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Conception of a Vertical Farm for the Maun Science Park in Botswana

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Affidavit

I hereby declare that we have written this paper independently and have not used any sources or aids other than those indicated. All text passages taken verbatim and in spirit from external sources have been marked.

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Abstract

Global agriculture will face major challenges in the future. In addition to the increasing demand for food due to constant population growth, the consequences of climate change will make it even more difficult to operate agriculture and supply people with food. In addition to further productivity increases in traditional agriculture, new concepts for sustainable and scalable food production are needed. Vertical farming offers a promising approach.

The aim of this project is to demonstrate how vertical farming can be used to ensure sustainable food production and how this concept can be applied in the pioneering Maun Science Park project in Botswana. In doing so, the Maun Science Park will address future challenges such as demographics, governance and climate change and become a best practice model for Botswana, the whole of Africa and the world. The country of Botswana grew to become one of the most prosperous countries in Africa in recent decades due to strong economic growth from mining. However, the population faces great challenges in the future; in addition to great social inequality, climate change threatens the country's overall supply.

With the help of a literature review and qualitative and quantitative interviews with stakeholders from Maun (Botswana), the potentials and challenges for vertical farming in Botswana could be identified and future measures for a possible realization could be derived. Basically, some challenges in Botswana are addressed by the technology, for example, Vertical Farming offers high food security through year-round production of food through the closed ecosystem and creates independence from current and future climatic conditions, poor conditions for traditional agriculture (e.g. infertile soils) and foreign imports. However, the main structural problems of agriculture in Botswana, such as the lack of infrastructure, know-how and policy support, are not addressed.

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II. List of abbreviations

GDP..Gross domestic product

HVAC .... *Heating, Ventilation and Air Conditioning*

MSP.. *Maun Science Park*

PFAL ....*Plant Factories with Artificial Light*

SIOM ....*System Integration and Optimization Model*

VF... *Vertical Farm*

1. Introduction

1.1 Problem definition

The number of people is growing steadily; according to forecasts, the world's population will rise from around 8 billion to around 10 billion in the next 30 years.[1] All these people need to be fed, which is putting enormous pressure on traditional agriculture worldwide. While one farmer in Germany was still feeding 17 people in 1940, today one farmer must feed 160 people, and the trend is rising.[2] In the future, agricultural productivity will have to continue to increase in order to ensure that humanity can be fed. At the same time, climate change is causing an increasing number of extreme weather events, resulting in poor harvests and declining yields. In addition, the availability of fertile arable land, as well as the amount of usable water resources, is becoming increasingly scarce, making conventional agriculture on large fields difficult or even impossible. The same applies to cities, where hardly any food is produced, while most food is needed there due to the high population density.[3] Regions in sub-Saharan Africa are particularly affected, including Botswana, which due to its geographical location will be strongly affected by the consequences of climate change and is already struggling with the consequences today.

In order to be able to feed people in the future, new approaches for sustainable food production are needed. One possibility is vertical farming, which promises high and sustainable yields on a small area, independent of external climatic influences.

1.2 Objective

The aim of this project is to demonstrate how vertical farming and the use of innovative technologies can ensure sustainable food security for mankind. The findings will then be transferred to the Maun Science Park in Botswana and tested for applicability. Thus, the future nutrition of this emerging self-sufficient district, in a symbiotic life between people, animals and the environment, should be achieved.

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[1] (Deutsche Stiftung Weltbevölkerung, 2021)
[2] (Bundesanstalt für Landwirtschaft und Ernährung, 2021)
[3] (Bayer AG, 2020)

1.3. Procedure

In the first part of this project work, the concept and the individual components of vertical farming will be explained. The basis for this is a literature analysis from relevant technical literature and other scientific sources. In the next part, the local and regional conditions in Botswana regarding economy, society, infrastructure, climate and agriculture are examined in more detail. After the presentation of the Maun Science Park, a closer look is taken at the challenges that can arise during the implementation of projects such as the development of a vertical farm in Botswana. The findings are derived from a further literature review and additionally supported by qualitative and quantitative interviews with stakeholders in Maun, Botswana.

