Market Brief:
Green technologies for urban food production

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Image credit: Western Cape DoA / Elsenburg

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Introduction

This market brief highlights green technologies and practices that could enable more sustainable and resilient food production in Cape Town. It highlights technology options for intensive primary agricultural production which minimise resource use and food loss.

It is written for:

Cities

- looking for innovative urban agriculture solutions
- looking to support urban agriculture SMME growth opportunities

Urban farmers

- looking for innovative urban agriculture solutions to intensify food production
- looking for innovation urban agriculture solutions to minimise resource use and reduce input costs

Entrepreneurs

- looking to pursue viable opportunities in urban agriculture (agriculture production and green technology solutions)

1.1. Context

As the population grows and urbanisation continues, there is an increasing demand for jobs and natural resources such as food, water, and land. In Cape Town, the population grew by an average of 2% annually from 2010 to 2019, reaching 4.5 million people. In the Western Cape [1], this corresponds to about 65% of the population. Moreover, climate change is disrupting the food supply chain. Increased temperatures and water shortages threaten agricultural productivity, limiting the availability, accessibility, and quality of food.

Due to increased competition for (urban) land and climate change, green technologies and practices can offer specific benefits that enable more resilient and sustainable urban agricultural production. The use of green technologies and practices can mitigate against the adverse effects of climate change and environmental degradation. The documented [2] benefits of green technologies and practices for urban food production are shown in Figure 1.

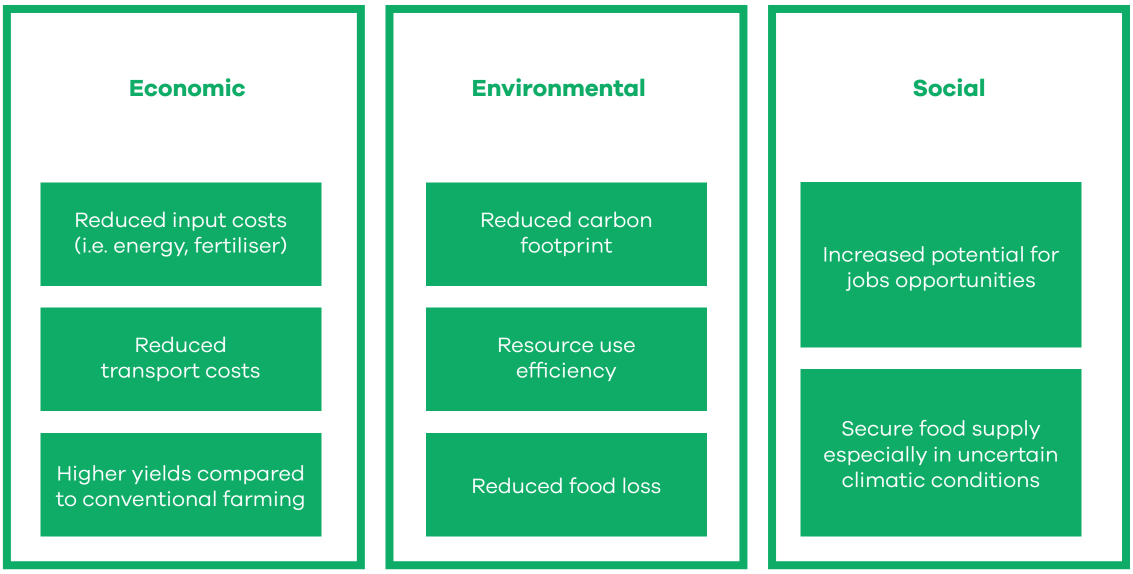

Figure 1 : Benefits of green technologies for urban food production (based on Boye and Arcand, 2013)

[1] Quantec (2020)
[2] Based on Boye & Arcand (2013)

1.2. Objectives, technology selection and evaluation

The objectives of the market brief are threefold:

1. To highlight green technologies and practices that enable sustainable agricultural intensification.
2. To determine the financial viability of the selected technologies.
3. To identify viable opportunities for investment in green technologies and practices in Cape Town.

Selection of green technologies and practices

The selection of green technologies and practices were guided by Gliessman's agroecological transition framework. The framework provides five levels of transition towards an agroecological system, from improving the efficiency of current practices to using transformational approaches to establish a new food system, as shown in Figure 2. For the purposes of this evaluation, Gliessman's framework was simplified and adapted to three levels to select and classify green technologies and practices that could enable intensive agricultural production. The fourth and fifth level were combined into one level, while level 3 was excluded. The reason for restricting the selection based on three levels of the framework is due to the type of technologies and practices and their market application. The adapted framework is shown in Table 1 below.

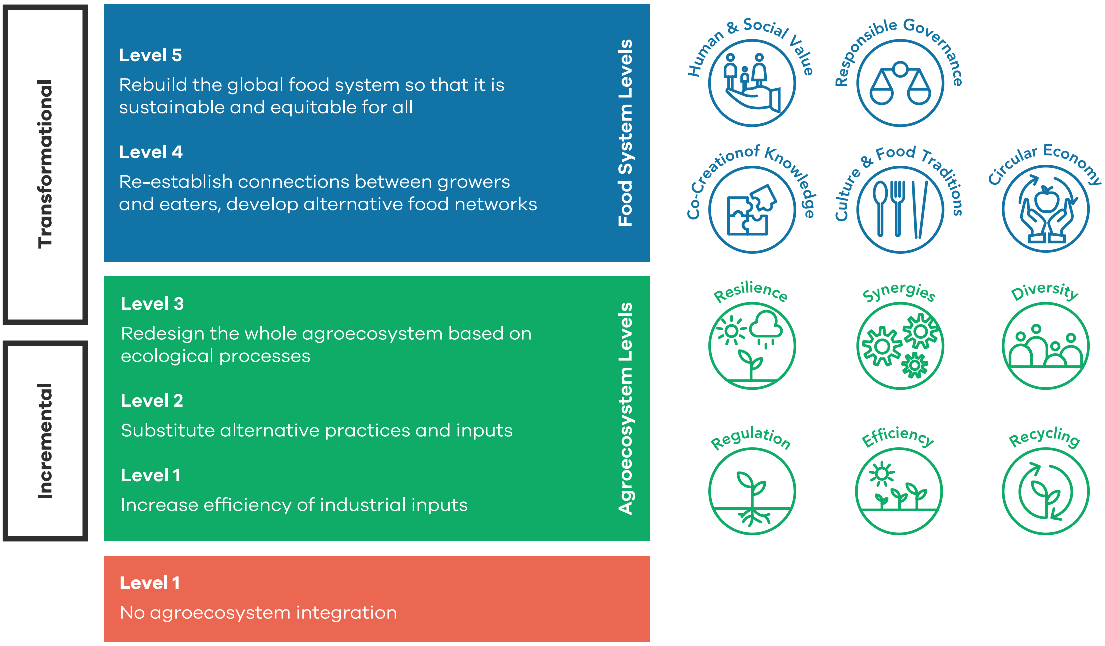

Figure 2 : Gliessman's five levels of transitioning to agro-ecological systems framework

Table 1 : Classification of green technologies and practices for intensive urban agricultural production based on Gliessman's framework

	Technology level	Description
Incremental	Level 1: Increase efficiency of current practices	Technologies that reduce water use, reduce input costs, while improving yields
	Level 2: Substitute alternative practices and inputs	Technologies and practices that improve soil health and pest management practices
Transformational	Level 3: Re-establish and rebuild of agricultural food production	Technologies that rebuild and re-establish sustainable agricultural production and establish alternative food networks such as novel growing systems.

Determination of the financial viability of green technologies and practices

A top-down approach was used for the evaluation of investment opportunities and the financial viability of green technologies. Secondary research, such as prior studies and reports, was used to assess the financial viability of selected technologies. A narrative business case showing the best use and investment case was developed for level 1 and level 2 technologies, where incremental changes are made to current farms. In the case of level 3 technologies, where new growing systems are introduced, the financial viability was determined using a simple payback calculation.

