THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Vertical Agriculture

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1. Technology Overview and Detailed Description

Controlled Urban Agriculture (CUA), or Controlled Environment Agriculture (CEA) includes any form of agriculture where environmental conditions (such as, light, temperature, humidity, radiation and nutrient cycling) are controlled in conjunction with urban architecture or green infrastructure[1].

Vertical farming can be defined in general terms as a system of commercial farming whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fibre or other products or services by artificially stacking them vertically above each other, such as in a skyscraper (multi-storeyed building), used warehouse, or (stacked) shipping container(s). The concept anticipates the cultivation of fruits, vegetables, medicinal, fuel producing plants and other plant products in the cities and their sales directly within the cities, thereby reducing the transportation costs and efficient utilization of land and water resources[2] .

More modern versions of vertical farming use indoor farming techniques and Controlled-Environment Agriculture (CEA) technology, where all environmental factors are controlled, using sophisticated IT (Information Technology) platforms. These facilities utilize artificial control of light, in particular LED lighting, environmental control (humidity, temperature, gases) and fertigation. Some vertical farms use techniques similar to greenhouses, where natural sunlight can be augmented with artificial lighting and metal reflectors[3] to manipulate plant physiological processes.

Vertical farming is to be distinguished from Uncontrolled Urban Agriculture, such as community gardens, vegetable gardens and rooftop farms.[4] Other types of CEA are zero-acreage farming (z-farming), and greenhouses, however this report is concerned with vertical farming (also known as sky farming), and henceforth will be dedicated to vertical farming.

Vertical farming includes:

1. Open air or in mixed use sky scrapers for climate control and consumption. This is a sustainable type of farming for personal or community use and it may not be for commercial purposes. A modified form of this concept involves cultivation of crops in the periphery of sky scrapers to provide enough sunlight.
2. Cultivation of plant and animals (fish) in sky scrapers in a closed system for large scale cultivation. These systems under are trials at various locations (Singapore, Canada, London)[5].

Vertical farms use one of three soil-free systems for providing nutrients to plants (1) hydroponic systems, (2) aeroponic systems, or (3) aquaponic systems, each of which will be described briefly below.

1. **Hydroponics systems.**
This is the predominant growing system used in vertical farms. Hydroponics involves growing plants in nutrient solutions that are free of soil. The plant roots are submerged in the nutrient solution, which is frequently monitored and circulated to ensure that the correct chemical composition is maintained.
2. **Aeroponics systems.**
Aeroponics is essentially the art of growing plants in an air/mist environment with no soil and very little water. Aeroponic systems is by far the most efficient plant-growing system for vertical farms, using up to 90% less water than even the most efficient hydroponic systems. Plants grown in these aeroponic systems have also been shown to uptake more minerals and vitamins, making the plants healthier and potentially more nutritious.
3. **Aquaponics systems.**
An aquaponic system takes the hydroponic system one step further, combining plants and fish in the same ecosystem. Fish are grown in indoor ponds, producing nutrient-rich waste that is used as a feed source for the plants in the vertical farm. The plants, in turn, filter and purify the wastewater, which is recycled to the fish ponds.

Vertical farming systems can be further classified by the type of structure that houses the system.

Building-based vertical farms are often housed in abandoned buildings in cities. New building construction can also be used in vertical farms.

Shipping-container vertical farms are an increasingly popular option. These vertical farms use 40-foot shipping containers, normally in service carrying goods around the world. Shipping containers are being refurbished by several companies into self-contained vertical farms, complete with LED lights, drip-irrigation systems, and vertically-stacked shelves for starting and growing a variety of plants. These self-contained units have computer-controlled growth management systems that allow users to monitor all systems remotely from a smart phone or computer.