2. Vertical Farming

In this chapter, the term "Vertical Farming" is explained in more detail and the structure as well as the mode of operation are described. In addition, the individual components of a vertical farm are shown and explained. Furthermore, the advantages and disadvantages of a vertical farm are compared.

2.1 Definition

There is generally no direct and specific definition for the term *Vertical Farming* or *Vertical Farm*, the following chapters are based on the following definition:

Vertical farming is an agricultural method that describes the cultivation of plant crops. The plants, preferably vegetable crops, are grown on horizontal surfaces stacked on top of each other in buildings. (see figure 1). The individual levels are located in an artificially created and completely closed system without external influences and are supplied with nutrients and water via a pipe system, while artificial lighting ensures plant growth (PFAL: Plant Factories with Artificial Light).[4]

Figure 1: Vertical Farm (PFAL)
Source: (ESCP, 2021)

Other designs work with a greenhouse structure, which uses natural sunlight. Through the use of modern and intelligent technology, this type of agriculture can be fully automated. Vertical farming has the potential to sustainably produce more food using fewer resources than traditional farming methods, using state-of-the-art greenhouse methods and technologies. The technology could help meet growing global food demand in an environmentally sound and sustainable way by shortening supply chains, reducing emissions, delivering more nutritious produce, and reducing water use and waste.[5]

[4] (Kozai, 2018)
[5] (ESCP, 2021)

2.2 Types of vertical farms

Depending on the field of application, different types of setups are available, which differ in scalability, efficiency, space requirements and type of plants that can be grown. Basically, a distinction can be made between two types of setup:

- Cultivation, on several levels of traditional horizontal cultivation platforms
- Cultivation, on vertical surfaces

Within these setup types, the configurations can be further subdivided (see figure 2).

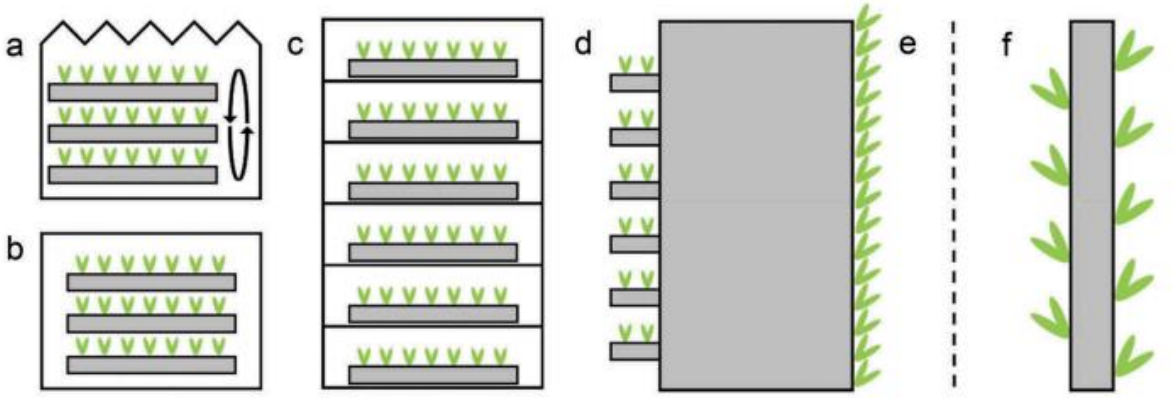

Figure 2: Structure types and configurations of VF
Source: (Andrew M. Beacham, 2019)

Horizontal growing platforms stacked on several levels can be operated in greenhouses or in completely enclosed buildings with a controllable ecosystem (a and b).[6] Another configuration using the same principle is the integration of vertical farms into mobile shipping containers. This type is particularly suitable for regions with poor infrastructure, as the system is an all-in-one solution and its form provides a mobile and scalable option.[7] Depending on the design, the cultivation platforms are also connected to a conveyor belt loop that continuously rotates the individual levels (a).[8] The plants are thereby supplied with nutrients and water via a spray. The continuous rotation ensures an increased production of certain plant hormones, which provide for an increased plant growth and volume.[9]

Another approach is the construction in multi-storey towers according to the principle of stacked horizontal growing platforms in a controlled environment (c). The use of a