The parameters considered to determine the simple payback include the following:

- Capital expenditure (CAPEX) of the system
- Annual operational expenditure (OPEX)
- Annual revenues

Image credit: Western Cape DoA / Elsenburg

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Green technologies for agricultural production

A variety of green technologies are used for agricultural production. The technologies and practices are often referred to as "green" or "climate-smart" because they enable increased productivity and incomes, minimise adverse environmental impacts, and build climate change resilience

Table 2 includes a summary of the current literature findings on green technologies and practices for agricultural production. The technologies and practices aim to address food production challenges such as:

- Soil degradation
- Water scarcity
- Rising input costs
- Decreasing agricultural productivity

Table 2 : Green technologies for food production

Green technology or practices	Description	Sources
Sustainable practices	Sustainable agriculture practices such as agro-ecology, organic farming and regenerative agriculture can increase agricultural productivity while contributing to a more climate resilient and sustainable forms of food production. These practices all have principles and approaches that guide the food production process, but ultimately aim to address the impacts of climate change by improving soil health and conserving natural ecosystem services.	D'Annolfo et al (2015); Ersek (2019); Saunders and Hansen-Kuhn (2020); Senyolo et al (2017)
Undercover farming technologies	Undercover farming technologies involves the growing of food under protection. These can range from low-to-medium tech systems such as shade nets and greenhouses which are fitted in open-field farming to more high-tech systems such as indoor farming technologies with controlled environment and growing methods (i.e. soilless growing mediums such as hydroponic, aquaponic and aeroponic systems).	de Visser et.al (2012); ARC (2016)
Precision agriculture and smart farming	According to experts, the expansion of smart farming will result in increased production per crop, and more efficient production systems. Precision farming manifests in different farming types, including vertical farming, controlled (urban) environment agriculture, dairy farming and livestock farming. The agricultural sector uses sensor technology mainly to collect data on soil, crops and animals through integration into all kinds of equipment and machines, aircraft and drones or even satellites. Sensors can be integrated into the entire value chain in farming, supply chain or post-harvest systems – from providing weather data to product processing.	USB (2018)

Irrigation technology	The amount of water applied in soils can affect the nutrient concentration in soils and the rate of nutrient uptake. Efficient irrigation technologies feed root system of crops by releasing water only when needed. It further reduces evaporation and limits water run-off, leading to less/no chemicals going into groundwater.	Senyolo et.al (2018)
Waste-to-soil	These are compost solutions that use aerobic conditions and worms to convert organic waste from farmers, manufacturers, wholesalers, retailers, restaurants and households into compost. The application of the resultant organic matter in soil provides nutrients to crops and acts as a soil conditioner enabling crops to achieve high yields.	GreenCape, (2020)
Improved seed varieties	Seeds developed to tolerate diseases or drought and mature early.	Senyolo et.al (2018)

2.1. Green technologies for the intensification of urban food production

Green technologies are mainly applied in urban and peri-urban environments to conserve land, reduce distances from markets, and improve water use efficiency and productivity. Figure 3 illustrates the array of technologies that enable sustainable agricultural intensification [3] in urban and peri-urban areas.

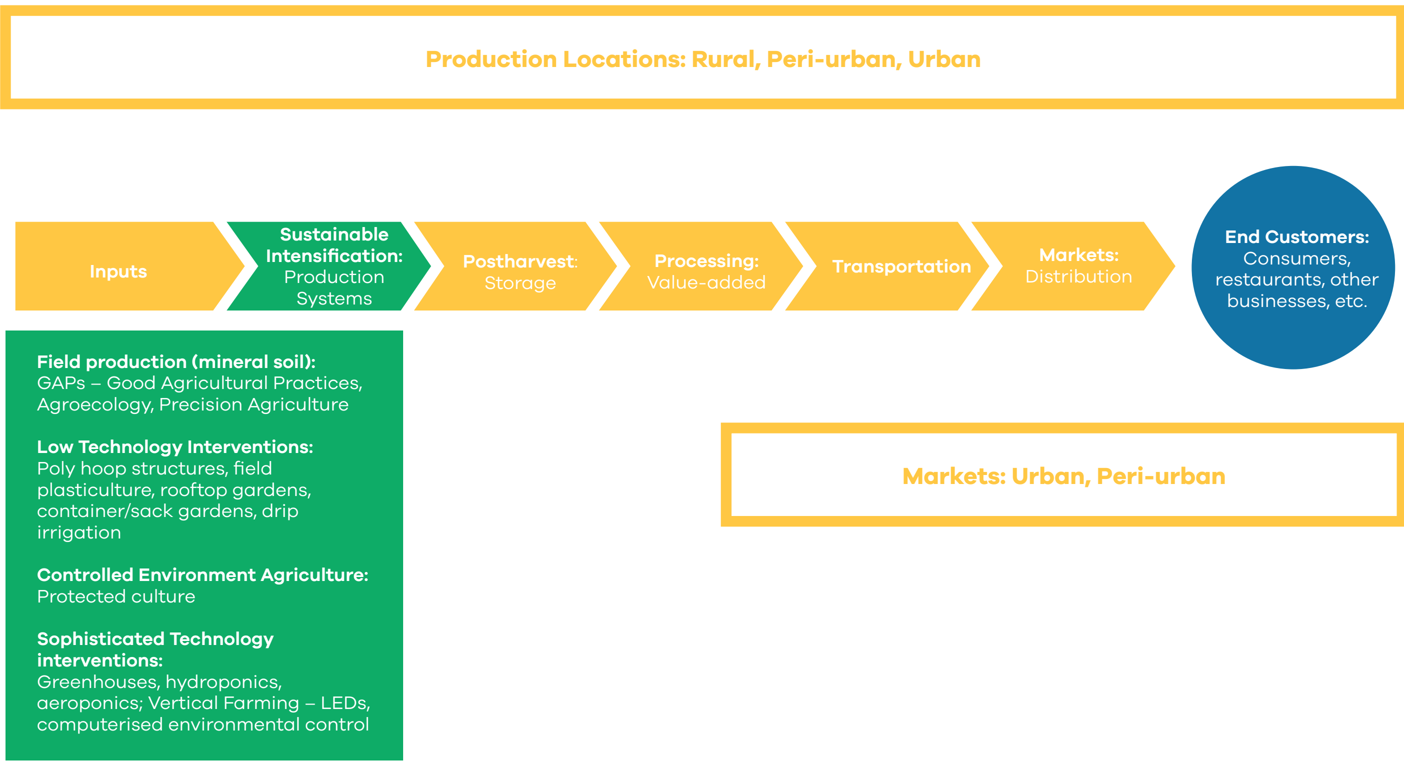

Figure 3 : The urban food value chain technologies for sustainable intensification (Davis & Garret, 2018)

[3] Sustainable agricultural intensification process focusses on five domains for agricultural production, which are: (1) increased yields per unit of land; (2) improved profits; (3) improved quality of natural resources and ecosystem services; (4) improved social cohesion; (5) improved health and nutritional outcomes (USAID, 2017)

2.2. Selection of green technologies and practices

Based on the existing literature, this market brief explored different green technologies and practices that could sustainably intensify primary agriculture production in urban and peri-urban areas. In light of the diverse and varied food production systems in Cape Town, the selection of technologies focused on technology interventions that increase yields and output per unit of land. The selected technologies and classification based on the modified Gliesseman framework (Table 1) are shown in Table 3

Table 3 : Selected green technologies and practices for intensive food production

Technology intervention Level 1		Technology intervention Level 2		Technology intervention Level 3	
Increase efficiency of current practices		**Substitute alternative practices and inputs**		**Re-establish and rebuild of agricultural production**	
Sensor technology	Drones	Waste-to-soil	Vermicomposting	Undercover farming technologies (high-tech)	Aquaponics
	Soil sensors		Organic compost		
	Satellite imagery	Sustainable practices	No-till		Hydroponics
Irrigation systems	Drip irrigation		Crop rotation		
Energy & water efficient system	Variable speed drives		Cover crops		Complete controlled environment agriculture systems
Low tech undercover farming technologies	Shade netting	Improved seed varieties	Organic seeds		

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Viable opportunities for investment in agricultural production

This section presents the evaluation of investment opportunities for viable green technologies and practices that can sustainably intensify urban agricultural production by:

- Increasing efficiency of current practices
- Substituting current methods with alternative sustainable practices and inputs
- Re-designing the food system through the use of novel growing systems

The information in the table illustrate the best use case of the technology in terms typical farm size, types of agricultural commodities and application; and the investment case for the technology.

3.1. Opportunities to sustainably intensify food production of current production systems through increasing efficiency of current practices

Table 4 highlights the viable opportunities for technologies that can intensify current production systems by increasing efficiency of current practices.