Crops in vertical agriculture systems have physiological and nutritional requirements, which are described in the text that follows:

i. An optimal temperature range, which is crop-type specific;
ii. Water quality must be kept at the optimum - water containing particulate, fluoride and heavy metal contaminants should be removed and sterilized before entering the vertical eco-farm system. Water should be carefully distributed through irrigation while any excess water should be collected and recycled. Black water can be cleaned by algae and made potable for irrigation in vertical eco-farming[6].

iii. Optimum light quality: The amount of light intensity required varies from plant to plant. The duration and intensity of the specific parts of the light spectrum that plants use during different stages of their growth rate should be carefully programmed into the computer management system. Halide and sodium metal type light is used by commercial growers to 'supplement' natural light and to extend the day length. Metal halide lamps give off a 'blue' light which is more suitable for young plants and vegetative growth. Generally, plants are intolerant of continuous light for 24 hours. Therefore, 12 to 14 hours of light per day are given to plants in such systems[7].

iv. Substrates: To serve as a suitable replacement for soil, the substrate must be capable of supporting the root system and holding moisture and nutrients. It should be inert, free of insects and diseases, and not easily broken down. Furthermore, the substrate should allow for the adequate aeration of the roots and have good drainage qualities. Commonly used substrates are coarse sand, gravel, perlite, coarse vermiculite, and rock wool.

v. Optimum nutrient concentration: Optimum nutrient and mineral quality are very important for maximum plant growth and the nutritional wellbeing of consumers[8].The levels of nutrition available to the plants should be constantly managed and adjusted to optimum levels relative to the growth stage of each crop.

vi. Optimum pH levels: Plants have pH ranges within which they grow best and each mineral is absorbed by plants within a certain pH range. The pH value therefore determines the nutrient availability for plants. The addition of plant nutrients to vertical eco-farming systems may be performed according to the plant nutrient requirement[9].

vii. Crop selection: The correct decision in the selection of crops to be grown ultimately results in successful farming venture. The major factors to be considered in crop selection include are prevailing farm conditions, crop or varietal adaptability, marketability and profitability, resistance to pests and diseases, available technology and farming system[10].

viii. Watering systems: There are several types of watering system for vertical eco-farming. The common watering systems are the wick system, water culture, flood and drain culture, drip systems, nutrient film technique and aeroponic culture. The features of the six important watering methods of vertical eco-farming are described in the literature[11,12].

2. Application Examples and Case Studies

The following examples of vertical agriculture are only five from several territories around the world, and serve only as illustrative examples of the extent of application of the technology[13].

Example 1: Urban Crops: Belgian Company Specialising in Indoor Growing Systems
Inspired by the US and Asia's growing investment in robotized plant factories with artificial lighting (PFAL), Belgian-based company, Urban Crops began creating a huge automated plant factory inside a climate chamber. With 30 towers, a production of 126,000 crops per day is maintained. The crops use RFID technology in the crates where robots can pick the crates from a conveyor belt and understand in what state the crops are in, handling them accordingly. They have three concepts: the large Plan Factory, Farm Flex and Farm Pro. The two latter examples are smaller in scale and focus on efficient food production, particularly in urban areas.

Example 2: Plantagon Agritechture and Sweco Architects
Plantagon Agritechture and Sweco Architects have a project called 'World Food Building' in Linköping, Sweden, which is a 16 storey tall "plantscraper." Specialising in Urban Agriculture and Industrial Vertical Farming, Plantagon has developed a vertical space-efficient greenhouse for cities, delivering locally grown organic food directly to the consumer.

Example 3: Kimbal Musk Building Vertical Farms in Brooklyn, New York
Kimbal Musk and Tobia Peggs launched Square Roots, a vertical urban farm using shipping containers to invest in young farmers and sustainability. The farms will include greens and herbs for young entrepreneurs to run a vertical farming business. Using technology from vertical farming start-ups Freight Farms and ZipGrow, Square Roots plans to use LED lights and water growth rather than soil.