[6] (Andrew M. Beacham, 2019)
[7] (Bundesinformationszentrum Landwirtschaft, 2020)
[8] (Andrew M. Beacham, 2019)
[9] (Maschinen- & Metallbau Vonhoegen GmbH & Co. KG, 2021)

kind of "balconies" (d) represents another possibility, so that this vertical farm can be integrated into existing buildings or other vertical surface (e). Or, as described in (f), the growth units can also be arranged vertically on cylindrical growing platforms.[10]

2.3 Structure and components

The internal value chain of a vertical farm consists of three main processes (see figure 3): sowing, growing and harvesting are supported by a variety of technology that ensures the artificial environment or directly provides for the growth of the plants.

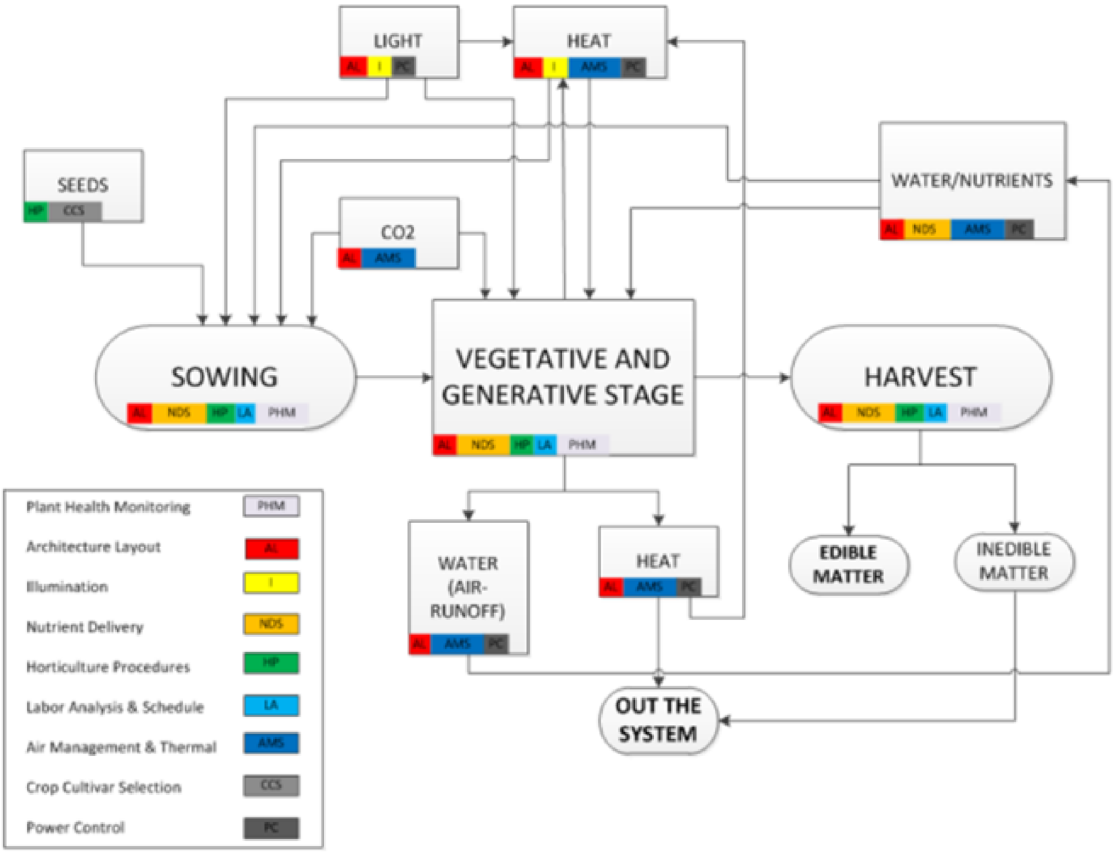

Figure 3: System and subsystem elements in the general VF process flow design
Source: (Conrad Zeidler, 2017)

The basic structure of a Vertical Farm consists of the following components and units:

- Nutrient supply
- Water management
- Lighting

[10] (Andrew M. Beacham, 2019)

- Air conditioning
- Energy supply
- Nutrient supply
- Pest control
- Automation

Depending on the type of vertical farm, further components can be added. In the following chapters, the different types and the individual basic components will be explained in more detail.

