and social aspects.

Production patterns and available services in UPA. The distribution of food production in the city of Ouagadougou is determined mainly by the availability of land and water. The city's large dams, located in Koubri and Loumbila (peri-urban area), Boulmiougou, Tanghin, Baskuy have been sites of food production since the 1920s (Bagré et al., 2002). Given the rapid population growth, and associated demand for land for housing, urban farmers struggle to access land. They therefore grow crops in the vicinity of wastewater sources (Sawadogo, 2008), on undeveloped areas or where infrastructure development is not very feasible (Bagré et al., 2002) and in the green belt that surrounds the city (Figure 2). Ouagadougou's greenbelt (2,100 ha in total, of which 1,050 ha are developed over a distance of 21 km and a width of 500 m), extends from the northeast of Kossodo starting from the extension of the Massili branch and crossing the Ouaga-Kaya Road to the Ouaga-Bobo Road at the West of the city (Koueta, 2019). The other 1050 hectaresof Ouagadougou's greenbelt are legally (some parts have been parceled out for housing) or illegally (informal settlements) occupied today due to urbanization and strong population growth.

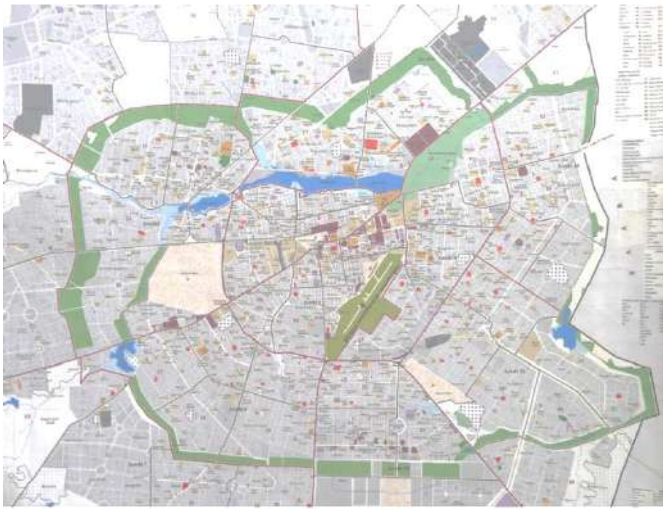

Figure 2: The Ouagadougou's greenbelt in Burkina Faso. Image: Griebel, S.

Market gardening is the main form of agriculture practiced in Ouagadougou. It accounts for nearly 70% of the sown area and the remaining 30% is dedicated to horticulture and cereal growing (Robert et al., 2018). Crops grown are dependent on the season and production areas (Bellwood-Howard et al., 2015). During the rainy season, the main crops produced in urban areas are lettuce, amaranth, okra, and peanuts, whereas farmers in peri-urban villages grow cereal crops such as sorghum, maize, and millet in the same period. In the dry season urban producers grow leafy vegetable such as lettuce, amaranth, cabbage, and the peri-urban farmers grow others. Thus, urban and peri-urban farmers complement each other in food production and contribute to food diversity. Production techniques depend on the available space. According to Sy et al. (2017), most urban and peri-urban farmers practice mixed cropping (polyculture) with the aim of maximising profits on small areas of land. Monoculture is typically practiced only with fairly profitable crops, such as strawberries, produced in Boulmiougou. Horticultural production is organised with an eye to eventual sale, with plants grown in nurseries using plastic bags for easy transport to the place of sale, usually alongside major roads. Agriculture in Ouagadougou and its peri-urban area is not only centred on crop production. Farmers also keep cattle, sheep and goats, pigs, rabbits, and poultry. Due to the high consumption of chicken by city dwellers (more than 80,000 are consumed per day in Ouagadougou), poultry farming is the most common form of livestock farming. Around 93% of the farmers settled in the periphery of Ouagadougou thus combine the production of one of these species with their agricultural production activity (Bellwood-Howard et al., 2015). Depending on the nature of the agricultural inputs used in production, urban and peri-urban agriculture in Ouagadougou, the people tend to categorize it as "conventional" and "agroecological" agriculture.

Collective action and organisation of farmers. Urban farmers in Ouagadougou are not well organised collectively, i.e., they are rarely self-organised around common objectives such as production planning in time and space, market access or capacity building sessions, etc. Conventional producers here defined by locals as those who still produce using chemical agricultural inputs, represent the largest group of urban farmers in Ouagadougou, mostly produce and market on their own. To our knowledge they are not much organised in cooperatives to defend their common interest and are unfortunately kind of neglected by some NGOs. On the other hand, producers who committed to the agro-ecological transition, which was encouraged by Thomas Sankara during the Revolution (1984-1987) through his policy of sustainable agriculture, tend to be better organised in cooperatives to defend their common interests under the aegis of the National Council of Organic Agriculture in Burkina (CNABio). Together with NGOs such as ACRA, Mani Tese, APIL, CEAS-Burkina, and development institutes such as PAID-WAS, trade fairs and weekly sales are organised to secure market access. Agroecological farmers also benefit from technical support, regular capacity building sessions and the establishment of a local certification (BioSPG), led by CNABio and its partners. They are supported in their efforts by specialised state and municipal services. Private services are focused on the agricultural inputs' commercialisation. It is important to note that farmers meet periodically to define the prices per kilogram of the crops they produce to be applied on the market.

Overview of the commercialisation of market garden products. The UPA in Ouagadougou is more oriented towards sale than private consumption (Robert et al., 2020). Agricultural products are marketed through several channels and strategies: there is domestic sale, which is based on neighbourhood and street markets; sales in the vicinity of production areas (market gardening fields/sites); and export of products to bordering countries bordering such as Côte d'Ivoire, Mali, Togo to mention a few. Exported products are of higher commercial value such as strawberries (Sy et al., 2020). There is also wholesale to hotels and restaurants in the city, who receive deliveries of organic products from urban and peri-urban livestock farmers (eggs, meat, etc.), and fruits and vegetables from market gardens in the city and on the outskirts. There are periodic fairs organised by professional associations, umbrella organizations and NGOs to facilitate the sale of agricultural products from UPA and help to integrate producers into more structured marketing networks and circuits. In terms of distribution, in most cases it is the producers themselves who take their products to the city markets in small quantities on their own motorbikes and bicycles. Some of the farmers increasingly use digital technology for marketing, e.g., associations like *La Saisonnière,* contact their customers via WhatsApp when products are available, organise deliveries, but still prefer a marketing policy that customers visit the urban farm to see produce quality and to socialise with the female farmers. Initiatives like mobile markets or online fresh produce markets (such as Ouagayaar or zinbis yaar) could give a boost to urban producers wanting to reach a wider market. Although processing is important to minimize losses and add value to agricultural products, products from UPA in Ouagadougou are rarely processed, and only to a limited extent. This could be maybe explained by the fact that production is small-scale, but also by the lack of expertise.

Barriers to UPA. There is a *lack of legal and regulatory framework* – UPA is neither officially recognised nor prohibited in the city. As such, there is no official law regulating it, but there are incoherent pieces of legislation such as the Agrarian and Land Reorganization Act (1996) that prohibits farming, and the Urban Development Master Plan for *'Grand Ouaga'* (1999) that allows farming on condition that the municipal authority can repossess the land for infrastructure projects (Robert et al., 2020). This creates confusing conditions that are detrimental to the development of the sector (Sy et al., 2017). *Access to land* is the main barrier to the development of UPA in Ouagadougou. Urban farmers live with the fear of being dispossessed of their land by the municipality, whether they are owners or tenants. Most producers do not have secure access to land. Land security is reserved and granted by customary chiefs, heirs and the municipality, who are the main holders of land control rights. Only 20% of the farmers have a property right on their production land. The majority have a temporary acquired right. This temporary acquisition can be done by renting (an area of 240 m² is rented for 39 euros per year) or by loan (the landowner gives his land to the producer because he is not yet ready to develop it) (Sy et al., 2017). Only a few well-organised associations (La Saisonnière, Beo-Neere, etc.) are legally established on their production sites with documents acquired from the local council. *Access to water is a barrier* –farming in Ouagadougou began around the dams initially intended to supply the city with drinking water. This need has intensified with the population growth, leaving less water available for agricultural purposes. During common water shortages from February/ March until July; the dams dry up, making farming activity difficult. Farmers say they dig wells up to 15 metres deep or pay for water. The difficulty of accessing quality water leads some farmers to settle around wastewater sources (Sawadogo, 2008), result in that 75% of farmers use wastewater to irrigate crops (Ouedraogo et al., 2018). Although the use of wastewater increases soil phosphorus and potassium levels, which improves soil fertility and crop yields, it raises public health concerns and has adverse effects on plants, animals and humans. Farmers in prolonged contact with this wastewater complain of dermatitis, dry skin and cracked feet. Some consumers report parasitic and diarrhoeal diseases (Ouedraogo et al., 2018). *Market access* – Market accessibility remains a major challenge for agroecological farmers. According to them, consumers prefer conventionally produced food of lower price. So, instead of selling at a loss, they try to raise awareness of the nutritional and health value of their products and organise weekly sales to create a market niche. *Expensive agricultural equipment and inputs* are a challenge as well – Most farmers in Ouagadougou have a very low income. They cannot afford equipment and inputs (seeds, fertilisers, pesticides, etc.). For example, in 2021 we visited a site where there were just two watering cans shared between a dozen farmers. In response to our question as to why, a farmer explained that a quality watering can cost 10,000 CFA francs, which he said is the equivalent of several days of household food.

Opportunities for the future of UPA. Urban agriculture in Ouagadougou is a source of income for farmers, job creation, environmental management and it contributes to the food security of vulnerable urban dwellers (Sy et al., 2017). Urban agriculture has the potential to mitigate climate change effects and desertification. The African Union has been implementing strategically the Great Green Wall for the Sahara and Sahel project since 2007 to combat the effects of climate change and the advancing desert in Africa. It is an initiative that aims to transform the lives of millions of people by creating a mosaic of green and productive ecosystems in North Africa, the Sahel and the Horn of Africa. Urban architect David Zouré, promotes urban agriculture in Sahelian cities and refers to the green belt in Ouagadougou as a practical case of using urban agriculture in a greening approach. The green belt was created to protect the city from wind and dust to control wind and water erosion, but also to create jobs and to provide rest and recreation areas for the inhabitants. It has subsequently been neglected, but the Ouagadougou City Council has recently undertaken a programme to reforest it, using an urban agroforestry approach. This approach includes to transform the so far illegally ran market gardens at the green belt into official market gardens. These gardeners are now responsible to take care of their gardens while maintaining and ensuring the survival of the trees planted for the reforestation of the green belt. In this way, horticulture, market gardening and forestry go hand in hand, each ensuring the sustainability of the other. Urban agriculture could also supply fresh food to schools. In Burkina Faso, the school meals lack nutrition diversity and key micronutrients. None of the feeding programmes serve fruit, raw vegetables, or fresh vegetables from market gardening (Garrido and Sánchez, 2015). In the past few years, the government has committed to provide at least one balanced meal a day for every school-age child. This could be an opportunity for urban and peri-urban agriculture. Local producers will provide the food for the canteens (in accordance with the new guide for the management of school canteens); this will increase agricultural production capacity (cereals, vegetables, milk, etc.). The *"Mangeons bien, mangeons sain"* project initiated by the Ouagadougou City Council, which is an-awareness-raising and training on nutritional standards and good hygiene practices and food standards in schools, would be a solid anchor to encourage urban populations to consume what they produce. Urban farmers could benefit from the market access opportunities offered by digital technology. Owners of online shops that specialise in selling fresh agricultural products (Zinbiss Yaar) seem to buy more from urban farmers. At the municipal level, the creation of the e-commerce platform *Ouagayaar* to increase the economic dynamism and visibility of social and solidarity-based enterprises, is an asset for urban farmers seeking a wider market.