Example 4: Aerofarms: World's Largest Vertical Farm in Newark, New Jersey
The largest vertical farm is Aerofarms, a 14,164 m^2 facility in Newark, New Jersey, run by Aerofarms. The farm has the potential to produce 2 million pounds of lettuce every year, without soil or natural sunlight. By using LED lights, this ensures consistent growth in the 69,000 sq ft warehouse.

Example 5: Sky Greens, Singapore
Sky Greens is a vertical farm three stories high in a greenhouse that produces five to 10 times more per unit area compared to normal farms. The greenhouse and low-carbon hydraulic system grows lettuces and cabbages year-round. Their mission is to provide improved agricultural solutions with minimal impact on land, water and energy resources, help cities with food supply security and to promote low carbon footprint agriculture into urban living.

3. Technology or Application Life Cycle: Current Status and Expected Development in 2020 and 2025

The technology or application life cycle for vertical agriculture is shown in Table 1 below.

Table 1: Technology or application life cycle for vertical agriculture

Technology Area	Current application in agriculture	Expected applications in agriculture by 2020	Expected applications in agriculture by 2050
Vertical agriculture	Food production Animal feed production	Adaptive LEDs Water purification Water desalination	Vertical agriculture will allow production much closer to the consumer, thus cutting transport cost. Arcology, a series of architectural design principles becomes prevalent. Future integration with technologies such as: • IT & IT infrastructure • Smart farming • Sensor technology • Aquaculture Big data capabilities (linear programming, non-linear optimization, machine-learning, artificial neural networks, cluster analysis. Atmospheric capture of water. Super seeds

4. Business Eco-System View

Several interdependencies are required to enable the successful application of vertical agriculture. These are shown in Figure 1 below.

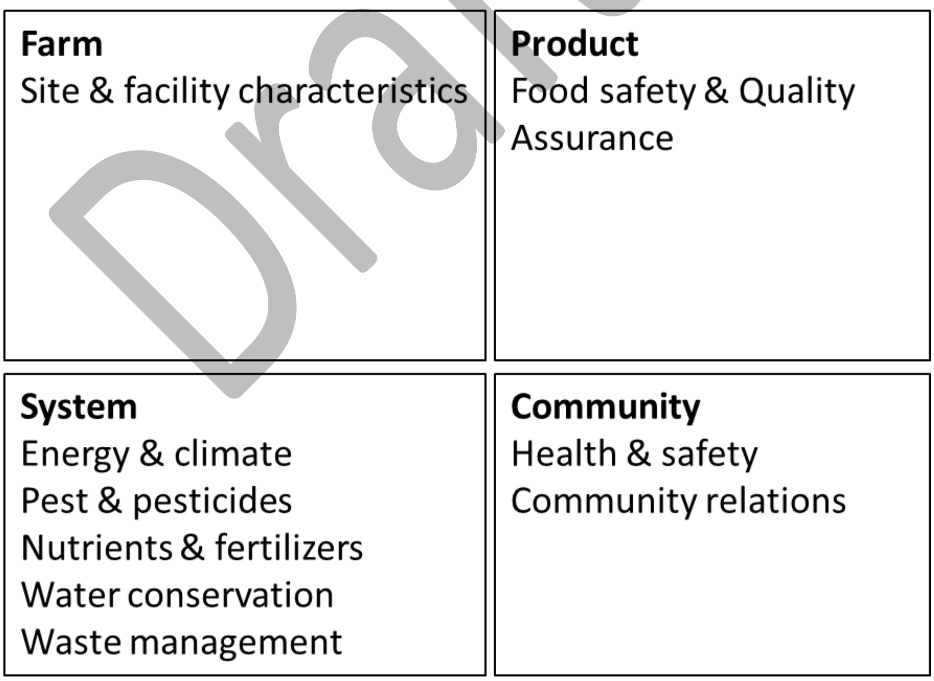

Figure 1: A business eco-system view of vertical agriculture

The proposed farm is to meet site and facility requirements. To optimize yield, the production system is to be optimised, by ensuring that the required inputs (discussed elsewhere) are met. The product should meet the minimum food safety and quality assurance standards, prior to dispatch for consumption by the public.