2.3.1 Nutrient supply

In order to supply the plants with sufficient nutrients, there are three different main supply concepts, which, however, are all based on an earth-free approach to cultivation:

- Hydroponic
- Aeroponic
- Aquaponic

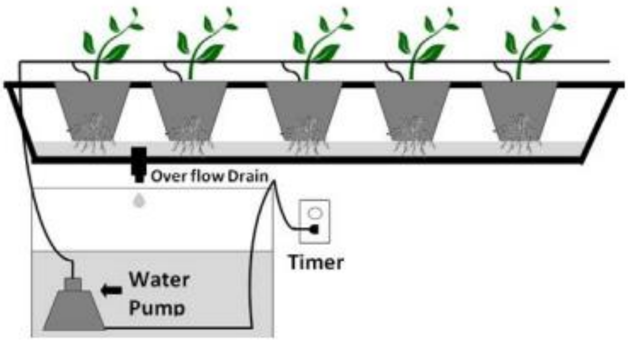

Figure 4: Hydroponics
Source: (Birkby, 2016)

Hydroponics describes the setup in a closed system in which the plants are supplied with water and nutrients via substrates and an aqueous nutrient solution. The plants absorb the nutrients via their roots, which are immersed in the nutrient solution (see figure 4). A distinction is made between an active and a passive system. In active systems, the nutrient solution is constantly exchanged and kept in motion, for example with the help of pumps. In addition, constant monitoring and automated readjustment of the nutrient composition is possible. In passive systems, there is no automatic monitoring and exchange of the solution, so the composition must be done manually. This method of hydroponics as an active system is the predominant system in the field of vertical agriculture.[11]

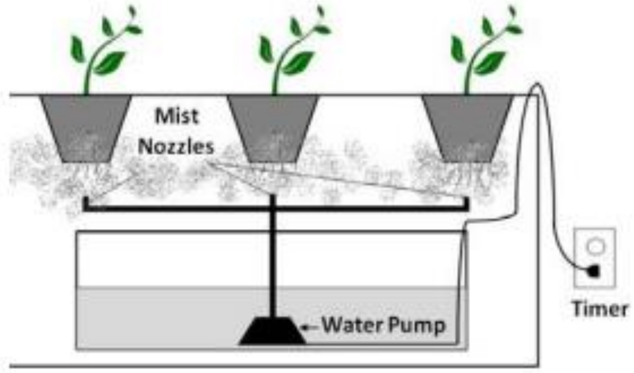

Figure 5: Aeroponics
Source: (Birkby, 2016)

The concept behind **aeroponics** growing systems was developed by NASA in the late 1990s to grow crops as efficiently as possible. The plants are grown in an air/fog environment. The nutrient solution is atomized into a mist of fine droplets using a pump. The roots of the plants are wetted by the nutrient mist in the air and can thus absorb the nutrients efficiently (see figure 5). This makes the system the most efficient concept in plant cultivation for vertical farms, as it can reduce water consumption by up to 90% compared to hydroponic systems. In addition, the nutrient uptake of the plants, in terms of vitamins and minerals, can be demonstrably increased.[12]

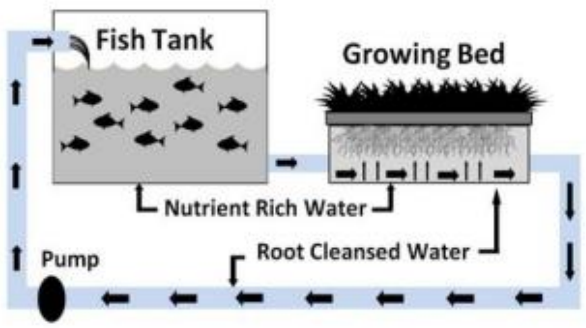

Figure 6: Aquaponics
Source: (Birkby, 2016)

Aquaponics refers to systems that further develop the concept of hydroponics, in which the cultivation of plants and fish farming are combined in a closed ecosystem. In this system, fish are grown in an external pond, and via the closed water circuit, the nutrient-rich waste produced by fish is transported to the roots of the plants, following the example of hydroponics. The plants then absorb the nutrients through their roots and filter the wastewater, which is then returned to the fish pond. This creates a nutrient cycle that can benefit both fish and plant production (see Figure 6). Due to complex economic and production issues, such systems are not yet widespread in the large-scale vertical farming system.[13]