4 Conceptual Framework of TEP 1 within Urban Food Futures

We aim to apply a resilience framework (**Figure 3**) to understand the potential of CEA in the context of UPA to enhance the capacity of a local urban food system to deal with uncertainties, absorb disturbances, re-organize, and maintain its functions (Elmqvist et al., 2019). When change occurs, resilience provides the capacity for renewal and reorganization (Folke et al., 2002). Vulnerability is the flip side of resilience: when a social or ecological system loses resilience it becomes vulnerable to change that could not be absorbed or adapted to (Folke et al., 2002). Cities in Sub-Saharan Africa are characterised by structural issues such as high rates of poverty and food insecurity, the world's fastest urban growth, inadequate infrastructure, and lack of access to services that make communities vulnerable to reoccurring and concurrent shocks (e.g., drought, flood, economic downturn) and stressors (e.g., corruption, insecurity). We understand that resilience results from a set of capacities or abilities (Béné, 2020). These capacities, depend essentially on a combination of assets or capitals (financial, physical, political, human, social, and natural) that households can draw on in anticipation, or in response to a sudden shock or a recurrent stressor (Béné, 2020). Communities' or households' coping capacities cushion shocks while their adaptive capacities provide the flexibility to deal with shocks. Transformative capacity provides the opportunity to create longer-term change to sustainably improve the community or household food system (Paganini et al., 2020).

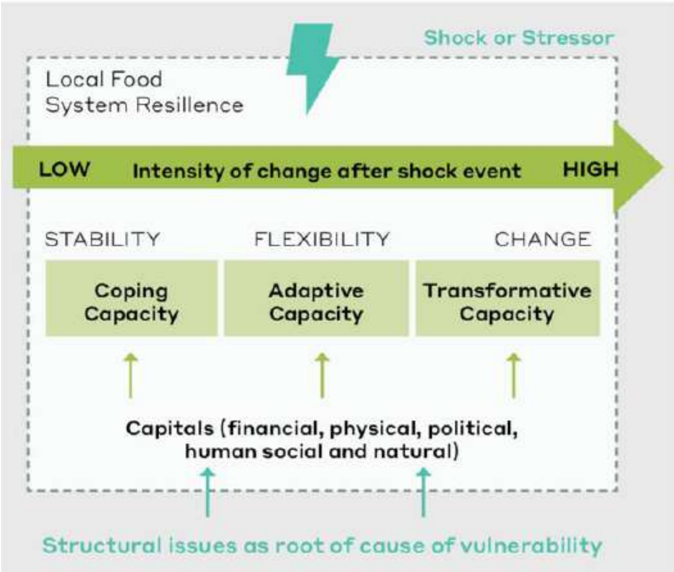

Figure 3: Local Food System Resilience adapted from Paganini et al. (2020) and Béné (2020).

4. Research Methods

In the following we describe our tools and methods used in the six-month scoping phase, which was time and budget constrained, to pave the way towards the action research and implementation phase of the five-year Urban Food Futures program. No long-term comparative studies took place between the three capitals/countries. Due to the limit in time and resources, and to the very nature of the scoping phase, no scientific studies could be conducted that build strong evidence answering the research questions.

Some sample sizes are rather small, some stakeholders/participants are not as independent as expected. Still, it seems there are different understandings of the meaning of agroecology by partners and participants in this study (compare FAO 2018; Gliessmann 2007, 2015; HLPE 2019), making it difficult to compile this report and discuss findings. However, the conducted studies and results provide valuable insights to help design the follow up phase.

4.1. Areas of study

To explore the field of UPA and CEA the three countries and capitals, Nairobi in Kenya, Ouagadougou in Burkina Faso and Cape Town in South Africa, were selected. The countries are geographically, culturally and climate wise very different and cover the West-African, East-African and South-African continent. The cities were selected based on their existing UPA and potential to research UPA and CEA in the context of climate change but primarily based on feasibility namely the capacity of the partner organizations to work in the country; have existing local partners; and country offices on the ground. TMG and WHH have country offices in Nairobi, while WHH has also a country office in Burkina Faso.

4.2. Stakeholders

Eight stakeholders were involved and selected based on their experience in the field of UPA and/or CEA and/or existing relationships with WHH or TMG. *TMG* is a think tank for Sustainability https://tmg-thinktank.com/about and leads the UFFP.

Welthungerhilfe (WHH) is a German based NGO with a vision of a world without hunger (https://www.welthungerhilfe.org/). WHH works in more than 35 countries in multi actor and multi country partnership programs in various sectors of the food system. The projects encompass the area of humanitarian assistance, development aid and research components. With its various country offices, WHH has implemented several urban and peri-urban farming projects over the past years (**Annex 4**). WHH aims to conduct local communities-oriented site-specific agriculture that works and helps to achieve the SDG goal two of "zero hunger" and the human right to food, and thus avoids being biased towards one approach that is supposed to fit all. Here the head quarter in Bonn Germany and the country offices in Kenya and Burkina Faso are involved.

The Miramar Group based in Kenya specialized on controlled environment farming, has a commercial and a non-for-profit arm (**Annex 1-3**). Miramar International Limited manages the commercial for-profit businesses of the group. The Miramar International Foundation (MIF) manages the non-for-profit aspects of the group with the support of international partners (https://miramarfoundation.org/). The Miramar International College (MIC) provides vocational agro-business training leading to certificates and diplomas such as training on agrobusiness management with a focus on controlled environments agriculture (CEA) including hydroponic and aquaponic growing systems (https://mic.ac.ke/). Over the past five years they have trained over 10'000 farmers on CEA systems and helped students set up their own agrobusiness by facilitating access to loans and markets.

Muungano wa Wanavijiji is a social movement and national federation of 'slum'residents and urban poor in Nairobi and all across Kenya (https://www. muungano.net/). They are active since more than 20 years, following a vision of inclusive cities where all people can live in dignity.

Sustainable Urban Neighbourhood Development (SUN) is an NGO, that supports communities in low-income neighbourhoods of Cape Town, South Africa, to transform their living environments into safer and more sustainable spaces with an improved quality of life (Annex 5).

Agro-Business Badouha located in Ouagadougou, Burkina Faso, is a limited liability company, founded in 2016, which evolves in the promotion of urban and peri-urban agriculture and CEA (Annex 8). The company focusses on agriculture under soil or no soil conditions, in the greenhouse and open field, including hydroponics in either environment. The company grows vegetables in greenhouses and open field on the outskirts of Ouagadougou and sells the fresh produce at the local markets. Badouha also accompanies farmers through training and provides technical advice in e.g., greenhouse construction, operational material and inputs needed up to the distribution of produce. In addition, they offer a four-month vocational training for youth to be trained in their local languages in UPA, CEA, including fish farming and agro-sylvo-pastoralism. They support to work sustainable and agroecological, while balancing out organic and conventional farming in a local context including access to agricultural inputs.

Association Béo-Neeré Agroécologie (ABNA) is a community-based association located in Ouagadougou, Burkina Faso, founded in 2013 (Annex 6). They do promote agroecology in Burkina Faso and provide training to youth, women and peasant farmers in Béo-Neerés' understanding of agroecology, which is understood as organic farming (zero input of conventional fertilizer and pesticides) as the way to go, that abandon conventional agriculture. The association works with local facilitators in four regions of the country that provide the support and training to the cooperatives related to livestock, growing vegetables and crops, building infrastructure, establish home and school gardens and market linkages, application of Béo-Neerés' inputs developed. The training and use of technics is adjusted to the different climatic areas of the country. The organization is a member of the National Council for Organic Agriculture (CNABio) and require their farmers to be or convert to organic farming.

La Saisonnière was founded in 2003 in Ouagadougou, as a small womens' pre-cooperative group supporting widows and female orphans only (Annex 7). Since 2006 it is a national association and supported internationally, focussing to overcome poverty of women in general. Their work is research oriented and in cooperation with local universities. Women and girls are trained in literacy, allotment gardening in UPA, to do carpentry, being a tailoress and all of this with a focus on a holistic approach including topics of moral, good citizenship to help them to integrate well into or back into society. Today the association is also a reference centre for sustainable agriculture and agroecology. The production is oriented towards the local market. La Saisonnière is a member of the National Council for Organic Agriculture (CNABio).

4.3. Surveys, interviews, group discussions on CEA and UPA

Each partner consolidated their experiences and lessons learned. The methodological approach includes surveys, key informant interviews and focus group discussions.

Key informant interviews in Kenya, Sudan, Zimbabwe, Lebanon and India by WHH: In the case of WHH an internal document study was conducted including a critical reflection on the studied documents and corresponding project evaluations. The identified five case studies provide insights into UPA (school and home/rooftop gardens) and CEA (hydroponics, greenhouses) in diverse settings (informal settlements, refugee and internally displaced people's camps (IDPs)) in Kenya, Sudan, Zimbabwe, Lebanon and India and were then used to identify corresponding key informants to be interviewed (Annex 4). A key informant interview (KII) guide was developed by WHH and reviewed by TMG Research and implemented during the scoping phase. The non-anonymous survey is based on open ended questions to obtain additional quality data of each case study. The interview guide was subset into seven sections related to the (1) project, (2) context description, (3) key benefits and enablers, (4) key challenges and solutions, (5) lessons learned and recommendations, (6) potential and (7) knowledge gaps of a case study. The KIIs were conducted virtually by WHH and TMG representatives with interviewees being key staff members of WHH, who had or still have a key role in the implementation of the case studies related projects. One key informant per case study was interviewed, while in the case of Kenya two people. Given the limited resources, limited time, the pandemic situation and the completion of some projects years ago, it did not allow us to interview a larger and more representative group of project participants involved. Thus, the sample size of six individuals, even from different projects' case studies, is small, hardly representative and cannot be generalized. However, it provides valuable insights for a scope study to start off and follow up. It is needed to keep in mind that the case studies do not represent the target environment of the target countries of the UFF project, except maybe the Kenyan studies.

Feasibility study of CEA- Key informant interviews (KII) and focus group discussions (FGD) in Nairobi (Miramar Group): The MIF conducted a feasibility study (Annex 1, 3) to assess the status and understand the potential of smart farming systems (here CEA) for food production in informal settlements in Mukuru, Nairobi. The methodology was a two-step process of (1) key informant interviews and (2) focus group discussions. The study was carried out in partnership with Muungano AMT (supported by TMG research; little by WHH). The participants' selection was facilitated by Muungano Akiba Mashinani Trust, already working in the community. *Key informant interviews:* The KII was a semi-structured survey, with a descriptive design and purposive sampling method. The KII were conducted with Mukuru community leaders and the Reuben Center (school). The KII with *Mukuru community leaders* were based on the specific questions (1) How is the availability and accessibility of land in Mukuru?, (2) How is the availability and accessibility of water in Mukuru? , and (3) What are the conflict resolution and management channels in Mukuru? The KI interviewees selected were community leaders, political leaders and community-chose opinion shapers, who have vast experience on land access, common resources management and policy development in Mukuru. In total four KI interviewees (gender balanced) were selected representing (1) the area chief, (2) the village elder and women leader, (3) the youth leader, and (4) Nyumba kumi leader. The KII *with Reuben Center (school):* The specific questions are (1) What is the general profile of Reuben Center with a focus on population, facilities, water quality and availability, electricity, and its challenges? and (2) Provide a brief description of Reuben School highlighting the number of students, teachers, school feeding status, type of food, frequency and its challenges, available idle space? The questions aimed to collect information on the possibility of the school establishing CEA and to supply food produce to the school kitchen considering the number of people to feed and how they can benefit. MIF conducted the interview with one key informant only, namely the director of the Reuben Center to learn about its feasibility to support crop production, accommodate CEA and provide food produce for the Reuben Centre primary school. Thus, the KII is hardly representative but provides valuable first insights. The additional *Focused group discussions with Mukuru farmers addressed* specific questions on (1) What is produced and consumed in Mukuru? (2) What are producer-market linkages that exist in Mukuru? (3) What gaps are there, in terms of knowledge and skills of hydroponic farming in Mukuru? and (4) What are the training needs of the Mukuru community? To address these questions, the study conducted FGD with food producers/farmers in Mukuru. In total eight farming groups were built and from each, one representative person selected. The eight representatives (gender balanced) build than one group to conduct the FGD.