Table 4 : Green technology opportunities to intensify current production systems through increasing efficiency of current practices

Technology	Level 1: Increase efficiency of current practices		
	Technology	**Best use case**	**Investment case**
Sensor technology	Drones	■ Medium-to-large sized farms ■ Livestock and crop monitoring ■ Irrigation management and crop health assessment	■ Cost range: R30/ha – R100/ha ■ 85% reduction in planting costs ■ ~5% increase in yields
	Satellite imagery	■ Small-to- large sized farms ■ All crop types ■ Soil and water monitoring	■ Cost range: R100 - R200/ha/season ■ 10% savings in water ■ 10% savings in input costs ■ ~5% increase in yields
	Remote sensing devices (e.g. soil moisture sensors)		■ Cost range: R10 000 and R12 000 per irrigation block (average irrigation block ~15 ha) ■ 72% water savings over a 3-year period ■ ~5% increase in yields ■ Payback period: 2 – 5 years

Irrigation system	Non mechanised drip irrigation kits	■ Small-to-medium sized farms ■ High value crops (i.e. table grapes, nuts, citrus, deciduous fruit, avocadoes, apples and berries) ■ Irrigation management	■ Cost range: R1 000 - R3 000 per kit (available in sizes 50 m², 100 m², 200 m²) ■ 50% reduction in water use ■ Payback period: less than a year
	Drip irrigation (surface, sub-subsurface, low-flow drip)	■ Medium-to- large sized farms ■ High value crops (i.e. table grapes, nuts, citrus, deciduous fruit, avocadoes, apples and berries) ■ Irrigation management	■ Cost range: R10 000 - R50 000/ha ■ Relatively lower fixed and operating costs ■ ~10kl/ha reduction in water use ■ Payback period: 5 - 7 years
Energy efficient systems	Variable speed drives	■ Medium-to- large sized farms ■ Installed on irrigation pumps	■ Cost range: R1 200 – R1 500 per kW ■ 20 - 40% in energy savings ■ 30% water savings ■ Payback period: 7 – 14 months
Low tech undercover farming	Shade netting	■ Small-to-large scale farms ■ High value crops (i.e. table grapes, nuts, citrus, deciduous fruit, avocadoes, apples and berries)	■ Cost range: R90 000 – R250 000/ha ■ 30% reduction in water use ■ 50% increase in yields ■ Payback: ~3 years

3.2. Opportunities to intensify production through alternative practices and inputs

Table 5 highlights viable opportunities for technologies that can intensify current production systems by through alternative practices and inputs.

Table 5 : Green technologies and practices to intensify production through alternative methods

Technology	Level 1: Increase efficiency of current practices		
	Practice or Technology	**Best use case**	**Investment case**
Sustainable practices	Cover crops	■ Small-to-large sized farms ■ Dryland production ■ Improved soil health	■ Cost range: R1 000 – R2 500 /ha ■ Fertiliser savings of R1 000/ha over a two-year period ■ Increased organic matter in soil from 0.3% to 1% ■ 50% increased yields over 10 years
	No till machinery		■ Cost range: R1 000 - R37 000 (small-scale) & R400 000 - R2.2 million (large scale) ■ Fuel savings: 30-40L/ha ■ ~50% increased yields over 10 years ■ Payback: ~5 - 7 years
Waste-to-soil	Vermicomposting	■ Small-to-large sized farms ■ Improved soil health ■ All soil types	■ Cost range: R2 000 – R2 500 per ton ■ 13% increase in organic material ■ 30% water retention ■ ~25% increases in yields
	Organic compost		■ Cost range: R20 - 35 per kg ■ 5% increase in organic matter ■ 30% water retention ■ ~5 – 20% increase in yields
Improved seed varieties	Organic seeds	■ Small-to-large sized farms ■ Vegetables ■ Typically disease tolerant	■ Cost range: R15 - 200 per kg ■ Expected growth with increasing demand for organic produce ■ Reduced yield losses - varies by crop type

3.3. Opportunities to intensify food production through novel growing systems

This section provides general business cases for novel growing systems that hold potential for intensive food production in Cape Town. Three different undercover farming technologies are explored, namely, hydroponics, aquaponics and complete Controlled Environment Agriculture (CEA) systems.

The section provides:

- A brief overview of the technology;
- General business cases [4] highlighting the competitive advantage and financial viability of the systems; and
- Case studies showing how the technology has been applied.

3.3.1. Hydroponic systems

Hydroponics is the process of growing plants in sand, gravel or liquid with added nutrients but without soil. The primary benefits of hydroponics are reduced water usage (due to direct delivery of water to crops' roots and thus mitigation of evaporation) and greater yields due to increased control of concentration of nutrients throughout the lifecycle of production. In areas were land is limited, hydroponics is an attractive option with diminished chances of pest, fungal and bacterial infections.

Hydroponic systems (as shown in Table 6) start from low-tech designs, which require minimal manual labour or automation, to highly technical, highly monitored systems that require frequent maintenance. The selection of a system is predicated mainly on choice of crop to produce but also access to amenities such as water, energy and internet connectivity.

Table 6 : Overview of hydroponic systems

	Kratky method	Wick system	Deep Water Culture (DWC)	Ebb and Flow (aka media bed)	Drip system	Nutrient film technique (NFT)	Aeroponics
Description	Plants are suspended over a nutrient solution with only roots submerged	Plants suspended above a grow tank; water delivered to the growth medium using capillary action	Plants suspended over a grow tank aerated by an air pump	Plants supported by grow medium in grow tank and intermittently irrigated	Nutrient solution piped directly to plants through individual pipes slowly	NFT systems provide a thin film of solution to the lower roots while the upper roots breathe	Pressurised nutrient solution is sprayed via nozzle to the roots in the form of droplets
Growth medium	None	Coco coir, LECA clay balls	None	Coco coir, LECA clay balls	Coco coir, coco peat, vermiculite, perlite	None	None
Best suited plants	Sweet potatoes, epiphytic orchids	Small herbs, non-fruiting vegetables	Basil, lettuce, cucumber, tomatoes, Swiss chard, parsley	Most produce	Fruit trees	Leafy greens, lettuce, Swiss chard, herbs; strawberries, watermelons	Mushrooms, microgreens, rooting crops, tree whips
Typical systems	Hobby	Hobby	Hobby and subsistence	Subsistence and commercial	Commercial	Subsistence and commercial	Commercial

[4] The basic parameters used across the business cases are: Department Agriculture, Land Reform and Rural Development market price for Q3 (Feb - April 2021); 2020/21 electricity tariff in Cape Town for small commercial users (~R3,24 per KWh) and 2020/21 water tariff for Cape Town for commercial users (~R27,94 per kL) under no restrictions.

Advantages	Simple and cheap; no energy requirement	Simple and cheap; no energy required	Simple and cheap; low maintenance needs	Excellent aeration; greater control of feeding and watering	Full control of nutrient solution; low use of nutrient solution; low risk of root rot	Nutrient solution is continuously recycled; allows for easy root inspection	Low use of nutrient solution; aeroponics chamber can take any shape
Dis-advantages	Minimal aeration for roots; unreliable yields and quality	Unsuitable for plants prone to root rot; constrained by capacity of capillary	Relatively still water allows for pathogen, algae and fungal growth; system must go offline for maintenance	Complex setup and farm management; higher rates of pipping breaks and clogging	Common problem of leakages, relatively higher farm equipment maintenance	Not suitable for large plants; roots that grow thick and large can block flow of solution	Highly advanced: requires controlled, enclosed space with expensive pumps

(Based on Sambo, 2019; Niekerk, 2019)

3.3.1.1. Business case

A business case for a hydroponic system has been developed based on two scenarios, namely:

- Assessing the competitive advantage of the application of hydroponics compared to soil-based farming;
- Assessing the viability of the two most common hydroponic systems in South Africa, namely Deep Water Culture (DWC) and Nutrient Film Technique (NFT) system. As indicated in Table 6, the systems typically grow leafy green crops, such as spinach, lettuce, spring onions, herbs etc.

Competitive advantage of hydroponics vs soil-based farming

The competitive advantage of hydroponics vs soil based farming is illustrated in the cost breakdown of the different growing methods in Table 7 and Figure 4.

The cost breakdown was based on the following assumptions:

- One hectare of productive area (10 000 m²)
- Production of lettuce: a commonly grown crop in hydroponic systems due to ease of production and high market demand
- Water usage reduction of 20 and 50% (for DWC and NFT systems, respectively)
- Growth period of 2 months when hydroponically grown
- Annual loan repayment calculated as 5% of capital expenditure (i.e. cost of system set-up)

Compared to soil-based farming, the capital investment and operational costs for both DWC and NFT systems increased considerably as seen in Figure 3. Notable increases in expenditure were in terms of purchasing of plants and labour costs - due to shortened growth cycles and increased plant density resulted in farm greater production turnovers in comparison to soil and greater labour hours associated with their maintenance. However, the increased production resulted in decreased costs per kg yield in terms of water and energy consumption as well as labour as described in Table 7.