5. Benefits and Risks

The benefits and risks of vertical agriculture may be articulated as follows[14]:

Benefits

Continuous crop production - Vertical farming technology can ensure crop production continuously throughout the year in non-tropical regions, in an efficient manner, superior to that of land-based farming irrespective of the environmental conditions. In vertical farming, the growing cycles are consistent and reliable, allowing commercial growers to commit to delivery schedules and supply contracts. In terms of quantity, a single indoor acre (0.41 hectares) of a vertical farm may produce yield equivalent to more than 30 acres (12.1 hectares) of farmland, when the number of crops produced per season is considered. The land productivity of vertical farming is more than twice as high and faster as traditional agriculture. For the same floor area, vertical eco-farm systems multi-level design provides nearly 8 times more growing area than single level hydroponic or greenhouse systems or open field system[15]. Looked at differently, a 30-storey high building with a basal area of 5 acres (2.02 ha) has the potential of producing crop yield equivalent to 2,400 acres (971.2 ha) of traditional horizontal farming. Expressed in ratio, this means that 1 high-rise farm is equal to 480 traditional horizontal farms[16]. Thus, a vertical farm of 9300 m^2 (roughly the size of a city block) with 30 stories should provide around 15,000 people with 2000 kcal of nutrition per day. Furthermore, the potential returns of CEA are higher crop yields than conventional agriculture for crops such as, carrots, radish, potatoes, pepper, tomatoes, strawberry, peas, cabbage, lettuce and spinach[17].

Elimination of herbicides and pesticides use - The controlled growing conditions in a vertical farm allow a reduction or total abandonment of the use of chemical pesticides. Some vertical farming operations use ladybugs and other biological control methods when needed to deal with any infestations. This benefit allows for the production of crop under organic conditions.

Protection from weather-related variations in crop production - Because crops in a vertical farm are grown under a controlled environment, they are safe from extreme weather occurrences such as droughts, hail, and floods.

Water conservation and recycling - Hydroponic growing techniques used in vertical farms use about 70% less water than normal agriculture (aeroponic techniques, which involve the misting of plant roots, use even less water). Thus, conservation and recycling of water resources is enhanced. Further, urban sewage waste may be used in composted and recycled form in vertical farming, which will further help in recycling of the resources[18].

Climate friendly - Growing crops indoors reduces or eliminates the use of tractors and other large farm equipment commonly used on outdoor farms, thus reducing the burning of fossil fuel. Deploying vertical farms on a large scale could result in a significant reduction in air pollution and in carbon dioxide emissions. Furthermore, carbon emissions might be reduced because crops from a vertical farm are usually shipped just a few blocks from the production facility, instead of being trucked or shipped hundreds or thousands of kilometres from a conventional farm to a market. Large amounts of electricity are required to provide light and to heat and cool the enclosed growing systems, although new energy-efficient LEDs are being developed that could reduce lighting costs. Vertical farming will reduce the dependency on land resources and help in regrowth of forests[19].

People friendly - Conventional farming is one of the most hazardous occupations globally. Some common occupational hazards that are avoided in vertical farming are accidents in operating large and dangerous farming equipment, as well as the exposure to poisonous chemicals.

Sustainable urban growth - Vertical farming, applied with a holistic approach in combination with other technologies, will help urban areas to absorb the expected rise in population (and subsequent demand for employment) and yet remain food sufficient. However, traditional farming will continue as many crops are (still) not suited to indoor farming[20] and this may change with the application of DNA-based breeding techniques.

Minimum production overheads - Minimum overheads and grow costs are maintained through low labour costs, low water usage, reduced cost of crop washing and processing and reduced transport costs[21].

Risks

Land and building costs - Urban locations for vertical farms can be quite expensive. Some existing vertical farms are based in abandoned warehouses, derelict areas, or Superfund sites, which can be more economical for construction.