Individual online interviews of farmers/market gardeners in Ouagadogou (Agro-Business Badouha). The goal of the scoping work of Badouha (Annex 8) was to collect insights on their own soilless CEA system in Ouagadougou. The starting point for Badouha's study was the socioeconomic and demographic context of the city of Ouagadougou. This allowed for a better understanding of the challenges related to the terrain, climate, water resources and access to land (intense pressure on urban agricultural spaces) due to the galloping demography and urbanization. A survey was conducted as a poll with 66 farms located at different market garden sites in Ouagadougou. The survey focusses on (1) water source used, (2) the period of water access, (3) the distribution of agricultural practices, (4) advantages and driving forces of Badouhas' system, (5) challenges, (6) potential solutions, and (7) its potential as a system.

Focus group discussions with producers and facilitators in Ouagadougou (Association Béo-Neeré Agroécologie (ABNA)). Béo-Neeré (also defined as support structure) conducted a literature review followed by the design of three questionnaires (drafted by TMG and WHH) that were used in interviews with individuals and in focus group discussions (Annex 6) to collect firsthand data of producers and facilitators in the peri-urban area of Ouagadougou with a focus on agroecological farming (here defined as zero chemical inputs, organic farming). All producers and the facilitator are located at four sites (1) the agroecological farm Roumtenga, (2) the women's garden Nioko II and (3,4) two farms at the dams in Tanghin and Tampouy). One questionnaire (focus group interview guide), aimed to guide four focus group discussions of 38 producers at four different production sites, while a second questionnaire was used to sub-sample 13 individual participants (gender balanced) of those focus groups. In addition, a third questionnaire was designed to interview organizations/facilitators that work with those producers. The focus group interview guide and the individual questionnaire are both divided into five sections addressing UPA such as (1) participants' information, (2) production techniques at peri-urban agroecological production sites, (3) challenges of peri-urban agriculture, (4) potential of peri-urban agriculture for young people, (5) training needs for young people in peri-urban agriculture. However even so the sub-sections explicitly ask for peri-urban agriculture, some questions address also urban agriculture. The third questionnaire for organizations/facilitators is divided into sub-sections covering (1) general information of interviewee, (2) support for UPA, (3) insights gained and recommendations, (4) potential of UPA system promoted, (5) knowledge gaps in UPA.

Retrospective study with market gardeners using an online platform in Ouagadougou (La Saisonnière). La Saisonnière conducted a retrospective study in Ouagadougou and surroundings with market gardeners/producers (Annex 7). For that they developed questionnaires, that were created as survey sheets implemented on the KoBotoolbox platform to collect data with mobile phones. The survey aimed to (1) define actors in UPA, (2) their activities, (3) identify benefits and (4) challenges, (5) determine the potential of UPA and (6) formulate recommendations for UPA and agroecology in Ouagadougou. In total 44 individuals of market garden sites from eleven locations in Ouagadougou participated, which were gender imbalanced (7 men, 37 women) and belonged either to a group working with the association itself or a group of independent market gardeners.

4.4 Soil sampling for chemical, physical and biological properties

The *organization Sustainable Urban Neighborhood Development (SUN)* investigated different urban farming sites in Cape Town to report on soil, water and plant leave samples and their potential health implications for humans. Since the water and leave sampling failed, the methodology of soil sampling and following lab analyses are reported only (Annex 5). The specific objectives to be addressed were (1) to assess the chemical, physical and biological properties of urban soils, (2) to determine the level and quantity of different heavy metals present and (3) to provide recommendations based on the soil test results. The sampling sites/urban gardens were selected based on where SUN works. These include: Gugulethu (Site 1), Fairdale (Site 2), and Mfuleni (Site 3). In total 15 urban gardens were sampled (Eight in Gugulethu, five in Fairdale and two in

Mfuleni) for soil chemical, physical and biological properties. Soil samples were taken as a composite soil sample, with 20 soil samples per garden being pooled together to form one sample. In total, 15 soil samples were collected and delivered to the Soil Health Support Centre Laboratory, in Cape Town, for analysis. The data were analyzed using R and SAS under the normality assumption with a parametric one-way ANOVA, and a Fisher's Least Significant Difference test for means separation at 95% confidence level.

4.5 Cost-benefit analysis of CEA

The cost benefit analysis (**Annex 2, 3)** was used to estimate costs and benefits of several CEA production systems (Nutrient Film Technique (NFT), Drip Fertigation System (DFS, Drip trough system and vertical drip system), Deep Water Culture (DWC), **Figure 4**), especially hydroponics, used in Mukuru, Nairobi. The cost benefit analysis was based on data from (1) MIF internal experience, (2) the feasibility study conducted in Mukuru Kwa Njenga and (3) Muungano's report on school feeding program in Mukuru informal settlement. Based on the following questions the analysis was conducted (1) What type of production system can people in informal settlements adopt? (2) What is the cost benefit analysis for investment in these systems, (3) What is the level of ease or complexity in the adoption of these systems and (4) What recommendations can be drawn? In case of the cost-benefit analysis targeting Mukuru, three systems were analyzed: (A) NFT, (B) Drip trough and vertical fertigation system, (C) DWC. The controlling systems can use different types of root support media): Different materials such as cocopeat, pumice rock, perlite or vermiculite were tested as growing material.

5. RESULTS

5.1 Feasibility of CEA in the informal settlement Mukuru, Nairobi

Based on focus group discussions and KII the findings are presented along the main topics identified being availability of land and water resources, socio-cultural dynamics, knowledge and capacity gaps within the Mukuru informal settlement, which is located around eight kilometres away from the central business district of Nairobi.

Land. Most of the habitable land in Mukuru has been zoned by the government for industries forcing the residents to settle on riparian, wayleave and privately-owned land. Such land tenure arrangements are temporary due to government and private-sanctioned evictions. Some of the settlers acquired land illegally through grabbing and intimidation of rightful owners and usually pay community gatekeepers (cartels) to hold onto the land. Other settlers claimed legal ownership citing the long duration of occupancy. Although Kenya has laws and policies that guide land use, they are usually bypassed due to weak enforcement mechanisms. For instance, in February 2022, the Environment and Lands Court dismissed a case filed by a section of Mukuru kwa Njenga residents to halt their eviction, observing that the land belonged to a private company paving way for their eviction. Due to such tenure land challenges, residents have improvised food production systems through sack gardening and plastic containers characterised by inefficient water use and lower productivity. The land available to the community has been prioritised for residential purposes and still overstretched by the increasing population. However, there is still some form of urban farming within Mukuru, mainly livestock and crop farming. Livestock keeping is commonly practised within the residential rooms while crop farming is usually practised on riparian land, available idle spaces, church land and school compounds for both subsistence and commercial purposes. Schools such as Reuben Centregrow food in Mukuru and train local community members on the same. Some community members were growing food crops in groups on leased church land.

Water is a key resource in both conventional and smart farming systems but is scarce. Water access is key; thus, six water boreholes were recently drilled as water supply in various locations within Mukuru for domestic use. Other sources of water areindustries, Nairobi River and informal water vendors, who supply water by carts and bowsers. Water accessibility is inconsistent and on top mainly under the control of cartels, who determine prices. In areas of reliable water supply local authorities discourage using the vital resource for farming. The quality of water is key. Most community leaders opine that the water in Mukuru is not safe for drinking or even farming due to the industrial effluent being directed to Nairobi River that passes through the settlement. The harmful waste also contaminates piped water through seepage due to vandalism, unhygienic handling of water and salty water sources from boreholes. Crops grown with such water can be harmful for human consumption. The local community tries to mitigate against this challenge by harvesting rainwater in tanks, but this is inadequate for farming. Water is a costly resource in Mukuru if obtained from water bowsers (water tanks) and cartels, thus the boreholes provide hope even the costs are not clear yet due to commercialization of the boreholes. Unfortunately, the most available and cheap water supply is from the river. The Reuben training centre is evaluating the challenges of water quality and costs for running boreholes.

There are existing *resource conflict resolution* and *management channels* within Mukuru settlement. Conflicts related to land scarcity are main causes for social unrest, which includes post-election violence and land ownership riots in which often informal settlements residents are pit against industrial companies and or government authorities. Alternative conflict prevention and scare space utilization (e.g., vertical walls for food production) is needed. Other conflicts are related to animal vandalism, trespass and low water storage capacity.

Farmer groups often collect money and tip security personnel of other companies for own farm security. Conflicts amongst community members are usually resolved through local political and civic leaders.

Socio-cultural dynamics. Mukuru informal settlement is a newer settlement from the 1980s dealing with old and new challenges. The community's socio-cultural behaviour influences food production and supply, such as that more vulnerable groups (women and youth) usually do the farming. The steady growth of the informal settlement especially in the last years causes a conflict between long-established households and those just moved in. Thus elders, responsible each for a certain zone in Mukuru, help to solve problems bevor police would step in. For land right issues the chief is key and helps to distribute land to the members. Even so elders help, the preferred process and conflict management is not clear yet. Urban farming is conducted in Mukuru but could benefit from education and training. The youth, who miss a life perspective, struggle and easily slight into crime. They feel neglected in ongoing programmes that foster education and training, leadership opportunities and access to capital. Women also feel neglected in education and training and thus easily loose motivation. It is worth to mention that farmers conduct urban agriculture mostly not for commercial purpose but as a resilience strategy to store their value in livestock and crops. The farmers help to distribute food to vulnerable people, save seeds for re-growth and sell surplus to other farmers of the community. Most conflicts are resolved within settlements by-community driven forums and local social leadership structures.

Knowledge and production capacity gaps. Technical knowledge and skills on smart farming was found to be limited in Mukuru despite a substantive awareness of its existence among residents. Non-governmental organisations have been training the local community on urban farming. Some were practicing urban farming using sack gardens and a local school had a greenhouse. Young people were more interested in modern farming approaches, and some were growing crops and keeping rabbits. Due to the limited access to government extension services, most farmers were relying on knowledge passed on by relatives and friends to control pests and diseases that attacked both crops and the livestock. These challenges coupled with the limited space/land and water for farming hinders the ability of farmers in Mukuru to produce quality food products consistently to meet local demand. Thus, food production and household resilience need to be strengthened while managing conflicts, thus training of farmers is needed on smart farming technologies for scarce land while working on improved land policies.

Food production, market linkages and consumer preferences. The main determinant of food consumption behaviours in Mukuru is income. Most of the residents are casual labourers in the nearby industries earning low incomes averaging USD 28 per month while others operate small businesses in Mukuru. This is supplemented by other sources of income such as milk sales from cows and eggs from chicken. Preferred were goats and pigs due to low costs of inputs. The most common vegetables grown were kales, spinach, cabbages and most preferably the traditional African vegetables (kunde, managu, sagaa, terere, kanzera). The traditional vegetables re-gained interest during the Covid-19 crisis. The farmers usually sell produce within Mukuru, to neighbours and to bigger markets. For livestock (less for crops) a middleman is preferred, who buys produce from farmers home and then sells it further. Crops were usually sold to neighbours or if produced in community gardens used for own consumption, shared with vulnerable households and surplus is sold to re-invest (e.g., buy seeds). In schools like Reuben Center cereals are grown together with kale and cabbage, while at household level the indigenous vegetables are favoured.