Table 7 : Resource expenditure per kg yield for soil and common hydroponic systems

	Soil	DWC	NFT
Average yield (kg/plant)	0.583	0.700	0.700
Growth period (months)	3	2	2
Plant density (plants/m²)	6	10	12
Total yield (kg/annum)	140 000	420 000	504 000
Water consumption (L/kg)	42	11	6
Energy consumption (kWh/kg)	0	0.0066	0.0055
Labour (hours spent/kg)	0.052	0.021	0.021

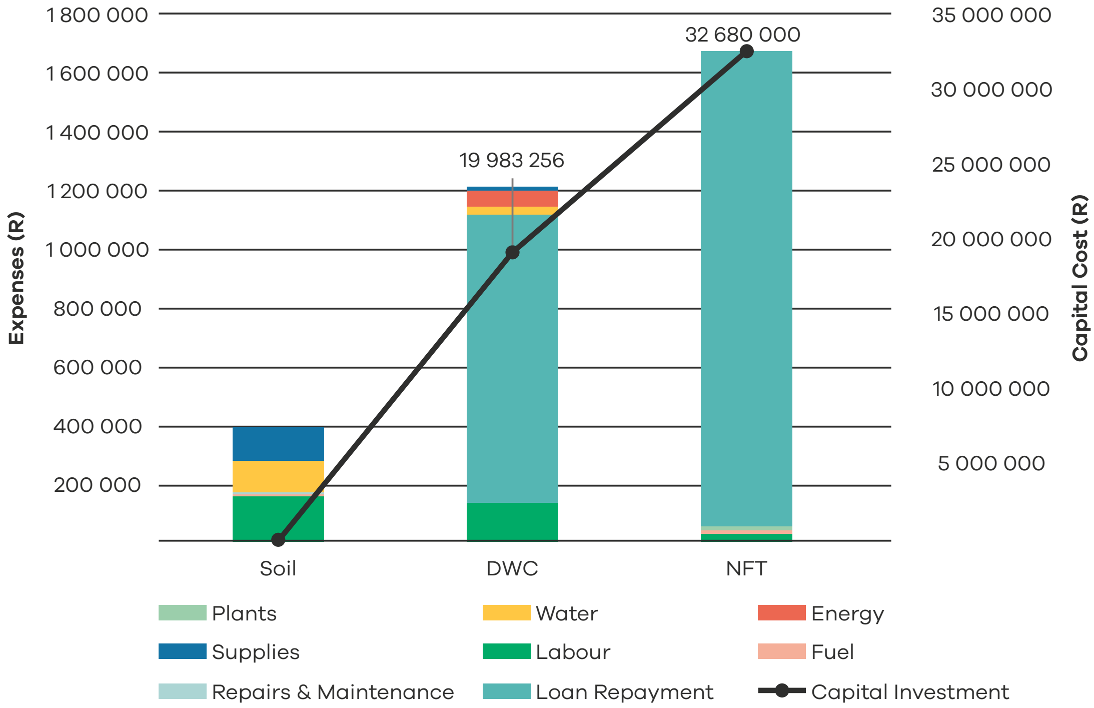

Figure 4 : Cost breakdown of primary costs for soil and hydroponic systems for 1 ha (10 000 m²) of lettuce (Singer et al, 2015; Mashego, 2001)

Financial viability

The determination of the financial viability of hydroponic systems was based on a simple payback for investment in a 10 000m² DWC and NFT system growing lettuce (Table 8). Compared to NFT systems, the DWC system was more viable with a payback period of 1.3 years. This is because a DWC system has lower setup costs compared to NFT systems and uses significantly less energy as it does not require a water pump. There are, however, technical limitations to DWC systems. The systems require constant aeration of the water, and if the water is not well oxygenated or the air pump fails, the plant roots will be at risk of drowning (further limitations are described in Table 6).

Table 8 : Simple payback calculations of common hydroponic systems

System type	DWC	NFT
Selected crops	Lettuce	Lettuce
System size (m²)	10 000	10 000
System set-up (R)	19 983 256	32 680 000
Revenue (R)	16 090 893	13 694 400
Cost of Production (R)	1 358 004	1 397 569
Gross Profit (R)	14 732 889	12 296 831
Payback period (years)	1.36	2.66

3.3.2. Aquaponic systems

Aquaponic systems are a combination of hydroponic and aquaculture systems that produce crops in recirculated aquaculture water. The application of aquaponics allows for more sustainable and cost-effective use of aquaculture effluent as nutrients for plants. In addition, the combination of aquaponic and hydroponic systems decreases some of the overhead costs typically associated with running them separately. Aquaponic systems are suitable for areas with poor soil quality, scarce water, and limited land.

The primary benefits associated with aquaponic food production are:

- Sustainable and intensive food production
- Multiple agricultural products produced in one system and nitrogen source
- Improved water efficiency
- Higher levels of biosecurity and reduced environmental risks of closed-loop systems

Aquaponic systems vary widely in size and scale of operation. These systems can be operated on a commercial, subsistence, or hobby scale. The typical sizes for the various systems are illustrated in Table 9. Growing food on a hobby scale is primarily about enjoying the cultivation process, not necessarily about producing for consumption. On the other hand, a subsistence-scale system is intended to provide food and income, with surplus produce going to informal markets. Food grown in a commercial system is destined for the market, and the systems can be small, medium or large scale.

Table 9 : Sizes of different aquaponic systems

	Hobby system	Subsistence	Commercial system
Sizes (L)	500 – 1 000	1 000 – 2 000	4 000 – 50 000
Fish stock (kg/m-3)	10 – 20	20 – 40	100 – 300
Typical cost range	R1 500 – R20 000	R60 000 – R100 000	R150 000 - 350 000

Source: (Fallis, 2013; Somerville et al, 2014; Love et al., 2015)

A study conducted by Mchunu et al. (2018) highlighted the geographic distribution of the different aquaponic systems in South Africa; this is illustrated in Figure 5. Based on the results of the study, the Western Cape has the largest distribution of commercial aquaponic systems, followed by Gauteng. In contrast, KwaZulu-Natal has the most aquaponic systems, which are predominately hobby systems.

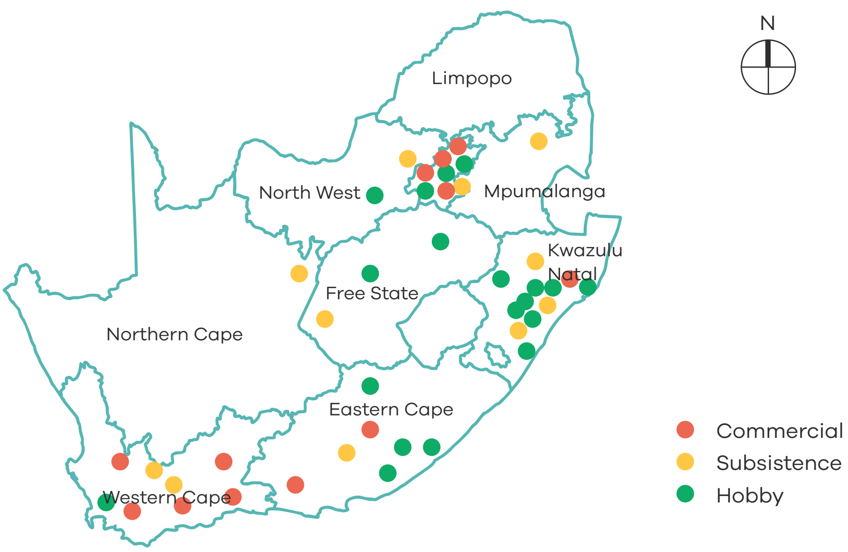

Figure 5 : Distribution of aquaponic systems in South Africa (Mchunu et al., 2018)

Components of aquaponic systems

The components of an aquaponic system depend on the technical design and the size of the system. The main components of the systems include a fish rearing tank, biofilter, hydroponics component, and a solid removal component. The following sections discuss the technical design aspects of aquaponics and the system's financial viability. The typical components of an aquaponic system and the types of crops and fish species cultured are in shown in Table 10.

Table 10 : Aquaponic systems components

Components			
Growing environment	Tunnel; greenhouse or open field		
Scale of production	Hobby, subsistence, commercial		
System tanks	Fish rearing tanks, filter tanks, degassing tanks		
Fish types	Tilapia, Barbel, Catfish, Trout, Ornamental, Bass, Bluegril (Tilapia is the dominant fish species cultured due to suitable environmental conditions)		
Crop production method (hydroponic)	Nutrient Film Technique	Deep Water Culture	Media bed
Growing method	Crops grown on vertical plane	Floats rafts to suspend plat roots into nutrient rich and aerated water	Filled with rock media such as gravel or clay
Produce	Best suited for leafy greens	Leafy and fruity vegetables	Fruits, vegetables, flowering plants or root vegetables

3.3.2.1. Business case

A variety of factors influence the viability of aquaponic systems, including the crop type, location, size, and technical aspects. The financial viability considered in this brief is based on a scenario in which different high-value crops are produced in a small-scale commercial aquaponic farm.