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[11] (Birkby, 2016)
[12] (Birkby, 2016)
[13] (Birkby, 2016)

2.3.2 Water management

There are about 1.4 billion cubic meters of water distributed around the world, but most of it is salt water, which is unsuitable for the life of humans and many species of animals and plants. From an economic point of view, only fresh water from rivers, lakes or groundwater up to a depth of about 1000m can be used, which represents less than 0.3% of the total water resources of the earth.[14] This very small percentage in relation to the total volume, fortunately, does not necessarily lead to water shortages, thanks to the naturally renewing water resources. However, the annual freshwater withdrawal, partly as a result of the world population increase and inefficient use, is already significantly higher than the renewing water resources in some countries. Around 70% of usable water is used for agriculture, which accounts for by far the largest share of global water consumption.[15]

To achieve a sustainable water supply, the water used should be continuously reused in a closed cycle. If this cycle is caused by humans, it is called an anthropogenic cycle. In such a cycle, the water, as shown in figure 7, permanently changes its state from freshwater to wastewater, which is produced when the treated process water is used. The wastewater, in turn, is treated and recycled so that it can be used again. However, water losses, e.g. through evaporation, can still occur. To keep the amount of water at a sufficient level despite this, fresh water must be added, for example in the form of previously collected rainwater. Another option would be to internally collect, condense and refeed the evaporated water. Nearby gray water can also be used to compensate for water losses after a two-stage treatment process, through biological purification followed by membrane filtration. Gray water is defined as only slightly contaminated water that is produced, for example, when showering or washing hands.[16]

[14] (Stiefel, Nachhaltige betriebliche Wasserwirtschaft, 2020)
[15] (Stiefel, Nachhaltige betriebliche Wasserwirtschaft, 2020)
[16] (ewuaqua, 2021)

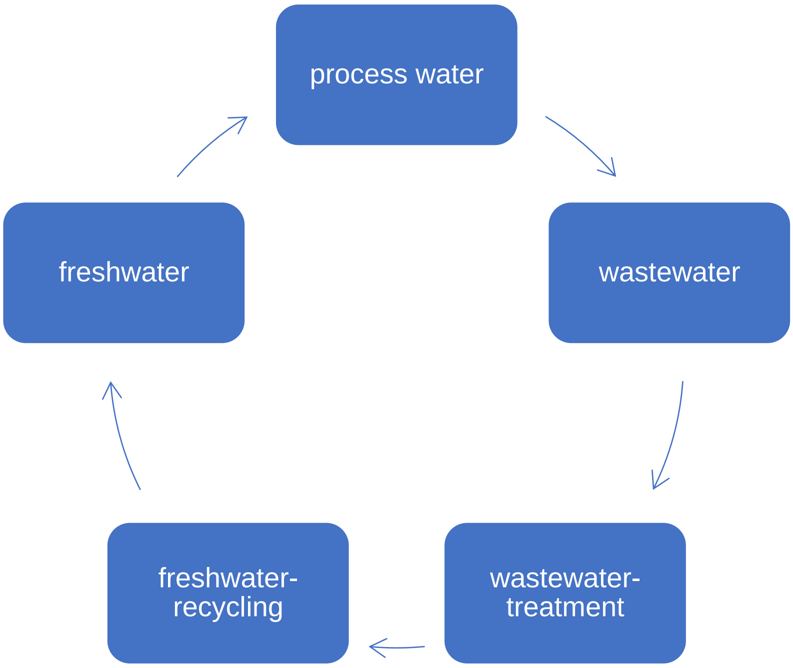

Figure 7: Anthropogenic water cycle
Source: Own representation based on (Stiefel, Nachhaltige betriebliche Wasserwirtschaft, 2020)

Such a closed loop system combines several advantages. On the one hand, it offers the user a secure water supply, sustainably protects natural water resources, and solves the problem of wastewater disposal even before it arises.[17]