5.2 Cost-benefit analysis of CEA in the informal settlement Mukuru, Nairobi

In Mukuru informal settlement the main agriculture sites are agriculture for subsistence production; for commercial enterprises and for school feeding purposes. MIF identified three CEA systems (NFT, DFS (1: drip through system; 2: vertical drip system), 3: DWC) (**Figure 4, Annex 2, Annex Table A1**) as suitable for UPA in the Mukuru informal settlement, that can be set up to fit individual needs.

The *NFT* is a media-free nutrient-solution-based CEA method (hydroponic system) for leafy vegetables (Swiss Chard, collard green, amaranth, African Night Shade), including vegetables preferred in Mukuru informal settlement. However, it is limited since the crops should be light weighted, of a short crop cycle and have a minimal growth surface. The nutrient solution is re-used in a circular system, making it cost-efficient, even so the material and set up costs are high (~8000€ = 957910 kenia-shilling). The system by its nature requires technical expertise incl. proper training of farmers, and nutrients and biochemicals as inputs to ensure good food production and food safety. The food safety, if handled well, is an advantage since the water used is pre-tested and certified for use. The returns on investment pay off and for one shilling investment on average 3.52 KES net income are generated after seven years. The system allows for production in urban areas with scarcity of land and can be adjusted in size. The average farming space available (in Mukuru) for set-up of this type of production system is 8m by 15m or 8m by 30m.

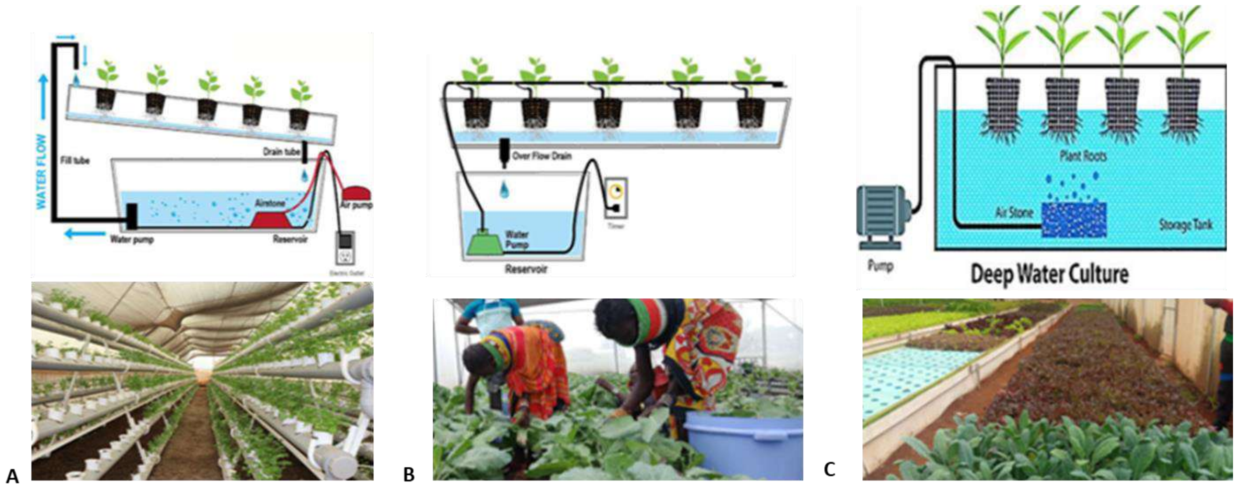

Figure 4: Example Model systems compared and identified for Mukuru informal settlement. (A) Nutrient Film Technique (NFT), (B) Drip trough system, (C) Deep Water Culture (DWC). Image Source: MIF, 2022.

Deep-Water Culture (DWC) is a passive system and nutrient-solution based CEA method (hydroponics system) for leafy vegetables (cowpea, spider plant, night shade, amaranth). The system is limited to vegetables that are light weight, short, have a minimum growth area and importantly with a high affinity for water. The large water tank is of advantage and helps to maintain stable water quality and the water can be re-cycled. The return on investments is good and for one shilling investment on average 4.88 shillings net income can be generated after seven years. The material and setup costs are high (~ 8200€ = 974450 KES). The system is easy to operate but still requires training and expertise and inputs such as biochemicals and nutrients to ensure food production and food safety. It is well suited for commercial and subsistence farming.

Drip fertigation systems (DFS) Those systems are suitable for commercial, subsistence and school feeding programs. The drip through system is a commonly used system especially in large scale production for commercial purpose but also for school feeding. The system is a nutrient-solution based CEA method and works well for tomatoes, cabbages including crops with a heavier weight, large growing surface area, taller in height, long crop cycles and larger roots. For school feeding usually white cabbage, with a short crop cycle, is grown.

The system requires little water. The return on investments is very good, since for one shilling invested, 8.66 KES net income can be generated end of year 7. The material and setup costs are high with ~6700€ (=797900 KES).

The *vertical-drip system*. This system is a CEA hydroponic system and the easiest to manage and most suitable for subsistence farming at household level for leavy vegetables, herbs, onions, fruiting vegetables. The costs are comparatively low with ~ 290€ (= 35.000 KES). But the average life span of crops is 4-6 weeks only. Ideally two households could share one system. The system can be adjusted based on needs and available space (a 2mx2m Systems holds 256 pots).

Overall, besides a hydroponic system, it is important to have access to good quality of water, electricity and if needed good growth media. While hydroponic systems are highly water efficient a reliable water source is key to maintaining the system. If municipal water supply is unreliable Miramar recommends having access to a borehole or harvest and store rainwater. Further, electricity is needed to pump the water through the system or regulate temperature e.g., with the use of electric fans. In the case of power outages Miramar finds that manual irrigation access to grid power, Miramar finds that is key to know how to manual irrigation and a solar power source or a generator are viable alternatives. A problem is that currently, financial institutions do not provide farmers with adequate investment/loan plans, they lack the certainty of cash flow to secure the loan.

5.3 Lessons learned on CEA in schools in Nairobi

In the following we present our lessons learned regarding the use of CEA in urban schools in Nairobi. We explored the main challenges and enablers of CEA together with several schools who have or are in the process of implementing CEA farming systems on their premises.

The case of Tumshangilieni Mtoto: Tumshangilieni Mtoto is home and school to over 170 children from disadvantaged backgrounds at the age of two to fourteen years. The charitable children institution is located in the Kibagare slum in Nairobi. In 2012 WHH started a project with Tumshangilieni Mtoto and the Kenyan Ministry of Agriculture, Livestock and Fisheries (KMALF). The project aimed to diversify the school food basket, reduce food expenses, and enhance nutritional value of school meals (Figure 5). The focus was on vegetables and animal production, with vegetables grown in diverse sets of vessels in the open field or in greenhouses with varying irrigation systems.

The farming unit implemented by WHH comprised the following components:

- An open field vegetable production unit and drip irrigation with assorted vegetables incl. kales, spinach, cowpea, managu and other indigenous vegetables, carrots, courgettes, eggplants, and herbs.
- A 15m x 30 m greenhouse for tomato and capsicum production with a drip irrigation system, as well as a hydroponic unit for strawberries, spinach, kales and herbs.
- Raised and hanging gardens
- Sack vegetable gardens for kales, spinach and cowpeas
- An agroforestry system with fruit tree production and agroforestry wood trees

- A rabbit production unit with 10 does and four bucks and 28 young rabbits
- A poultry production unit, which has grown to 258 chickens
- A fish production unit with 2500 fingerlings
- A goat production unit with 2 goats was set up

Figure 5: (A) Preparation of multistorey bags, (B) planting in a sunken bed and (c) processing of harvested vegetables and cooking of a nutritious school meal.

The project met the main goal of the delivery of fresh nutritious and diverse food for the school kitchen using diverse CEA methods. The key benefits (**Table 2**) were access to a more diverse school meal, that is more affordable and organic. The kitchen waste was used as manure in the school garden. A nice add on was the raised income from surplus sales. The project included a pedagogical component for the children to gain practical skills while running the school garden. This was enabled by the opportunity to obtain training of any kind related to UPA under the close cooperation with the KMALF and private sector, who helped train participants and provided technical expertise. The training was adjusted where needed when challenges occurred to help solve them (e.g., pests and diseases). A key enabler was the availability of water for irrigation which was a challenge at first but was made available via constructed shallow wells connected to drip irrigation. The school garden would not have been able to be maintained without the knowledgeable and capable hired farm manager. The project continued and is financially supported by "Friends of Tumshangilieni Mtoto". The interviewees mentioned that animal production was a challenge they could not solve. The fishery was expensive, provided fingerlings were of a poor quality and that there was no market to sell surplus rabbit meat. The available space at the school compound was first an enabler while it later became a challenge since the school infrastructure was expanded. No cost benefit analysis of the different farming systems was conducted, hence I not available. Overall, the school garden was of a high potential and applicable for other schools in the urban area.

Table 2: The case of Tumshangilieni Mtoto – Benefits, enablers, challenges and lessons learned.

Key benefits	Key enablers	Key challenges	Key lessons learned
Provision of a variety of vegetables allowing for a nutritious and balanced diet children and staff	Economic resources and continuous support by donors	Irregular support by extension officers from Ministry of Agriculture	Farm management requires solid skills and knowledge.
Additional income generation: selling surplus	Employment of a trained farm manager	Pests and diseases in greenhouse	
Reduction of food expenses	Training on farming practices	Degradation of soils in greenhouse	
Phytosanitary control of food products	Water supply: borehole and drip irrigation system	Cost of livestock and missing market linkages	

Initially Shangilia sourced its water from the Nairobi City Council. Quickly however it became clear that the water supply was too irregular and too expensive to sustain the school farm. While the project included a rooftop rainwater harvesting system water was still not sufficient. Subsequently, WHH supported the financing of a 280m deep borehole, an electric pump, and a water distribution system. Since, the water supply has been cost efficient and reliable. The installation of the drip irrigation system in the greenhouse and the open field farm further reduced the water demand of the farm. The greenhouse unit was installed by a private company who maintained the greenhouse, provided the crop seedlings and inputs (such as fertilizer and pesticides). Shangilia confirmed that the greenhouse was highly productive during the first three to four years after its construction. More productive in fact than the open field system. However, after several years, pests and diseases heavily affected the tomatoes. The private company managing the greenhouse did provide chemical pesticides that initially helped control the pests and diseases. However, after a while, Shangilia decided to manage the farm exclusively organically to reduce chemical inputs and decrease the environmental impact of the farm. The private company managing the greenhouse could not support Shangilia with the organic pest management. Further after several years the soil was depleted, and yield reduced. Shangilia's farm manager tried organic soil rehabilitation and pest management practices which were however not successful. Ultimately, Shangilia decided to dismantle the greenhouse. Learning from the experience, the farm manager received training on organic farming practices and specifically organic pest and disease management. However, the institution never saw the need to rebuild the greenhouse as in their experience organic production on the open field is easier to handle. For example, by applying organic manure and by intercropping the soil fertility on the Shangilia farm is being maintained, and yields remain stable. While the greenhouse failed, overall, the school farm is highly productive and fulfils its purpose of reducing food expenses while providing Shangilia children and staff with nutritious vegetables and fruits all year around. In 2014 the farm was rendering around 150kg of vegetables per week (WHH internal project report, 2014). Excess produce is being sold to the nearby market.