Energy use - Although transportation costs may be significantly less than in conventional agriculture, the energy consumption for artificial lighting and climate control in a vertical farm can add significantly to operations costs.

Controversy over organic certification - It is unclear if or when there will be agreement on whether crops produced in a vertical farm can be certified organic. Many agricultural specialists feel that a certified organic crop involves an entire soil ecosystem and natural system, not just the lack of pesticides and herbicides.

Limited number of crop species - The current model for crops grown in vertical farms focuses on high-value, rapid-growing, small-footprint, and quick-turnover crops, such as lettuce, basil, and other salad items. The most common and profitable crop varieties grown in vertical eco-farms are cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers. Slower-growing vegetables, as well as grains, aren't as profitable in a commercial vertical farming system, and this renders the vertical farming technology applicable to a limited variety of crops.

Pollination needs - Crops requiring insect pollination are at a disadvantage in a vertical farm, since insects are usually excluded from the growing environment. Plants requiring pollination may need to be pollinated by hand, requiring staff time and labour.

Challenges to adoption of the technology – This is due to:

- Inability to adopt uniform practices because of variable weather conditions in different regions of the world;
- Lack of crop varieties suitable for the vertical farming;
- Lack of knowledge and skills required for farming practices in urban populations[22].

A SWOT analysis of vertical agriculture may be summarised as in Table 2 below.

Table 2: A SWOT analysis of vertical agriculture[23,24]

Strengths	Weaknesses
Faster and high yields, grows healthier crops, no pesticides needed, savings in water, reuse of nutrient solution, can grow round the year, requires less land surface, no carbon footprint. Opportunities for the Physical Environment ▪ Less need for packaging, storage, and transportation ▪ Proximity to services, including waste treatment facilities ▪ Waste recycling and re-use possibilities Opportunities for the economic environment: ▪ Potential agricultural jobs with low barriers to entry ▪ Non-market access to food Opportunities for the Social environment: ▪ Availability of fresh fruits and vegetables ▪ Community bonding ▪ Access to green spaces	High initial costs, requires precision monitoring, limited to low profile crop, requires higher energy.

▪ Emergency food supplies ▪ Soil treatment ▪ Environmental stewardship	
Opportunities	**Threats**
Highly controlled environment, artificial lights may be used, no seasonal restrictions, crop needs-based nutrient	Failure to the any system components of the vertical irrigation system, or the introduction of plant pathogens may lead to rapid plant death, if not detected and contained quickly. Risks for the physical environment ▪ Increased competition for land, water, energy, and labour ▪ Reduced environmental capacity for pollution absorption ▪ High levels of air pollutants in cities and microbial ▪ contamination of soil and water Risks for the economic environment: ▪ Limited production quantity ▪ Varied seasonal production quality Risks for the social environment: ▪ Environmental and health risks from inappropriate ▪ overuse of pesticides and fossil-fuel based fertilizers

6. Potential Economic, Social, Ecological and Political Developments and Impacts

Whilst vertical farming shows promise for commercial application, economic, social, ecological and political impacts are to be taken into consideration. A scan of the literature highlights the following considerations, also applicable/relevant for the Western Cape Province:

Economic Developments and Impacts

- Jobs creation
- Training (skills development)
- New business creation through incubation
- Savings of revenues on food
- Increased real estate value

Implications for municipal development:

- Municipalities and practitioners need to work together to make urban agriculture financially affordable.

- Urban agriculture is to be better incorporated into city plans.
- The benefits and selling points for urban agriculture should be well articulated for greater adoption and buy-in (political engagement and community facilitation).
- The application of the best management practices to curb the liabilities of urban agriculture is almost mandatory.
- Land use and associated cumbersome city zoning legislation, as wells as the use of city greenbelts for agricultural purposes
- Access to capital for infrastructure support and maintenance
- Support for local foods – the feasibility of institutional purchasing of local foods for both the city and local growers requires consideration;

Environmental Developments and Implications

Much of this section has been covered above Risks and Benefits.