The following assumptions were made regarding the farm:

- The farm is a 300 m^2 tunnel sized farm with 40 grow beds sized 3 m^2 and 4300L fish tanks (based on Table 9). The choice of the system is based on one that is already installed and operating at a small commercial scale.
- The system produces both crops and fish
- The yields from the farm are from a constant production of 12 months
- All sales from crops and fish are marketed at current prices

Table 11 : Summary of illustrative aquaponic farm characteristics

Illustrative farm components	Units
Tunnel size area (m^2)	300
No of grow beds	40
Size per grow bed (m^2)	3
Fish tank (L)	4 300
Fish stock (kg/m^3)	300

Competitive advantage of aquaponic systems

The case for aquaponic systems is strengthened by harsh environmental conditions, leading to a decline in freshwater pond aquaculture in South Africa (Swap et al 2002; Mchunu et al 2019). The competitive advantage of aquaponic systems compared to traditional aquaculture systems are:

- Diversified incomes, especially in cases where fish and crops are produced
- Reduced fertiliser costs
- Increased water use efficiency (~90% water saved)
- Better utilisation of land and space

Moreover, the produce from aquaponic systems is chemical-free, making it appealing to consumers shifting towards more environmentally friendly products.

Financial viability

The viability is modelled under a scenario where both crop and fish are produced in the aquaponic system. The products are:

- Crops - lettuce, tomatoes, basil and brinjals
- Fish – tilapia

The choice of crops is mainly because these are the crops that can currently attain a high market price (as shown in Table 12). In addition, leafy vegetables are mostly widely raised in aquaponic systems due to lower nutrient requirement and higher density, while fruity vegetables present a high economic value. In the case of tilapia fish, it is the most suited fish species for the environmental conditions and the industry in South Africa is anticipated to grow to about 6 000 t/year over the next 10 years (Dempsey, 2021).

Table 12 : Sizes of different aquaponic systems

	Crops	Density (plants/m²)	Estimated production (kg/m²)	Growing cycle (weeks)	Market price (R/kg)	Expected value(R/m²)
Leafy vegetables	lettuce	30	9	3	11,66	104,92
	kale	30	0,89	3	20,97	18,67
	basil	16	1,8	4	72,04	129,67
	spinach	30	1,44	3	16,65	23,97
Fruity vegetables	tomatoes	5	29,29	9	12,65	370,38
	cucumbers	8	6,2	6	10,62	65,84
	brinjals	3	7,6	9	9,38	71,31
		Density (kg/m3)		**Harvest time**	**Market price (R/kg)**	
Fish	tilapia	100-300		6 months - a year	177	

The capital and operating cost of the aquaponic system under the various scenarios modelled are indicated in Table 13. The small-scale commercial aquaponic system is estimated to have an initial investment of R350 000 and annual operating costs between R120 000 and R350 000, depending on the type of crops cultivated and fish cultured.

A breakdown of the operating costs of the aquaponic system is indicated in Figure 6. Electricity contributes the most to the running costs of an aquaponic system, accounting for about ~85% of the total costs, followed by fish feed at ~2.3% and fingerlings ~1.6%.

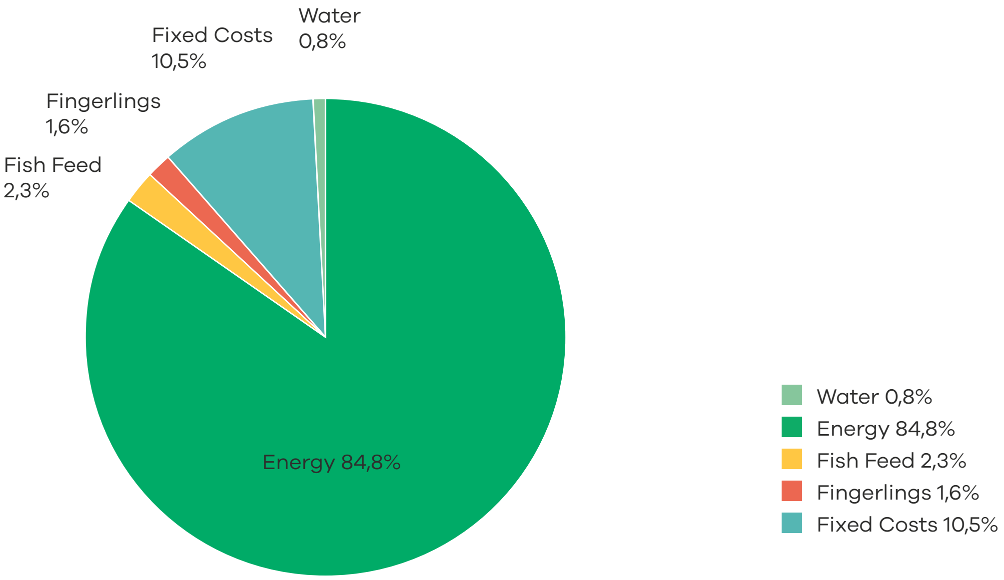

Figure 6 : Breakdown of operating costs of aquaponic system as a percentage of average total costs

Table 13 : Summary of illustrative aquaponic farm characteristics

CAPEX (R)					350 000
Model	Lettuce, tilapia	Tomato, tilapia	Lettuce, tomato, tilapia	Lettuce, tomatoes, basil, tilapia	Lettuce, tomatoes, basil, brinjal, tilapia
Ratio of plants in grow beds	40	40	30:10	20:15:5	20:10:5:5
Annual OPEX	R128 317	R331 744	R253 979	R225 375	R247 602
Annual fixed costs [5]	R28 000	R28 000	R28 000	R28 000	R28 000
Annual revenues	R552 951	R490 750	R369 805	R383 151	R360 721
Annual net profit	R396 634	R131 005	R87 825	R129 775	R85 119

The payback period for various crops and tilapia cultured in a small-scale commercial aquaponics system is shown in Figure 7. As illustrated, growing just lettuce (a leafy vegetables) and tilapia will pay for itself within one year. While a system producing tomato (a fruity vegetable) and tilapia will pay off in 2.7 years. The payback period increases as more crops are grown, and can take up to four years. It is important to note that the annual revenues determined are based on the current market price for the crops. However, high-quality produce from the aquaponic system may gain premium prices since it is often regarded as an environmentally friendly and, in some cases, labelled as organic. As a result, the payback period for the systems could be further reduced.

Most growers often choose to produce various crops to diversify incomes and reduce production risks. With adequate crop type and markets, the minimum length of payback that can be achieved is just under a year and the maximum about four years for a typical small-scale commercial aquaponic system.

[5] Based on an average percentage of the total capital costs (~8%)

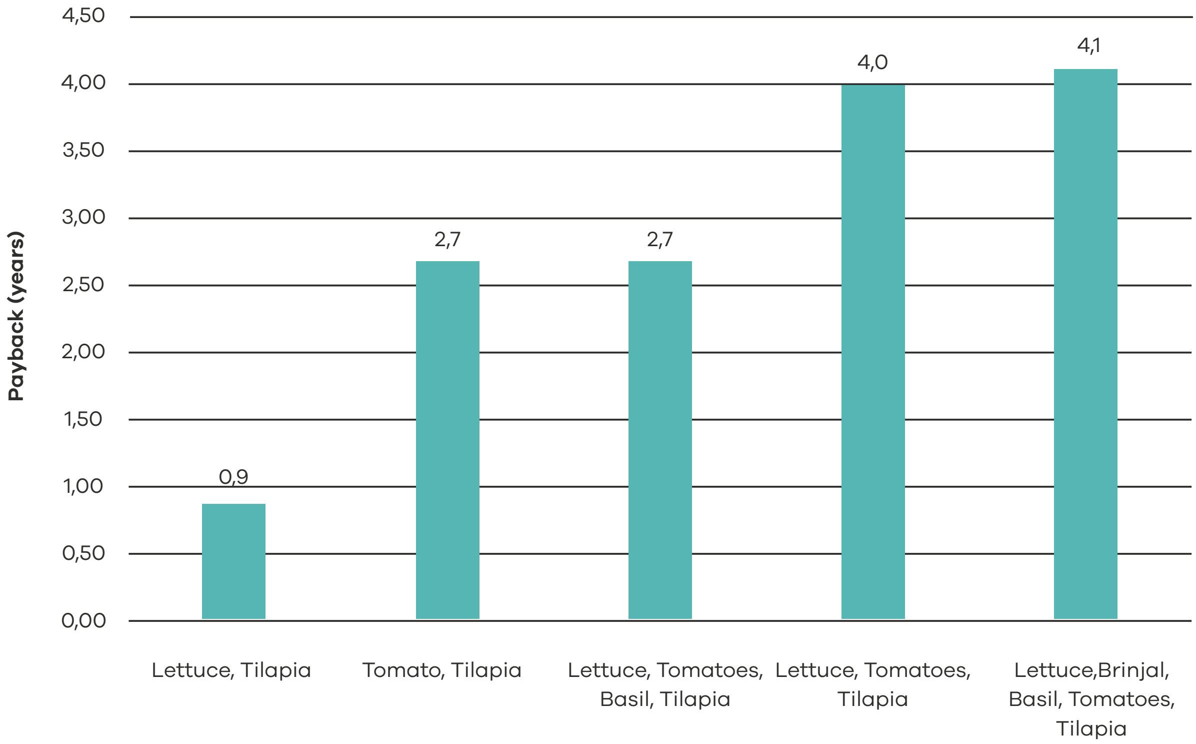

Figure 7 : Simple payback for small scale commercial aquaponic systems for different crops produced and tilapia

3.3.2.2.Case studies

While the type of crop produced and market is critical for viability of an aquaponic system, the technical design of the system and how it is operated are also key factors for consideration.