The case of the Kangemi and Dagoretti Rehabilitation Schools. Between 2017 and 2018, Miramar International Foundation in cooperation with KCB Foundation and GIZ supported the set-up of hydroponic greenhouses at the Kabete and Dagorreti rehabilitation schools in Nairobi. Both public schools are a rehabilitation center for underage youth with a criminal background. The objective of the programme was to provide the teenagers with agro-entrepreneurial skills and income that would support their re-integration into society after completion of their sentence. The school management agreed to provide the necessary land, water, and electricity. At the Kabete campus five 8m x 24m greenhouses were set up and at the Dagoretti campus two greenhouses with the same dimensions were set up. The production was market oriented. All crops grown were sold to the San Valencia group of hotels. Hence the type of crops grown were defined by the customer. During the implementation of the programme a number of challenges emerged (Table 3). While the school management had agreed to provide water and electricity, the greenhouses were disconnected from electricity due to outstanding balances. The crop quality and quantity thereby suffered greatly and deals with buyers could not be kept. The biggest challenge were the teachers themselves who obstructed the project. Teachers would harvest the crops and sell them on the side instead of supporting the students to deliver the crops to the hotels. In the beginning the Miramar team did not understand why the teachers would act like that. After a while they learned that the teachers had to work additional hours due to the project. Hence, the teachers wanted a share of the benefits generated from the sale of the crops. Unfortunately, the conflict could not be solved at the time and the contract with the San Valencia group was dissolved.

Table:3 The case of the Kangemi and Dagoretti Rehabilitation Schools – Benefits, enablers, challenges and lessons learned.

Key benefits	Key enablers	Key challenges	Key lessons learned
Production of high-quality crops (while water and electricity were running)	Technical support by Miramar	Disinterest of school management	Involvement of all key stakeholders in project conceptualization
Generation of income for the students		Lack of resources by the public school to pay their water and electricity bills	Commitment and ownership by the project hosting party
		Opposition by teachers	Clear distribution of roles and responsibilities of all parties involved.

The case of Beacon of Hope. In 2021 Beacon of Hope approached MIF asking for support with the set-up of a farm on the premises of the institution. Beacon of Hope is a non-for-profit organization providing healthcare, education, and skills training to disadvantaged communities. The main campus is located in Kajiado, a town of approximately 1 million inhabitants located South of Nairobi. The campus includes a nursery, a primary and a secondary school as well as a health facility. Several people go in and out the premises every day.

The main objective of Beacon of Hope was to reduce food costs while providing students, patients and staff with a balanced diet including greens and vegetables. Kajiado is located in the arid and semi-arid lands (ASAL) characterized by low rainfall and frequent drought. While the institution has a borehole on their premises guaranteeing continuous water supply (**Table 4**), water in Kajiado is scarce. Hence a highly water efficient hydroponic system is best suited for the context. Three 8m by 24m greenhouses were installed. Based on the type of vegetables in demand including leafy greens, tomatoes, capsicum, and cabbage, MIF recommended NFT and TRAF hydroponic systems. The interest by Beacon of Hope in the project guarantees their full support and ownership over the project. The only challenge was to find a skilled and committed farm manager. But after some scouting the right person could be found who was then trained by MIF on the management of the hydroponic systems. In December 2022 MIF handed the management over to Beacon of Hope, since the greenhouses are running efficiently.

Table 4: *The case of Beacon of Hope – benefits, enablers and challenges.*

Key benefits	Key enablers	Key challenges
Cost-efficient production of variety of vegetables allowing for a balanced diet of students, patients, and staff	Interest and ownership by the institution	Finding a skilled and committed farm manager
Additional income generation: sale of cabbages, substituting other food expenses	Borehole providing continuous water supply	
	Technical support and training by MIF	

The case of Reuben Center. To put the feasibility of a CEA system to the test in a school in the Mukuru informal settlement, MIF collaborated with Ruben Center. Building on their previous experiences of implementing hydroponic production systems in schools, MIF was looking for an institution with an intrinsic interest in implementing such a CEA system on their premises. Reuben Center had been practicing urban farming and was interested in increasing production since a long time. Hence the collaboration with Reuben Center was a perfect fit. Ruben Center is a charity organization providing quality education, health, financial and social services to children and families in the Mukuru community. Over 2700 children are enrolled in the Reuben primary school cared for by approximately 50 teachers who receive lunch at the school daily. Based on the needs of the Center, MIF designed an 8m by 15m greenhouse that could fit the space available on the premises of the institution. The main objective of the project is to reduce food costs while providing students and staff with a nutritious and balanced diet (Table 5). Based on the nutritional needs and preferences, MIF included three hydroponic systems in the design. A TRAF system to grow cabbages, tomatoes and *kunde* (cowpeas), a NFT system to grow collard greens, and a Deep-water Culture system to grow spinach and *managu* (amaranth).

Figure 6: (A) NFT system with collard greens, (B) TRAF system with tomatoes and cabbages, (C) TRAF system with cabbages and kunde, (D) Deep Water Culture system with manage. (Image source: Miramar).

Water for the system is provided by the borehole that was already in place at the Reuben Center. As part of the project, MIF also installed a rainwater harvesting system to supplement water supply. Since the start of operations, 20 people from Mukuru have been trained on the management of hydroponic systems at Reuben. The trainees were selected based on their interest in urban farming, many of whom are urban farmers themselves. Five trainees are staff members of Reuben who are now managing the greenhouse independently with a good production of vegetables per week. Production is running well, so well in fact that Reuben Center has commissioned MIF with the construction of a second greenhouse.

Table 5:The case of Reuben Center – benefits, enablers and challenges

Key benefits	Key enablers	Key challenges
Cost-efficient production: variety of vegetables allowing for a balanced diet of students, patients, and staff	Interest and ownership by the institution	Availability of construction materials in Mukuru to build a greenhouse.
	Borehole providing continuous water supply	
	Technical support and training by MIF	

5.4 Soil health and quality in Cape Town

In the following paragraph we provide the findings of the case study conducted by Sustainable Urban Neighborhood Development (SUN) at three sites in Cape Town (for greater details see **Annex 5**). The study focused on soil health (nutrients) and soil quality (heavy metals) in Gugulethu, Fairdale and Mfuleni. The soils at all three locations were deficient in the nutrients N, K, Fe, Mn, Cu while not significantly different in their levels and Volumetric Aggregate Stability (VAS) between the three locations. The pH of soils in Gugulethu, Fairdale and Mfuleni was not significantly different and led to the conclusion of slightly alkaline soils. Such alkaline soils are known to lock out available nutrients to plants. The nutrients P, S, Ca and Mg met their respective required ideal levels and did not differ between locations. Zn was significantly highest in Gugulethu ($p<0.05$), followed by Fairdale, then significantly lowest ($p<0.05$) in Mfuleni. SOM was conspicuously below the required ideal level in Fairdale and Mfuleni. The mean concentrations of the heavy metals in Gugulethu varied and decreased in the order of Pb > Cr > V > As > Ni > Co > Cd > Se > Hg. The mean values were Pb (20.19 mg/kg); Cr (6.42 mg/kg); V (5.08 mg/kg); As (2.99 mg/kg); Ni (2.3 mg/kg); Co (0.21 mg/kg); Cd (0.81 mg/kg); Se (<1.2 mg/kg) and Hg (< 0.36 mg/kg). Lead, however, was above the maximum permissible levels according to the recommended levels by the South Africa government, though; As, Cd and Hg are harmful even in small concentrations.

5.5 Experiences in urban and peri-urban farming of various approaches in Ouagadougou

Three local stakeholders, the Association Béo-Neeré Agroécologie (ABNA), Agro-Business Badouha and La Saisonnière, report on their experiences made in UPA and CEA in Ouagadougou. Either partner partly operates in the greenbelt and market garden sites and mentioned the green belts' potential for the city. In Ouagadougou, farming is commonly conducted close to the dams providing the city with drinking water and in the so called 'green belt' surrounding the city. The green belt was created to protect the city from wind and dust, facilitate water infiltration, and a recreational area for its inhabitants. While the green belt has subsequently been neglected by the Ouagadougou City Council and only now regains interest, it is an interesting case study to gain insights on the multiple function's peri-urban farming can provide.

The case of Association Béo-Neeré Agroécologie (ABNA): The interviews and focus group discussions (**Annex 6**) with producers and the facilitator Béo-Neeré came to the following results that can be group into (1) production techniques, (2) challenges in UPA, (3) agricultural potential in UPA, and (4) training needs for young people in UPA. At the four sites the cultivation practices follow majorly agroecological and conventional farming practices, where especially the conventional farmers focus on expanding their production. It is important to note that the majority of people at the four sites interviewed, have had already prior training in agroecological production **and further needed according to interviewees,** techniques for market gardening and organic farming by Béo-Neeré. The survey results show that the producers usually adjust their planting to the water and soil availability, whether the plant has a short and easy to handle production cycle and if there is a market need. The water sources used are dames, water reservoirs and boreholes with water towers and wells for irrigation (supported by solar panels). The vegetables grown are leafy vegetables (e.g., amaranth, spinach), bulb/root vegetables (e.g., carrot, turnip) and fruity vegetables (e.g., tomato, African eggplant). The producers organize themselves into cooperatives to better access hard-to-reach organic inputs (fertilizer, pesticides, seeds) or to produce inputs in the required quantity. Based on the results it can be stated that there is not a clear understanding respectively different interpretation of the meaning of agroecology vs conventional and organic farming. Several challenges of UPA were mentioned such as land ownership and land scarcity, poor soils, missing financial resources and technical equipment, lack of water, poor quality and availability of seeds, availability, and costs of organic inputs (purchase or production of organic fertilizer), and poor sales and lack of market linkages. The production of biofertilizer and biopesticides in a participatory approach between producers and Béo-Neeré was successful, but it failed in its commercialization to expand into the organic market, since there were difficulties in its shelf life and standardized treatment. Challenges are also the self-production of organic seeds (e.g., carrots, parsley, cabbage). Innovations in the area of soil preservation techniques, composting and irrigation techniques were developed. The potential of UPA was seen by producers as a contribution to their socio-economic development (income generation, job creation, more children go to school), the health resilience of the communities (organic produce) and environment protection (e.g., agroecological farming to protect species). It was noted that capacity building is helpful which is seen financial wise but also in production techniques support, better transportation to markets and provision of input materials. The capacity building of the facilitator Béo-Neeré focusses on agroecology here seen as organic farming re-stricted to zero chemical inputs, water saving management, and inputs provided by Béo-Neeré themselves.