To implement sustainable water management, three main steps are necessary. First, a mathematical model of the water flow in the vertical farm must be created. This involves precisely calculating the necessary water flows to determine where, when and how much fresh water is needed, or wastewater is generated. This information can then be fed into software, such as the simulation program SIOM (System Integration and Optimization Model), for example. Sensors must then be installed and integrated into the system in order to monitor the determined requirements and initiate measures.[18]

2.3.3 Lighting

In addition to supplying the plants with water, optimal illumination of the plants is a core requirement in agriculture. While conventional agriculture mainly relies on the sun as

[17] (Stiefel, Nachhaltige betriebliche Wasserwirtschaft, 2020)
[18] (World Horticenter, 2021)

a light source, artificial light sources offer great potential as they can be adapted for optimal illumination of the plants.

In general, plants have three basic requirements for the light factor. The first is the light duration, i.e., the time over which the plants are continuously illuminated. Depending on the plant species, the optimal lighting duration is shorter or longer, but as a guideline, a maximum lighting duration of about 14 hours is recommended to simulate a day-night change. The change should not be abrupt, but gradual.[19]

Another requirement is the luminous intensity i.e., the intensity of the lighting. It is measured in LUX and can also be specified in lumens per square meter. In normal daylight, values between 6000 and 25000 lux can be measured; in full sun, the values can rise to 100000 lux.

The third basic requirement that plants have for light is the light spectrum. This involves the different wavelengths of light, which provide different colors. As a rule, plants absorb blue and red light, while reflecting green-yellow light. This is also the reason why people perceive most plants as green and yellow. Therefore, light that contains the colors red and blue is suitable for plant growth. The red light is needed by plants for photosynthesis, while the blue light is helpful for morphogenesis.[20]

LEDs are a promising artificial light source, as they can be used to meet all of the requirements that plants have for light. Exposure duration, intensity and light wavelengths can be dynamically adjusted to the respective plant species and growth phase, while the long service life and good energy efficiency represent further advantages. Since LEDs can be controlled by communication technologies or internet-enabled protocols, they can be well integrated into an automation system of a vertical farm.[21] The individual LED modules are integrated into the individual growth levels of the vertical farm, depending on the setup, so that each plant crop is exposed to the optimal lighting conditions (see figure 6).

[19] (Holtforth, 2021)
[20] (Kalantari, Mohd Tahir, & Kalantari, 2017)
[21] (D. Podmirseg, 2020)

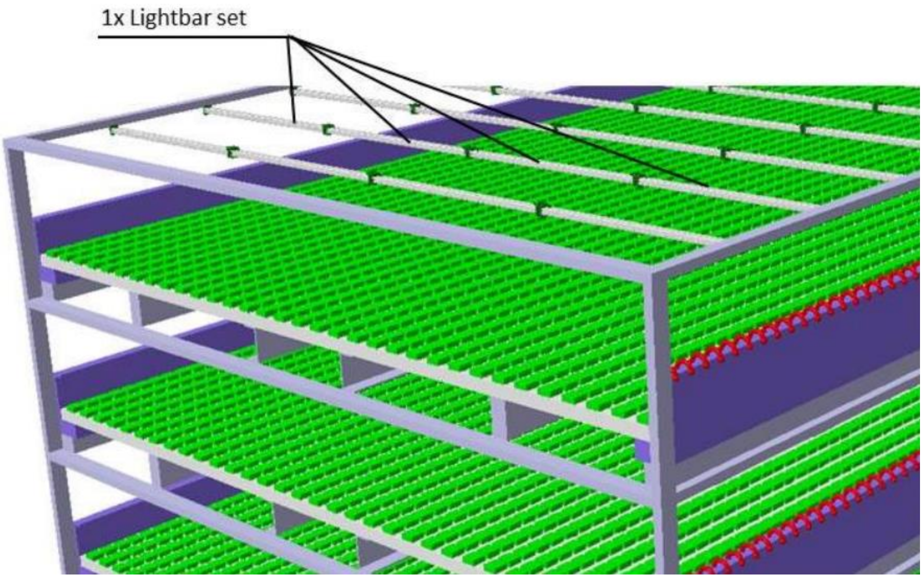

Figure 8: Figure showing the LightBar set up in the growth racks
Source: (Conrad Zeidler, 2017)

2.3.4. Air conditioning / atmosphere

The climate in which plants are located is another crucial factor influencing plant growth and crop yields.