Table 14 presents case studies of different commercial aquaponic systems installed in the Western Cape.

Table 14 : Case studies showcasing the viability of aquaponic systems (Lepere et al, 2010)

	Farm 1	Farm 2	Farm 3
System components	Growing environment: two tunnels Construction: brick and concrete Hydroponic: gravel medium Solid removal: sand filter Biofiltration: gravel medium Heating: solar pump & wood fired boiler	Growing environment: three greenhouse tunnels Construction: wood and plastic Hydroponic: gravel medium Solid removal: settling tank Biofiltration: biofilters tank Heating: wood fired boiler	Growing environment: one greenhouse tunnel Construction: PVC half pipe Hydroponic: gravel medium Solid removal: none Biofiltration: gravel medium Heating: heat pump
System tank size	55kl	112kl	28kl
System CAPEX	R100 000	R250 000	R200 000

NPV over 10 year period	Positive net present value in year 4	Negative net present value	Negative net present value
Produce	Fish poor quality, plants very good	Fish poor quality, plants good	Plants and fish poor quality
Conclusion on viability of farm	Farmer installed the system so the cost of installation was reduced. The system also has a solar water heater, which significantly reduced the cost of electricity. The wood fired boiler was not used during the winter time and resulted in the water temperature decreasing during colder months, resulting in reduced growth of fish.	The system is among the largest in the province and grows a range of produce. The wood fired boiler as a heating system makes it difficult to main the water temperature during colder months which affects the growth of the fish.	The high capital cost of system is a result of outsourced construction. The system incorporated 300 chickens and the chicken droppings were used as fish feed. While this reduced the operation cost of fish feed, it affected the water quality and growth rate of the fish. The vegetables produced in hydroponic were also not suitable for the sale and were provided to chickens, making this system economically unviable.

The key lessons from these case studies are:

- Technical skills are needed to ensure that the design of the system is suited for the type of produce and fish culture. Only Farm 1, showed a positive net present value at year 4 over the 10-year study period. This is mainly due to reduced capital and operational costs from own installation of the system and use of solar water heaters. Farm 2 and 3 showed a negative net present value over a 10-year period, partly due to poor water temperature control.
- Water temperature and quality plays a key role in the growth and development of the fish. In all the cases presented, the water temperature was not optimum for the growth of fish, which reduced productivity and limited the potential benefit of the double income stream that the systems provide.
- It is important to take into account certain factors to reduce the operating costs as part of assessing the opportunity cost of investment. Farm 1's farmer installed the system and cut installation costs; whereas in Farm 3's case, the farmer used chicken droppings as fish feed. While Farm 3's operational costs were reduced, the water quality was affected by the feed, making it not financially viable.

3.3.3. Complete controlled environment systems

Controlled environment agriculture (CEA) is the production of plants and animals in a protected environment where optimal growing conditions are maintained throughout the life cycle of the plant or animal. The benefits of CEA include:

- reduction in water use
- reduction in pesticide and fertiliser use
- reduction in water loss through recycling
- high quality produce
- year-round production of seasonal produce
- higher production volume compared to conventional farming on the same size land

The soilless nature of production also makes CEA an attractive opportunity for urban and peri-urban farming where there is competition for space for housing, commercial interests and recreational use.

Infrastructure such as netting cover, tunnels, fertigation etc. are all various components of controlled environment agriculture and can be implemented individually. However, the best results are found when several components of CEA are implemented in conjunction to one another. In this document, these multicomponent systems will be denoted as complete controlled environment agriculture systems (CCEA). A typical CCEA system is often soilless, and growing chambers can be extended vertically to intensify food production. Water, nutrients and lighting are carefully controlled to meet the needs of crops throughout their lifecycle through integrated software that collects data and uses data to inform tasks and interventions where needed.

Components of a CCEA system

CCEA systems range from low-tech options such as shade netting and tunnelling to highly-technical, fully automated production systems. The basic components of a complete CEA system are detailed in Figure 6 below:

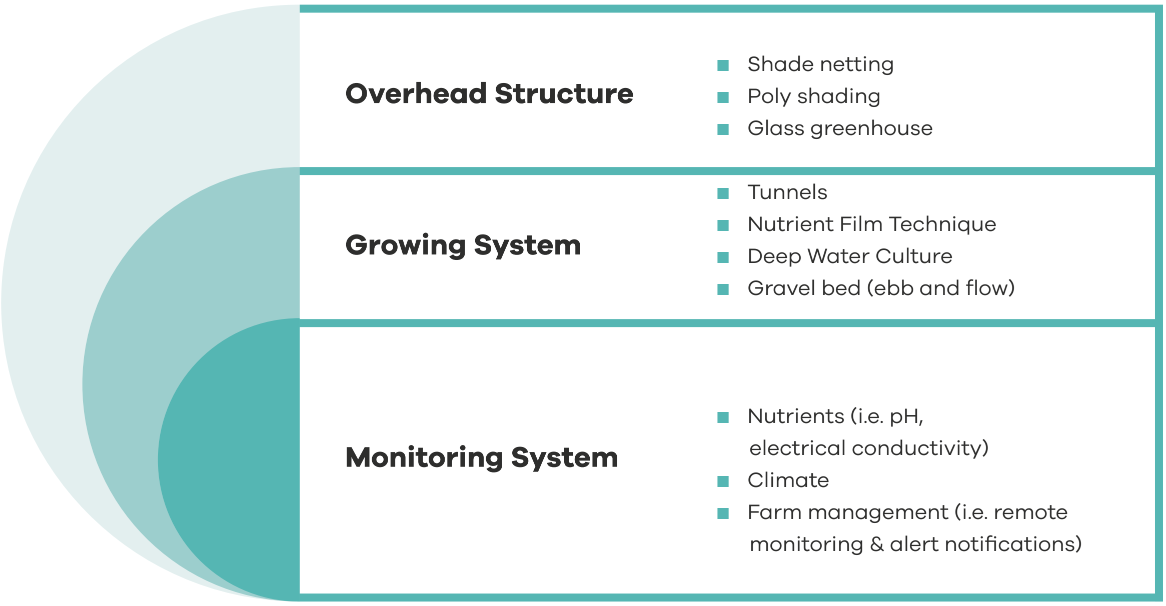

Figure 8 : Components of a complete CEA system

3.3.3.1. Complete CEA systems business case

The financial viability of complete CEA farming is mostly predicated on the following factors:

- Initial infrastructure capital costs
- Site selection and weather forecasting
- Crop selection and production density
- Electricity costs and reliability
- Data costs and access to the internet
  (Bosman van Zaal, 2020)

The business case is based on assumptions on a model CEA farm. The following assumptions were made:

- A model CCEA farm was based on a container system installed the United States (described in Table 12) and adapted to a South African context
- The calculation of loan repayments was based on an annual repayment amount of 5% of the total capital expenditure.
- The business case was modelled under two scenarios (different technical design systems and crops)

The model CCEA farm is completely contained in a 30m² shipping container, with automated LED lighting with various arrays, adjustable plant spacing, data collection software for remote monitoring and crop scheduling, as well as full fertigation and water harvesting capabilities. The table below summarises the key descriptors of a model complete CEA system.

Table 15 : Summary of model complete CEA farm characteristics

Illustrative farm	
Total container size (m²)	30
Production area (m²)	20.4
Total capacity (no. of plant sites available)	8 800
Water consumption (kL/annum)	7
Electricity consumption (kWh/annum)	72 000
Data consumption (GB/annum)	12
Labour (mh/annum)[6]	1 040

(Source: FreightFarms Greenery S product booklet)

[6] mh denotes man hours; a full working day consists of 8 man hours

The capital expenditure for purchase of container is R1 827 800 ($125 000 excluding installation, delivery, VAT etc.). The selected crop for the analysis under a complete CEA system was basil – a popular crop in South Africa year-round and well-suited for this growing system. One can expect an average yield of 2 080 kg of basil per annum (pa) based on production in a single container. Supplies encompassed the nutrients, pesticide and herbicide for maintaining the fertigation system of a CCEA. Figure 9 provides a cost-breakdown of the annual costs of production.