The case of La Saisonnière. The survey results show that UPA is practiced by farmers since decades in Ouagadougou (Annex 7). Most farmers practice either conventional farming or farming with focus on agroecology (defined as that at least one of the following techniques is applied: sandwich mounds, flat beds, raised beds, crop-rotation/grouping, micro-gardening, Zaï, hollow beds, mulching). Farms operating conventional usually farm since generations and often apply chemical products and used manure. The benefits of UPA are in descending order economic-, nutritional-, health-, social-, environmental-, and cultural benefits. It is assumed that factors such as access to land and water, capacity building are key for income generation. The factors access to finance, markets and local knowledge were of a lower importance. It was observed that certain techniques were applied in UPA that could contribute to better climate resilience of farmers. Such techniques include micro-gardens, agro forestry, mulching and sandwich mounds, which reduced the vulnerability during flood periods. Even so UPA is practiced since a long time it faces several challenges. One key challenge is a lack of good legal and institutional frameworks and coordination of the relevant stakeholders. Other challenges include lack of water during the dry season (depletion of wells, dams), floods, crop-raiding, social conflicts between farmers (crops vs. livestock), land tenure and lack of security. Especially flooding can destroy market gardens, can disable access to land and the food source for households and surplus-sales and can cause unemployment. Other challenges are how to deal with biotic stressors and soil degradation including the handling of pesticides and potential health risks. Social challenges include the ambivalent relationship of citizens to practice UPA and see its value but also the land use conflict (lack of land ownership), and that livestock sometimes destroy crops grown, and theft of vegetables is common in some places due to insecurity. However, the three largest challenges are lack of water followed by flooding and crop-raiding. The results of the survey suggest that market gardeners and how the association works helps to mitigate some challenges such as lack of water and flooding. The participants dig wells and solar boreholes for irrigation and adjust the crop grown to the environmental conditions (season). The techniques to improve sowing beds, tracing routes for drainage of water and micro-gardening on tables help to reduce problems caused by flooding. The mediation helps to solve some social challenges between market gardeners and inhabitants of the community. For environmental reasons the promotion of organic agriculture including organic inputs is promoted e.g., bio-fertilizer and bio-pesticides, however not restricted to certain seed sources only. Overall market gardeners try to adapt to some challenges by adjustments of their agricultural system incl. the usage of cultivation practices (Zaï, mulching, half-moons and different types of beds) and crop rotation. The organic practicing market gardeners associated with La Saissonniere, are a member of the National Council for Organic Farming (CNABio) and see an advantage in using the organic Participative Guarantee System (BioSPG) to improve their visibility, traceability, and access to markets. The System can also provide a legal and regulatory framework for organic agriculture. The results suggest that UPA is important, has largely untapped potential and contributes to economic development in urban areas since the market gardeners not only produce for own consumption but also sell directly to individual consumers or to wholesalers and resellers. The linkage to markets to sell produce and buy inputs (seeds, manure) can be a challenge. The e-commerce and online platforms that gained importance during the Covid-19 pandemic worked well. Despite the advantages of e-commerce, it has its challenges to be operated and needs good training of market gardeners to get the most out of it and to study supply and demands that often do not match. Besides e-commerce local sales directly at famer gates is still key for some customers to build trust and to maintain produce quality. The modern online marketing helps to promote UPA gardeners produce and is seen as a tool to further increase economic growth.

CE and soilless agriculture in the peri-urban area of Ouagadougou by Badouha. Badouha is in the dynamic of promoting local solutions through the provision of agricultural inputs, equipment used, construction techniques of greenhouses (Annex 8). The 66 farmers interviewed (partly trained by Badouha) practice varying farming systems and 94% use fertilizer (45% organic, 30% natural, 25% chemical), 67% pesticides (45% organic, 23% natural, 32% chemical pesticides). The survey results can be grouped into (1) water source used, (2) the period of water access, (3) the distribution of agricultural practices, (4) advantages and driving forces of Badouhas' system, (5) challenges, (6) potential solutions, and (7) its potential as a system. A total of 43% of the farmers interviewed are unable to produce throughout the year due to water scarcity and 57% of this proportion claim to have water outside the rainy season only from October to February, thus the soilless agriculture in open air or with greenhouse production technique in a controlled environment could allow those agricultural producers to easily adapt to climatic difficulties, in order to ensure the availability of agricultural products throughout the year. The construction of the local greenhouses is based on local technology and local materials (e.g., wood), uses less resources, is at low cost, scalable and adapted to the local environment and climate to offer to the plants the climatic conditions necessary for their growth and the financial means of the customer. Industrial greenhouses are not of focus and not suitable to the Burkina environment, while farmers prioritize the local greenhouses or just open-air soilless agriculture. The prioritized water sources were boreholes (32%) and taps (40%, distributed by the national system), where water from dams (19%) and wells (9%) was secondary. The hugh proportion of tab water could be related to the fact, that 50% of the farmers households practice soilless agriculture, 34% conventional and 16% soilless and conventional agriculture. In order to popularize this technique, Badhoua offers training at social cost on the technology of soilless agriculture in general and under greenhouse more particularly with a curriculum adapted to the main local languages of the country. This training is accompanied by a module on agricultural entrepreneurship to encourage learners to entrepreneurship and a technical follow-up of learners until the installation of their agricultural business. In 2021 an International Agricultural Incubation Center was established to train agriculture practices not limited to certain approaches such as conventional agriculture, soilless agriculture, entrepreneurship, digital marketing, organic fertilizer production, livestock and fish farming, irrigation techniques, hygiene and conservation. The 4-month training is open to the learners from the region and offers the opportunity in day- or boarding-mode. The training is well accepted, and farmers interviewed benefit from it overall.

In addition, Badouha experiments with substrates for soilless agriculture and development of organic fertilizer from local ingredients. Badouha encourages farmers to conduct good agricultural practice and to use organic and natural fertilizer to lower soil erosion and water contamination. But they still suggest the usage of chemical pesticides that are regulated and authorized in Burkina Faso in compliance with correct application for serious diseases to save the production. The farmers gain access to a broad toolbox to be used at their own desire which contains conventional practice, but also natural, organic, locally produced and easy-to-use maintenance techniques adapted to the local context. Finally, Badouha is positioned in the dynamics of perpetuating food in cities, in a continuous way. To bring the producers closer to the consumers, Badouha has a delivery service. Short distribution channels help to reduce production costs by 30% and produce are available at the markets. Around 81% of farmers produce for the market and 19% for own household consumption. Beyond the delivery of vegetables, they make the customers aware of the need to produce themselves in their limited place of residence through simple and adapted techniques. This is taken up well and 52% of informed households practice now soilless agriculture at home. The distribution channels are mainly to wholesaler (54%), retail (37%) and export (9%). The challenges include climate and socio-economic ones such as very hot weather, water scarcity, soil problems and erosion and other climate related issues. For a year around production in UPA short production cycles are needed and a stable and clean water supply. The distances between farming plots and dams are often too far and farmers dig channels to drain water. The reuse of wastewater is still used knowing of sanitation and environmental risks. The soilless greenhouse model by Badouha is a simple and low-cost solution that requires less water, less space. Even so Badouha trains in local languages it is still a challenge, since more than 60 languages are spoken in the country and the education levels are low.

6 Discussion

We explored the potential of UPA and CEA in the three capitals of Burkina Faso, Kenya and South Africa to assess the capacity of UPA and CEA systems to increase the resilience of urban food systems in Sub-Saharan Africa to climate change. However, we will discuss a selection of our current findings from the scoping phase only.

No matter of climate change or shocks, an enabling framework for UPA and CEA is needed and should address a selection of key challenges such as land, healthy environment (water and soil), socio-cultural dynamics, knowledge and market linkages. These challenges are not new and known since decades (FAO, 2007) but still remain an issue. Our study showed that uncertain land rights and the decision by officials whether UPA is legal and whether land should be used primarily for housing over growing food, all determines the output of farming systems and long-term planning. People grow vegetables in easily movable containers ready to use any time and hazard the consequences of low productivity. Farming is often done in riparian land, idle spaces, schools but also in greenbelts like in Ouagadougou. The greenbelt re-gains importance and value by officials, which gives hope to farmers and the environment ministry to legally conduct farming and livestock production and protect the forest. Critical for UPA and CEA is water, but the water quantity, quality (see also Moglia 2014, FAO, 2007), access and costs are even today problematic. Rivers are a low-cost source in Kenya and Ouagadougou, best available but of poor water quality due to industry effluent and sewage, while the boreholes, water bowers and city water are difficult to access, costly and likely controlled by cartels. The soil health and soil quality studied in market gardens cannot be neglected and confirms earlier findings (FAO 2007). The soil deficiency in certain macro and micronutrients in Cape Towns' informal settlements likely impacts plant growth and yield and with that food security. The occurrence of heavy metals is alarming and can be expected to harm plants and human health in small concentrations. The legal frameworks for UPA and food standards differ between the three countries studied but a legal framework of heavy metal disposal should be addressed. The water and land rights not legally clarified causes social unrest and conflicts. Other socio-cultural dynamics may result in conflicts in informal settlements like competition of long-established vs new households and farming vs livestock production. Education, training and leadership opportunities provided in local languages is key to help youth and women, who often do the farming, to stay motivated and see a perspective in life. Technical knowledge, skills and access to it via governmental extension services, is often limited, thus farmers relay on information passed on by relatives and friends. Some farmers seem to conduct UPA not for commercial purpose but to store their value in livestock and crops as a kind of resilience strategy. Overall, UPA is related to economic growth and can result in raising income (Cilliers et al., 2020). Our scoping work shows that UPA and CEA can help to raise income while it was difficult and even endangered the loss of invested capital if CEA systems needed high investments given lack of institutional financial security and governmental support. Selling surplus requires producing in quantity and good quality and having access to an existing market, which was a challenge as reported in other studies (Cilliers et al., 2020). Miramar observed that contract farming over direct farming has the benefit of guaranteeing farmers an output market which builds security but also creates dependencies since farmers are guided on which crops to grow and how much. We would like to reiterate here the interdependencies between urban and peri-urban farmers and rural farmers, which were considered also by the FAO as critical (FAO, 2017; FAO, 2007). These interdependencies have not been explored during the scoping phase but popped up as important point e.g., how UPA changes the produce prices, market access, market sales and might change the balance of the current economic system (FAO, 2007).

Are the costs for CEA worth the investment? CEA allows farmers and producers to control different variables of the growing environment from simple protected cropping in the field at lowest costs up to high end fully controlled facilities (Dalrymple, 1973; Agrilyst, 2017). Here we do not focus on high end fully controlled environment systems but rather simple protection in the field, low tech-plastic/greenhouses, hydroponics used in open field and in plastic-/greenhouses and outdoor vertical farms. Depending on the CEA systems used in Kenya and Burkina Faso, the participants report to be able to modify the production environment at low to medium high costs, use less water and extend the growing period to produce ideally all year around, given that Burkina Faso and Kenya do not face harsh winters. This is important since the climate change will require to cope with variability in temperatures and rainfall while ensuring food production with the help of CEA (Koundinya et al., 2018; O'Sullivan et al., 2019). The results indicate that participants, who have no land, are in favor to use an out-door vertical wall, use multi-storage gardens, roof tops and vertical stacks in greenhouses, which are all space efficient. Such systems described are known to likely be more productive if compared on a m² basis to the open field and can enhance productivity of land by using non-arable land such as walls and roof tops (Agrilyst, 2017; O`Sullivan et al., 2019). Some CEA systems are reported to restrict the entry of pests and diseases thereby reducing the use of pesticides and insecticides (Roberts et al. 2020) but this is probably valid only for highly controlled/high end facilities and not for the CEA systems studied herein. We observed that occurrence of pests and diseases cannot be prevented (Goodman and Minner, 2019), especially if a standard plastic-/greenhouse or screenhouse is used as in our case. Our study suggests that food produce from hydroponic systems might be healthier in urban settings, but we need to account that even in CEA human pathogens from water, substrates and human contact can be introduced and impact human health (Gómez et al., 2019). The high energy demand of hydroponics systems in hot climates (Arizona) questions if it is a good alternative for open field vegetable production (Barbosa et al., 2015). Developing a hydroponic system that does not need intense heating and cooling systems as in Arizona could dramatically reduce the energy demand. Thus, hydroponic systems use is not independent of climate, since its feasibility depends on the climate and farming location. Miramar has developed such CEA systems (hydroponics in plastic/greenhouses) suitable for hot climates in Kenya and not being high-end controlled facilities, however Kenya will not face harsh winters as in Arizona and we do not know if the production is comparable. The cost benefit analysis conducted for the three types of hydroponic systems in Kenya found that the returns are worth the investment and are an alternative food supply for urban dwellers. However, the use of the CEA model is purpose and location specific and should be adjusted for subsistence production, commercial enterprises and school feeding purposes or individual needs. The systems even so some of them are more or less easy to operate require technical expertise, investments, inputs (electricity, water) and are restricted to certain crops only. We observe that that usually leafy vegetables and herbs are grown in hydroponics that are of light weight and have a rather short growing season, which is common for such systems (Al-Kodmany, 2018). However, Miramar has developed a systems that can also deal with heavier weight crops and longer growing seasons. Even so it might be an advantage for growers to expect higher sales from vertically grown crops, they are likely not affordable by urban dwellers (Al-Kodmany, 2018) raising the question of an existing market and who are the customers. A relevant issue is input costs of hydroponic systems (capital- as well as operational costs), so that farmers need financial support which are often loans they were not able to pay back and thus drives them in great financial dependency, poverty and maybe to lose their land. We observed that financial institutions do not provide farmers with adequate investment/loan plans, they lack the certainty of cash flow to secure the loan. Since February 2022 a new crisis evolved, the war in Ukraine, which results among others in raising energy and food prices and causes produce shortages that effect humans globally. The results of the cost-benefit analysis might change especially with the current crisis and increasing energy costs; thus, the energy question is very relevant, specifically under CEA. "Despite higher energy demand of controlled environment growing systems, it is argued that urban agriculture can decrease energy use by removing the need to transport food over long distances" (Kemp et al., 2010). There are also concerns about the food miles concept. There is evidence that reducing the distances required to transport food may have only a limited impact on the greenhouse gas (GHG) emissions because the bulk of the GHGs are emitted during the production phase (Weber and Matthews, 2008). Mohareb et al. (2017) note that the limited data available to quantify resource demand directly associated with urban agriculture systems make it difficult to make universal claims on benefits of urban agriculture to energy use in food production.