Socio-Political Developments and Implications

A study[25] examined the socio-political implications of adopting vertical farming. The summary of the study is documented in the text that follows. In summary, vertical farming will:

- Revolutionize agricultural sectors of economies
- Minimize agricultural susceptibility to climate variability, improve environmental sustainability and regenerate ecosystem functions and services
- Achieve governmental goals of poverty reduction and food security
- Protect resources and foster environmental stewardship
- Increase standard of living and socio-economic equality
- Reduce pressure on farmland

However:

- The adoption of vertical farming will be region specific according to geography, economics, government and culture
- Uncertainty about population projections and the ability of vertical farming to meet food needs remains a topic for research
- Involvement of traditional farmers is essential, as they hurt by vertical farms, and may encourage resistance from interest groups
- Shifts in politics regarding the agricultural sector of the economy are a risk

Annexure 1 illustrates the alignment of Vertical Agriculture with the key policy mandates of DAFF, articulated in the NDP, and APAP, and illustrates where Vertical Agriculture and possibly technologies of the future may be used to support the delivery of the South African government's proposed interventions as articulated in the APAP.

7. Conclusions

Considerations for a vertical farm to be implemented, as well as conclusions on the feasibility, eco-system dependencies and scaling potential to increase access/users are discussed.

According to the estimates of UN population projection, world population could reach 9.15 billion by 2050, thus the expected rate of increase in world population will be 2.25 percent over the next forty years[26]. This means that food grains and food production needs to be doubled to meet this demand. It is projected that to feed the global population by 2050 require 70 percent increase in global food production needs to be achieved, and food production from developing countries needs to be doubled[27] . The options open for feeding the projected global population size include the deployment of vertical agriculture technologies. To this end, the implementation/feasibility of vertical farms depends on several factors, some of which are listed below:

- Optimal agro-climatic factors for food production - for example the desert region of Middle East and North African countries have not enough soil resources to produce food; comparable situation in the Taiga and in the mountain regions, or Nordic countries, which do not have suitable conditions for agriculture;
- Elevation of the urban population - the mega-cities have environmental problems linked to the production, logistic and quality of food;
- The existence of an eco-friendly attitude of the public administration - their policies can both facilitate and hind the vertical farm construction;
- The availability of investment capital - initial capital outlay must be readily available, as the technological systems used in vertical farming often imply high initial and functioning costs;
- The potential market - if the purchasing power of local consumers is not high enough and if there are not the facilities able to activate a large-scale market, vertical farming will not be an attractive venture

The importance of certain factors in different geographic areas may impact urban agricultural activities as well as render vertical farming sustainable (or unsustainable if not managed appropriately): competition for resources (land, water, labour, energy) and the productive use of under-utilized resources; financial support from the private or public sector; the application of horticulture techniques and best practice; low input processing and storage techniques with micro-credit support[28,29] .

8. Synthesis and key trends from the literature

There are (arguably) indisputable trends in modern development that have necessitated the need for alternative ways to produce food. These are:

- the deterioration of agricultural soils, linked to intensive production techniques, which is linked to the rapid climate change, which causes the increase of desertification and the rising of sea levels, which could decrease the arable land;
- the growing demand for food due to the steady growth of the world population, which increases at the rate of 80 million people a year;
- the continuing growth of the urban population - it is estimated that in 2050 nearly 80% of the earth's population will reside in urban centres, resulting in the exponential expansion of soil artificialisation.

With the adoption of vertical agriculture, the future implications on food security, and environmental sustainability appear positive in the following ways:

- Population growth will stabilize
- Agricultural sector of the global economy will be transformed
- Global poverty will be eradicated
- Food security will be achieved
- Nutrition and health will be improved
- Ecosystems will be restored
- Energy innovations will decrease dependency on fossil fuels
- Recent global warming will be reversed
- Millennium Development Goals will be met

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