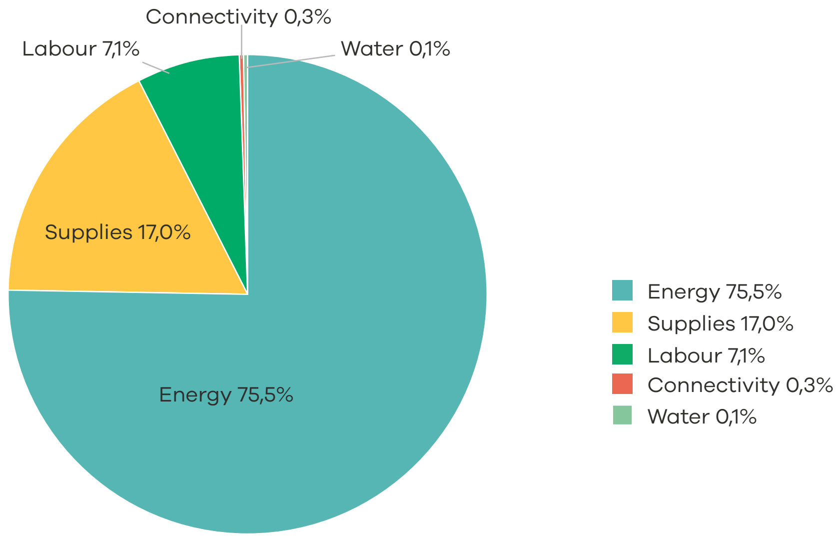

Figure 9 : Breakdown of CEA system's operational costs as a percentage of the total cost of production [7]

Energy is a large portion of the operational expense (approximately 75%) and its cost undermines the financial viability of the business case for a high-tech complete CEA system[8]. Several additional parameters should be considered in evaluating the financial viability of these types of systems. Additional business studies looked at the impact of adding complete solar PV generation capacity and the selection of higher-value crops.

Table 16 : Description of different complete CEA systems

	CCEA container	CCEA container with solar capacity	CCEA container with higher-value crops
System components	Completely automated CEA container	Completely automated CEA container and solar PV system with 200 kWp generation	Completely automated CEA container
Crops	Basil	Basil	Asian Greens
Total yield (kg/annum)	2 080	2 080	2 948
Market price (R/kg)	78.10	78.10	181.57
Water consumption (kL/kg)	3.32	3.32	2.34
Energy consumption (kWh/kg)	34.62	0.00	24.42

[7] The cost of repairs & maintenance, fuel and plants also contribute the total cost of CEA system but the contribution to the total cost of the system is negligible.
[8] The annual energy consumption was based on values from a US context, where the climate is relatively cooler in comparison to SA. This value warrants further investigation as to energy consumption is split between automation, lighting, space heating etc. and may increase or decrease due to changes in heating requirements.

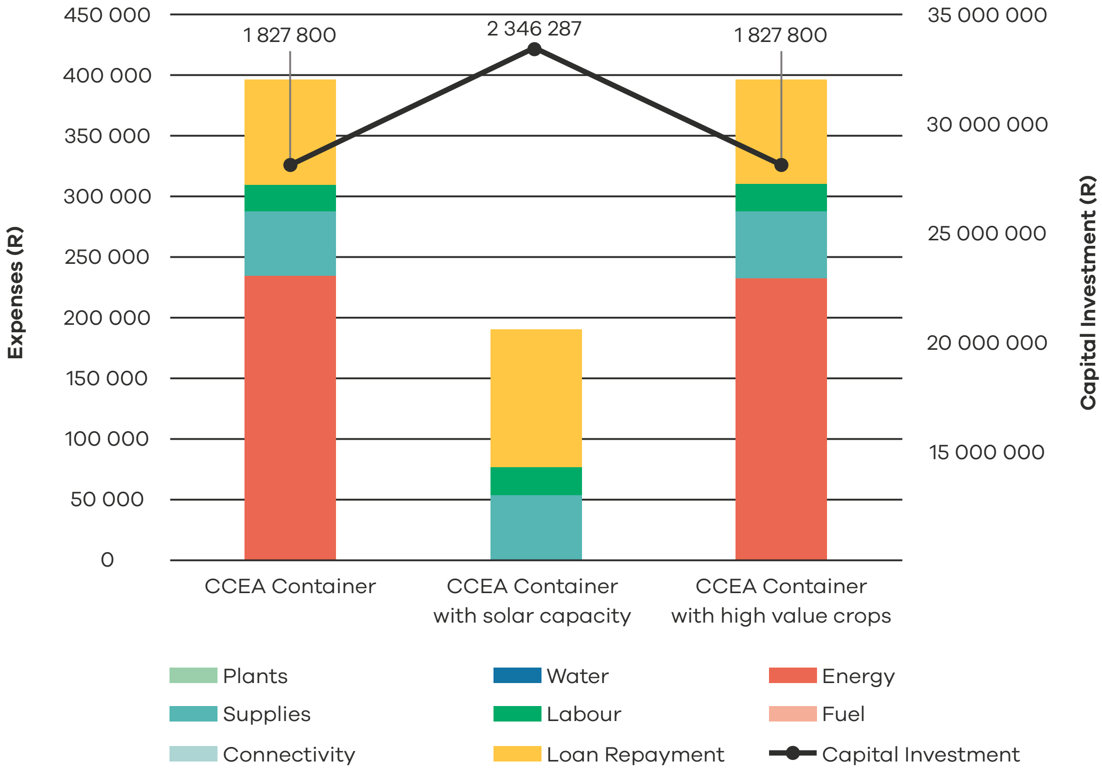

Figure 10 : Capital investment and cost breakdown of CEA systems' OPEX (Sources: Radmore & Chilwan, 2017; FreightFarms Crop projections, 2021)

Table 17 : Financial viability of complete CEA systems

	CEA container	CEA container with solar capacity	CEA container with higher-value crops
CAPEX (R)	1 827 800	2 346 287	1 827 800
Revenue (R)	162 452	162 452	535 341
Cost of production (R)	309 141	75 753	309 221
Gross Profit (R)	-146 689	86 699	226 120
Payback period (years)	Not profitable	27.1	8.08

Key insights from business case models

The previous section compared different CEA technical design systems and crop selections.

The key insights from the business cases were:

- The greenhouse container producing basil is not viable in theSouth African context. The cost of electricity is extremely high and is projected to climb significantly in the coming years
- Incorporating solar PV generation capacity for a greenhouse container system moved the system to profitability. The payback period (27.1 years) is greater than the system's lifespan of 20 years, thus rendering the system financially unviable. However, as the cost of solar PV systems and battery storage decreases and Eskom opens its grid for power producers to feed in electricity and generate further revenue, this business case may become financially viable.
- Producing higher-value crops, such as Asian greens, was also financially viable. However, these crops in South Africa often lack a sufficient market. The successful production, marketing, and selling of Asian greens would require extensive research into the market size of the crops and offset agreements with retailers.

3.3.4. Low technology interventions

The various growing systems highlighted in the previous sections are also offered at a scale where they can be used for either subsistence or hobby related activities. The technologies, often referred to as "low-tech", require minimum capital investment and are simple and easy to use. There are a few examples of low-tech urban food technologies that can be applied at household or community level to further increase food productivity. The different systems and the associated costs are highlighted in Table 18.

Table 18 : Low technology innovations for increased urban food productivity at household or community level

Low-tech innovation	Description	Cost range
Soilless growing kits	Indoor hydroponic growing kits that can grow a range of herbs and leafy greens	R1 000 – R20 000
Wicking beds	Self-watering raised garden beds which are suitable in areas with water constraints and suitable for growing a range of crops.	R800 – R15 000
Vertical garden pockets	These are small pockets typically made of textile fabric. The pockets are ideal for area where land or space is limited and can be grown on walls. The typical plants are herbs, vegetables and edible plants such as microgreens	R200 – R1 000
DIY vertical gardens	Growing wall or pillar which utilise simple welded-wire fencing for the structure, fabric for the inner lining, and high-quality compost or some combination involving soil as the growing medium.	Varies by size, design and selected construction material

04

Viable opportunities for Cape Town's food production systems

This section provides an overview of agricultural production in Cape Town and the different green technologies and practices that can be implemented to increased efficiency and productivity of food production systems.

4.1. Overview of Cape Town's agricultural production

Agricultural production in Cape Town takes place predominantly in the city's peri-urban[9] areas and varies by commodity type, scale and end market. Table 19 illustrates the different food production systems in Cape Town, the types of crops produced and typical challenges experienced.