UPA and CEA can diversify school menus with a healthy diet, reduce food expenses, has pedagogical effects, address nutritional needs and preferences. It is widely recognized that school feeding provides multiple benefits including food security and nutrition, education, gender equality, employment, and agricultural development. Research shows that positive impacts of school feeding programmes not only reach the pupils themselves but can have positive impacts on the household, and the wider local economy too. Homegrown School Meal (HSM) programmes source food from smallholder farmers and local food suppliers (FAO and WFP, 2018). By incentivizing and diversifying local food production, HSM programmes bear the potential of increasing the resilience of local food systems. In Kenya, school meal programmes are funded by the government and covered meals of 11% of children enrolled in public primary schools in 2020-2021 (GCNF, 2021). In Kenya the school feeding program focuses on the most food-insecure areas with low enrolment and completion rates, that include arid and semi-arid areas and Nairobis' informal urban settlements (WFP, 2018). A survey in 2021 revealed that schools meals in Kenya include exclusively grains, legumes, oil and salt, with no fresh foods and meat or dairy (GCNF, 2021). Most schools in informal settlements like Mukuru are of informal nature and hence fees are paid either by parents or other donors like NGO's. To alleviate costs and increase the nutritional content of meals, schools in Nairobi have started to grow food on their own premises. But they face constraints. Space and water are often the main limiting factors, making CEA particularly interesting for schools. Yet, there has been little research conducted on the feasibility of CEA in schools in urban areas. To start understanding the matter better, we explored the main challenges and enablers of CEA together with several schools in Nairobi who have or are in the process of implementing CEA farming systems on their premises. Various types of school gardens exist that grow vegetables on their land, build greenhouses with or without drip irrigation, use hydroponics, multi-storage gardens, and agroforestry systems, but also raise livestock (rabbits, poultry, fish, goats). A school in Nairobi for example was able to produce 150kg of vegetables on a weekly basis in 2014 and successfully diversified the school diet with nutritious and healthy produce. Some produced so well that surplus was sold to markets and raised income for the school, but sometimes the market linkages were missing. The case studies reported the importance of a farm manager with solid skills and that the teachers and adults are committed to the project. Key was to have access to technical support and training provided by extension services of ministries and private companies, which was sometimes not working well. However, there were also challenges such as the costs of livestock, disease and pest-pressure in plastic-houses. The schools in either case provided the land, water and electricity. However, the quality and quantity of produce was limited if a continuous water and energy supply was not available. Overall, the school gardens worked well and could make us of different farming systems up to plastic-greenhouses and a bit more complex NFT hydroponic systems. There is certainly value to foster school gardens in Nairobi to contribute to a more diverse and healthy school meal.

UPA's potential to help cities build climate resilience and adapt to climate change – *experiences from Ouagadougou*. Studies showed that UPA can play a role in multifunctionality, sustainability and resilience (Langmeyer et al., 2021; Cilliers et al., 2020; Ruhweza, 2020). Our scoping work hints towards the multidimensional benefits and contributions UPA in its different forms can provide to society and how UPA can contribute to local climate change action. The case of Ouagadougou with its green belt indicates that urban and peri-urban farming and forestry when embedded in wider nature-based solutions can be implemented at scale. Nature-based solutions (NbS) are increasingly considered valid and cost-effective solutions for climate change adaptation and urban regeneration (Fink, 2016). Current research dealing with urban NbS focuses on climate resilience in urban areas (Artmann et al., 2021). The concept of NbS promotes systemic approaches for social, environmental, and economic challenges by supporting, restoring, and maintaining the ecosystem and sustainable urbanization. Our findings from the scoping work support the point of resilience in terms of additional food production, strengthening of community networks and social cohesion to mention a few. The studies showed that UPA and CEA are feasible in urban and peri-urban areas and different ago-ecological zones if adjusted to the location's context. Thus, listening to relevant stakeholders and their needs makes the approach more sustainable, successful and inclusive. The green belt in Ouagadougou (established decades ago) bears the potential for multifunctionality such as urban cooling, recreation, farming and social cohesion. The UPA is practiced since a long time in Ouagadougou and especially in the greenbelt, which just re-gains interest by the officials to be legally protected (personal communication). The scoping work focused on the farming component in Ouagadougou, where various approaches like conventional and organic farming but also agroecology in general are practiced. With a changing climate, the farmers face drier seasons, water scarcity and floods, soil erosion and soil issues in Ouadagoudou. Especially flooding can destroy market gardens, disable access to land and the households' food source and surplus-sales and thus can cause unemployment. The farmers tend to adjust their agricultural systems and transfer well known farming strategies from the rural area (Nyamekye et al., 2018) to the urban and peri-urban areas that may help to address the climate related challenges, to better adapt to climate change. Such techniques include agroforestry, sandwich mounds, mulching, zaï and composting, irrigation techniques, adjusted planting periods and choice of crop towards water and soil availability, and crop-rotation. The type of planting beds varies and could be (1) flat beds or half-moons varying in design and water holding capacity but also (2) raised beds incl micro gardens (raised tables to grow on top) and hollow beds to better withstand floods. The soil and water conservation measures such as zaï, mulching, half-moons and agroforestry help to control soil erosion and rehabilitate land productivity (Nyamekye et al., 2018). Agroforestry also improves soil fertility and crop production, and mulching helps to fertilize the soil and attracts termits to improve soil permeability (Nyamekye et al,. 2018). The half-moons help to collect run-off water and increase filtration, while zaï also fosters retention of soil moisture and increases availability of nutrients (Nyamekye et al., 2018). Our study identified that soilless hydroponics in greenhouses and open field are practiced and trained and could help so save water and be used in urban settings. Greenhouses build from local materials can be built at low cost, are not dependent on imports and help to protect plants from abiotic stressors. If a year-round production is desired for Ouagadougou, then short production cycles are important and a staple and clean water supply at close distance to the farmers is needed. Training in local languages is key for an urban and peri-urban farmer to have access to a wide toolbox to individually farm and have the potential to deal with lack of water, floods and others to better adapt to climate change. The UPA in Ouagadougou has great potential to be an additional food supply under a changing climate, however this impact needs to be researched further.

UPA can play a critical role in food security and affects countries, their agricultural and other sectors of the food system in diverse ways (Vermeulen et al., 2021; Borman et al., 2022; Moseley, 2022; Cillliers et al., 2020). The potential need for shortening some supply chains might increase resilience and, including agroecology, could help in food systems transformation and make food systems more resilient and sustainable (Moseley, 2022). The scoping phase brought up some points to build up more evidence for such as the impact of UPA and CEA on food and nutrition security, food diversity and food access to build resilient food systems. The case studies provided insights in how to deliver fresh and nutritious foods and at the same time diversify the diet and sell surplus. Our studies found that CEA in UPA is feasible in informal settlements even if space is limited and thus to potentially reduce food insecurity. Khumalo and Sibanda (2019) found that UPA practicing household's vs non-practicing households worried less about food security due to better access to food. In literature, the impact of UPA on food and nutrition security of low-income households is controversially discussed (Paganini et al., 2018; Crush et al., 2011; Frayne et al., 2016; Warren et al., 2015; Khumalo and Sibanda, 2019; Ruhweza, 2020). The poor quality and experimental designs of many studies are a major reason and hinder to find an evidence-based association and causation even so there is an impact (Warren et al., 2015). We can carefully state that there is first evidence that UPA and CEA contribute to food diversity, food access, improved food availability and in some examples to raised income but needs research to build evidence. There is certainly a need for UPA in the food system, especially in a crisis ridden context such as magnified by Covid-19 with limited mobility and transportation to reach food systems outcomes (Borman et al., 2022), however, the rural areas progress is still key to fulfil the 2030 Agenda (FAO, 2017).

UPA and CEA clearly has a potential to increase the resilience of urban food systems in Kenya and Burkina Faso to climate change and could be an additional food supply. However further research is needed to clearly show the impact.

7. Conclusions and Recommendations

Based on the results of the scoping phase, the discussion, and reflections so far in the Cape Town partners workshop, as well as on aspects, which evolved during the write-up of the present report, we would like to come up with a draft of few core recommendations related to CEA in urban areas. The recommendations will require critical reflection within the overall research team vis a vis the results and recommendations of the other Thematic Entry Points.

Urban and Peri Urban agriculture cannot be neglected. It plays an important economic and social role in socio-economic and health development in UPA. It can be speed up by an elevation of existing agricultural activities and professional training of labor. Indeed, it involves many women and young people, helping them to prosper fully in society and to become more resilient. There is a growing interest of women and youth. UPA and CEA potentially allows them to make vital contributions to food security and the household economy, however, it is important to take a careful look at CEA, to provide the solutions that are urgently needed over time, to contribute to the development of the urban and peri-urban populations of the city and to strengthen the socio-economic growth of the country.

A: Nairobi and Ouagadougou - proven technology under controlled environment

- The studies in Nairobi show and prove that suitable production technologies are there especially with reference to hydroponics and greenhouses even towards the higher end technology (automated systems). CEA is space and water efficient, and crops are protected against climate variability, making the system more resilient to climate change. However, a CEA system is dependent on a reliable water and energy / electricity source and technical expertise of those who maintain the system.
- The studies in Ouagadougou show that controlled environment agriculture technologies are available at low costs, some made from local materials and are already used/adopted. Such CEA systems range from simple field crop protection to (soilless) hydroponics systems in the open field and plastic-/greenhouses. The soilless hydroponics model has enormous potential as it uses less space, fewer resources and is scalable.
- Access to affordable clean water is key for crop growth and consumers health. We recommend investing more in water management incl. accessibility and availability at low costs e.g., create drilled wells run by solar energy pumps and water quality control.
- Some CEA systems require relatively high investment (capital costs) and operational costs (financial capital, financial institutions or finance schemes which will provide or secure this funding) as well as solid agronomic and technical skills (human capital). Miramar learnt that farmers practicing CEA require at least four to five years of loan repayment periods. Currently, financial institutions do not provide farmers with adequate investment/loan plans, they lack the certainty of cash flow to secure the loan. (Miramar's finding in Kenya).
- Taking this into account, it would be worthwhile to have a look at various models of ownership and control: be it more informal at small size at household level, private individual small- or large-scale enterprise, communal ownership, ownership by associations and cooperatives, which will require logistic and economic management skills.
- Association La Saisonniere", "Association Beo Neere Agroecologie" and "Agro-Business Badhouha International" are applying different local approaches, incl market-based gardens and greenhousesses. Options of multiplying their approaches or components in the sense of adaptive research and scaling up options should be pursued.

B: Supporting services and capacity development is a must. Clarify who should be in charge and find means of establishing and coordination in a multi-actor setting

- Support policies and regulations are needed. Project experiences by WHH do recommend, that the government resp. government agencies like Ministry of Agriculture, Health, Finance should be involved from the start to enable support and out scaling.
- Support and capacity building especially after training and during the implementation of CEA systems are important. This support is needed throughout, at least until the CEA systems are stable enough to cope with minor shocks and will not be given up. Extension and follow up phases of ongoing projects to consolidate knowledge are needed.
- Training e.g., on integrated pest management is key, especially in hydroponics systems and the greenhouse environment. Follow-up beyond the project period is necessary, especially by subject matter specialist, sharing of experiences, technical advice.
- Strengthen technical and operational capacity of producers, particularly women and young people (agroecology, organization, management of micro-enterprises, digging wells for market gardening, solar boreholes for irrigation, agricultural material, etc.).
- In the formal sector, pending on the legal framework of the CEA system, organizational development support for associations, cooperatives etc. will be also crucial. Strengthen leadership and develop the connection between groups of women and young people and for marketing of UPA produce.
- Look at the support services in the informal sector, in the formal private business sector, and on a governmental level like Agricultural Extension services. Find out what works, who is suited best, and how one could make governmental services more accountable.
- The experiences of e.g., Miramar could be documented and converted into production guidelines, aiming in the medium term to reduce the users' dependencies on technical expertise.
- The challenges coupled with the limited space/land and water for farming hinders the ability of farmers in Mukuru to produce quality food products consistently to meet local demand. Thus, food production and household resilience need to be strengthened while managing conflicts, thus training of farmers is needed on smart farming technologies for scarce land while working on improved land policies.

C: Multifunctionality: dive deeper into issues of ownership and on how to generate and maintain responsible ownership

- Multifunctionality of urban and peri-urban agriculture has been observed on several occasions in this report, especially also in the context of the WHH supported projects: skill development of youth, psychosocial engagement in refugee camps and meaningful livelihood generation as well as increased social interaction and cohesion in polarized environments. Educational value of school gardens, improved quality of life in Mukuru, besides contribution to nutritional diversity, health and life skills have been observed.
- Awareness creation on this multifunctionality at various stakeholder level in the civic society might be a good investment to generate more ownership by government and civic bodies with the purpose of creating more acceptance, accountable responses and foresight on urban and peri-urban agriculture. This will also ensure the sustainability of the UPA systems promoted. Lack of ownership frequently goes hand in hand with indifference, which easily will contribute to negligence and environmental degradation, like e.g., dumping of waste in open green urban spaces.
- A recommendation is there to look in more detail at the interrelationship between ownership, motivational factors and actual engagement and maintaining that engagement over several generations in peri urban and urban agriculture. Can this be nurtured by state level-, NGO - or private business intervention?
- We recommend also to build policies that support land ownership and help to secure the current production sites and foster the identification of new sites.

D: Crisis / Resilience: UPA provide coping mechanisms, still there are many open questions

- In crisis ridden contexts with high unemployment rates UPA and CEA in densely populated areas could be a coping strategy of households by diversifying their income source and marginally contributing to the overall income of the household. This should be evaluated.
- More indebt analysis is needed, best with specific reference to actual UPA systems, with special considerations on the aspect of time, "incubation of a crisis or shock" seasonality of production, meso- and macro level aspects of the crisis.
- Evaluate, improve and promote micro-gardening as a potential strategy for resilience to climate change and the lack of space for production.

E: Monitoring and environmental monitoring

- A monitoring system is needed for quality of space, land, soil and water, key in UPA
- Soil health and soil quality must be analyzed, e.g., contamination with heavy metal. The option to go for hydroponics should not become an excuse for negligence of proper "soil management". We can consider soil as a kind of "heritage", once polluted it is gone, "gone" cannot be replaced. Proper garbage management (organic waste / inorganic waste) recycling and composting in cites is crucial to avoid pollution and contamination. The presence of heavy metals (As, Cd, Hg, Pb) in soils is alarming since it is harmful for humans via food produce and also for the eco system. Strict policies are required on heavy metal disposal and management. In addition, a study is needed to understand how soils heavy metals enrich in edible plant parts.
- It is recommended to investigate good reliable environmental monitoring systems, to contribute to environmental protection in time and establish a reference system for decision making on UPA concerns.
- For awareness raising and learning on climate adaptation it will be worthwhile to reflect on the climate field schools experiences in Burkina Faso so far and, if useful, consider horizontal scaling up and adaptability on urban areas
- On several occasion in the report, e.g., in the WHH cases we mentioned lack of detailed production data and impact on participants/ nutritional status etc. So, we see the need to establish right from the beginning of a project a detailed monitoring system, that being well maintained should be also part of the budget.

F: Market forces are providing both risks and opportunity for UPA and CEA

- There are aspects of regulated and unregulated markets, market protection, taxation, standardization and certification, seasonal supply and demand, competitiveness between local, regional, export/import, product prices and input prices.
- The energy question is very relevant, specifically under CEA. Right now (triggered by the Ukraine war) we are experiencing sharp increase on fossil energy cost as well as green energy, leave alone competitiveness of biofuels vis a vis food crops.
- How can we conceptually take market forces into account for the further research program on UPA.
- Market linkages and how supply meets demand need to be explored to better plan some production that is aimed to be sold ideally at a timepoint that guarantees a good price. This includes the availability of storage facilities and processing techniques for CEA produce.
- The production of indigenous African vegetables under CEA and the corresponding market linkages and demand should be fostered and researched.

8. ANNEX

9.1. Partner reports from Kenya, Burkina Faso, South Africa and Welthungerhilfe

Annex 1: Kenya Miramar Feasibility Study Report
Annex 2: Kenya Miramar CBA Factsheet
Annex 3: Kenya Miramar Lessons Learned Report
Annex 4: Welthungerhilfe Case Study Report
Annex 5: South Africa Urban Soils Chapter SUN Cape Townf
Annex 6: Burkina Faso Beo-Neere
Annex 7: Burkina Faso La Saisonniere
Annex 8: Burkina Faso Badouha

9.2. Figures

Figure A1: *Overview of the most prominent growing systems and facility types* by Agrilyst (2017).

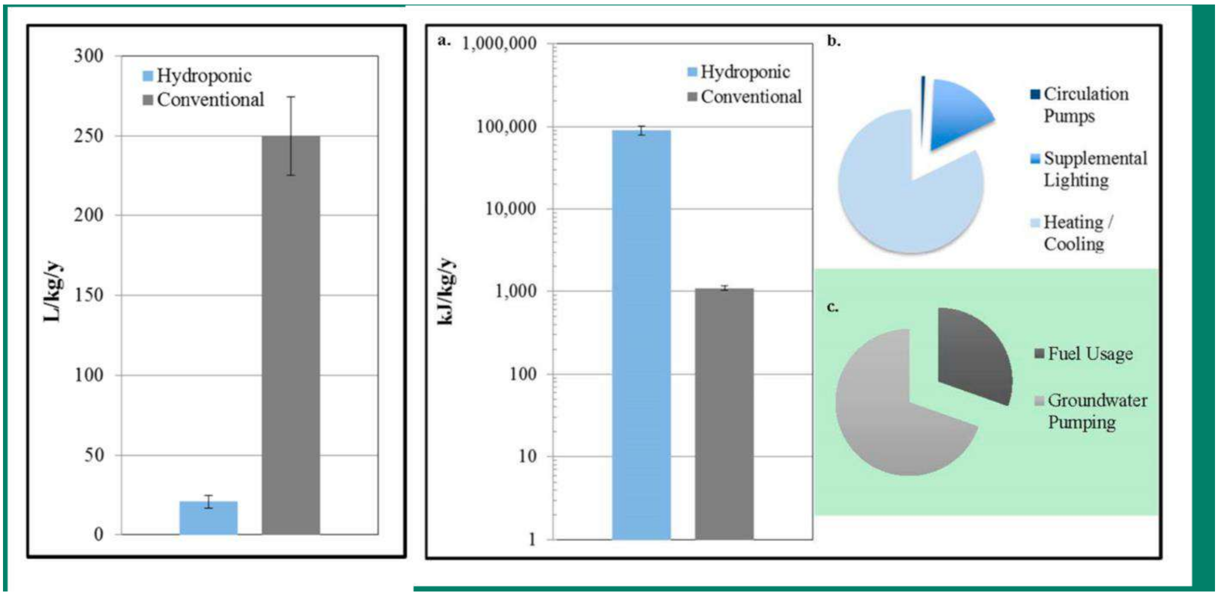

Figure A2: Modeled annual water use in liters per kilogram of lettuce grown in southwestern Arizona using hydroponic vs. conventional methods (Error bars indicate one standard deviation). Figure 2b) Modeled annual energy use in kilojoules per kilogram of lettuce grown in southwestern Arizona using hydroponic vs. conventional methods; (b) The energy use breakdown related to the hydroponic production of lettuce; (c) The energy use breakdown related to the conventional production of lettuce (Error bars indicate one standard deviation) (Barbosa et al., 2015).

9.3. Tables

Table A1: Application of different CEA systems for subsistence-, commercial farming or school feeding purposes. Different manifestations of power

Stakeholder	Target group	CEA system	Pre-requisite	Advantages	Training required	Potential
Subsistence production	Local communities._	vertical drip system	wall and some little space	Cheap and easy to execute and managed; System setup in people's homes without need for additional land leasing; Portability; Adds nutritional value for households and aesthetic value to area	Yes: Operationalization and maintenance	4 years, over 2,000 households in informal settlements could be supported to achieve food security.
Commercial production	Business oriented farmers	DWC, NFT, Drip System in 8M* 15M and 8M*30M greenhouse	Space	suited for commercialization: large population of crop population; ease of maintenance and projections on expected output; Potential to integrated to host aquatic life Suitable for cowpea, spider plant, swiss chard, sukuma wiki, amaranth, african night shade.	Yes: Iintense training, coaching and mentoring	intense training, coaching and mentoring of 200 agripreneurs, being 50 agripreneurs per year for 4 years. These agripreneurs will be linked to potential financial service providers and landowners willing to lease their land to these agripreneurs for commercial farming
School feeding		DWC, NFT, Drip System in standard greenhouse 8M*30M		easily customizable to what the schools need to offer in their plate; can meet school demand	Yes: Intense training, coaching and mentorship	intense training, coaching and mentorship of 10 schools interested support in financing and set up of a total of 10, 8M*30M greenhouse units in 10 schools., after working on the demo unit in Rueben Center for 1 year

Note: "Domestication of these systems can work in all areas depending on location, with production assured all year round. Different greenhouse designs would be recommended for the different climatic conditions i.e., jacked roof greenhouse design is recommended for hot climate, tunnel type greenhouse is recommended for cold climate, while dome-shaped greenhouse with cyclones is recommended for windy and humid climatic conditions." (Miramar stated)

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