Table 19 : Cape Town food production systems

Types of food production systems in Cape Town	Description	Crops produced	
Community gardens	Mostly in located townships and informal settlements; vegetables are mostly produced for subsistence; some gardens may also serve educational and training purposes	Vegetables (spinach, kale, carrots and onions)	■ Climate risks ■ Scarce water resources ■ Competing land availability ■ Poor soil quality ■ Access to markets ■ Food loss and waste ■ Rising input costs ■ Safety and security
Home/backyard gardens	Food produced in backyards at a subsistence level and to generate extra income.	Vegetables	
Small-scale commercial farms	Produce organically for commercial purposes The sales of produce is mostly to organic stores or markets like the OZCF[10] market. Farms also operate as knowledge hubs and education centres for small-scale farmers. The farms are located in areas such as Philippi, Mitchells Plain, Milnerton Rural, Brackenfell and Scarborough etc.	Vegetables	

[9] Peri-urban areas can be described as the landscape interface between town and country or also as the rural—urban transition zone where urban and rural uses mix and often clash. It can be viewed as a landscape type in its own right, one forged from an interaction of urban and rural land use (Özel et al., 2015).
[10] Oranjezicht City Farm

Large-scale commercial farms	Large-scale commercial production of commodities such as grains, fruit (predominantly wine grapes) and livestock farming takes place. The farms are located in areas such as Durbanville, Helderberg, Botfontein, Philippi and Constantia etc.	Grains Fruit (wine grapes)	

4.2. Investment opportunities for green technologies and practices

Economies of scale play a critical role in determining the investment opportunities for green technologies and practices in food production. Farms may transition to different technology levels to improve farm productivity, depending on the enabling opportunities available. Table 20 highlights viable opportunities for investment in green technologies and practices for different food production systems located in Cape Town.

As illustrated in the table and detailed below, the investment opportunities vary for the different food production systems:

- **Home and community gardens:** This category of farms comprises households and communities facing economic constraints that make them unable to develop profitable agricultural activities. Many food gardens engage in subsistence farming and face constraints that impede their participation in commercially-oriented food production. These constraints are well-documented and include insecure land rights, inadequate infrastructure, and problems related to access to inputs and markets. As a result, there is little capital available for investment in high-cost green technologies. Most food gardens adopt agroecological and organic farming practices and simple tunnel systems to be viable and sustainable. With the increasing number of food gardens in Cape Town, there are still more opportunities to scale up green techniques and practices on these farms. Farms operating at this size are best served by low-cost green technology and interventions. In areas that already produce food, non-mechanised drip irrigation systems or alternative inputs, such as organic compost and intercropping, can increase efficiency and further intensify production. While in areas (typically urban areas) where there is limited food production, options to grow food for own consumption is possible with low-tech soilless growing kits such as indoor hydroponic soilless growing kits, vertical garden bags or wicking beds.
- **Small scale commercial farms (peri-urban & urban):** Farms in this category are already involved in profitable agricultural activities but are limited by resources and scale of operation. Given this, there is some capital available for investment in green technology. There are farms in Cape Town that have already introduced some green technologies in their farm operations such as shade nets, tunnels, greenhouses, sustainable practices and irrigation systems. However, there are opportunities to further increase efficiency on farms and intensify food production. Green technologies such as soil sensors, variable speed drives and drip irrigation can improve the water and energy efficiency of these farms and reduce input costs. Alternative methods and inputs can also be introduced to improve or maintain soil health; these can include small-scale no-till planters, intercropping methods or organic fertilisers. In addition, soilless growing systems such as hydroponics can be added to operations, especially in cases where the soil quality is poor and costly to maintain.
- **Large scale commercial farms**: Farms in this category operate profitably and at a large scale. The capital available ranges from medium to high and can allow for investment in a range green technologies. However, because a lot farms operating at this scale have some infrastructure in place, the key investment opportunities are mainly centred on increasing efficiency and reducing input costs of farm operations. As a result, level 1 and level 2 technologies potentially hold the largest investment opportunity, with potential to introduce level 3 technologies such as soilless growing systems in areas where soil quality is poor or too costly to maintain.

Along with the opportunities for farms outlined above, there is potential to establish new commercial farms and alternative food networks using novel farming technologies such as aquaponics, hydroponics, and complete CEA systems. Farms of this nature are still emerging in Cape Town, with several enterprises using soilless growing systems to grow mushrooms and others are involved in aquaponics. Further investment, however, is needed to take advantage of the job-creating potential that these systems provide.

In addition, investment in novel growing systems unlocks business opportunities for players both downstream and upstream in the agricultural value chain. These opportunities are highlighted in Figure 11.

Opportunities for entrepreneurs

- Local manufacturers to develop and maintain green technology infrastructure and equipment
- Input suppliers (i.e. seedlings, feed)
- Agri-processing businesses to process produce into value-added products

Opportunities for new & existing urban farms

- Produce high-value niche products (e.g. mushrooms, berries or cannabis)
- Existing farms can diversify incomes by accessing new markets (e.g. home delivery, online orders)
- Intensify food production and/or minimize resource use and reduce input costs through adopting level 1, 2 and/or 3 technologies

Cities can support business growth opportunities

Figure 11 : Business opportunities downstream and upstream agricultural value chain

Image credit: Western Cape DoA / Elsenburg

Table 20 : Viable green tech and practices to invest in, broken down by Cape Town farm type

Opportunity for intensive food production																		
			Level 1							Level 2					Level 3			
Cape Town production system	**Farm profile**	**Current technology use**	**Drones**	**Soil sensors**	**Satellite imagery**	**Drip irrigation**	**Non-mechanised drip irrigation**	**Variable speed drives**	**Shade netting**	**Waste-to-soil**	**Intercropping**	**No-till**	**Cover crops**	**Improved seed varieties**	**Aquaponics**	**Hydroponics**	**Complete CEA**	**Low-tech growing systems**
Home & community gardens	Average size: 0 - 5 ha Gross farm income: R6000 – R15 000 Market: own use Capital availability: low	Shade nets & tunnels Container gardening Sustainable practices i.e. organic farming or permaculture or agro ecology					•				•			•				•
Small-scale commercial farms	Average size: 5 - 100 ha Average annual turnover: R2.25 million – R13.5 million Market: largely domestic Capital availability: medium	Shade nets, tunnels & greenhouses Sustainable practices Waste-to-soil solutions		•		•		•		•	•	•	•	•	•	•	•	
Medium-large-scale commercial farms	Average size: 100 - 1500 ha Average annual turnover: > R 22.5 mil Markets: domestic & exports Capital availability: medium - high	Conservation & regenerative agriculture Remote sensing technology Drip irrigation	•	•	•	•		•		•	•	•	•	•		•		

4.3. Actions to increase the uptake of green technologies and practices to enable more sustainable and resilient urban agriculture in Cape Town

The green technologies and practices highlighted present opportunities for cities, urban farmers and entrepreneurs to facilitate sustainable and resilient food production in Cape Town. However, the investments cannot be realised if measures are not in place to support and enable growth in urban agriculture. These proposed measures include:

Providing technical support to accelerate adoption of green technologies and practices

There is a lack of awareness of the opportunities and associated benefits that investment in green technologies and practices can bring. As such, there is a need to engage proactively with farmers on the investment opportunities that exist. This can facilitate the adoption of green technologies and practices and provide an opportunity for farmers to participate in the design process by providing greater insights and end-user specifications to tech suppliers.

Developing technical and business skills

Although Cape Town has a strong agricultural and agri-processing industry that can be leveraged to support urban agriculture, using more green technologies will require a new set of green skills to keep up with the advancing technologies. However, there is an opportunity to adapt existing structures (e.g. PEDI[11]) or set up partnerships to leverage off existing programmes and experience. An example is Izindaba Zokudla's[12] farmer school and innovation lab, where a series of workshops on urban agricultural enterprise development were co-developed with urban farmers and entrepreneurs. Among the topics discussed in the sessions were "How to design and manufacture your own irrigation system" and "How to construct your own biogas digester". A similar approach can be applied to build skills for the adoption of green technologies and practices in Cape Town.

Providing access to markets

Accessing markets and producing products that the market demands is a key barrier experienced by many urban farmers. The City of Cape Town can support by identifying functions that buy food and encourage these City functions and agencies to purchase produce from local urban agriculture producers. These could include City clinics, schools, Early Childhood Development centres, canteens at City buildings etc. In addition, further assistance can be provided with farmers' markets (e.g. space, safety, cleaning, permits).

Providing access to finance

New and emerging farming enterprises need initial financial support to scale up. The City can engage with Development Finance Institutions and other financing institutions to identify funding sources that can be leveraged to finance start-ups under an urban agriculture incentive programme in Cape Town.

Further research to understand the socioeconomic impacts of green technologies and practices

The intent of this market brief is to promote understanding of viable opportunities for green technologies and practices in Cape Town. Further research is needed to better understand the socio-economic impacts of green technologies and practices for urban food production in Cape Town. Undertaking this research will provide an understanding of the other factors beyond the economics that can enable or inhibit the uptake of green technologies to enable more sustainable and resilient urban food production in Cape Town.

Image credit: Western Cape DoA / Elsenburg

[11] Philippi Economic Development Initiative

[12] iZindaba Zokudla (an isiZulu phrase for 'Conversations about food') is a project that draws on multi-stakeholder engagement and action research methods to create opportunities for urban agriculture in a sustainable food system. It links the university, researchers, students, communities, entrepreneurs and other stakeholders in the development of service-learning and applied research projects and enterprises that can contribute to a socially equitable, economically productive and ecologically sound food system.

05

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