In addition to the CO2 content in the air, the temperature plays an important role. It should be noted that the air temperature does not necessarily correspond to the plant temperature, since plants are able to cool down by increasing their transpiration rate, i.e. by evaporation, and to warm up by an optimal environment so that the plant temperature is above the air temperature. A high plant temperature usually results in faster growth and also faster formation of fruits. However, if these are formed too quickly, it can cause the fruits to become smaller, which in turn can be considered a disadvantage.[22]

In order to achieve an optimal environment for the perfect plant temperature, the air temperature, the lighting conditions described in the chapter 2.3.3 and the humidity must be coordinated, as they influence each other. Humidity should be between 60 and 85 percent, depending on the plant. Especially for vegetables with a very high water content, such as tomatoes or cucumbers, high humidity is essential for satisfactory development.[23]

[22] (Canna, 2021)
[23] (Brune, 2021)

For the implementation of optimal air conditioning, commercially available Heating, Ventilation and Air-Conditioning, abbreviated HVAC-systems can be used. These offer defined interfaces, which facilitates integration into the automation system of the vertical farm. However, care must be taken to ensure that the system is designed for the high humidity required by the plants, as the normal application range of such systems is at a lower humidity.[24]

Another possibility for a sustainable heat supply, is the use of surplus heat with heat distribution groups from the surrounding buildings (see figure 9). This concept can further increase efficiency and reduce the overall cost of heat management.[25]

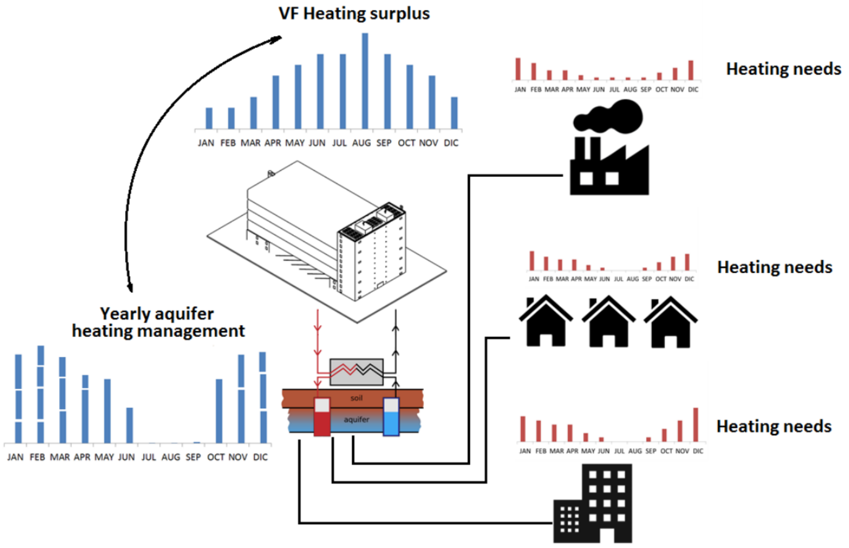

Figure 9: Heating management for a VF
Source: (Conrad Zeidler, 2017)

2.3.5 Energy supply

The technology needed to implement a vertical farm requires energy. For reasons of sustainability, this energy should be harnessed as far as possible with the help of renewable energies.

Photovoltaics can make a significant contribution here. Even if the conversion of sunlight into electrical energy, which is then used for artificial lighting of the plants, seems very cumbersome at first, the use of this technology is nevertheless justified. On the one hand, because the generated electricity is also needed for other consumers, such

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[24] (D. Podmirseg, 2020)
[25] (Conrad Zeidler, 2017)

as the computer center, water pumps, or air conditioning. On the other hand, because artificial lighting can be better adapted to the requirements of the plants than sunlight itself. The photovoltaic system can be installed on the roof of the Vertical Farm, thus making double use of the area already sealed by the construction of the Vertical Farm. Orienting the panels to the east and west allows for a more consistent yield throughout the day than a south-only orientation. The dark phases, which some plants require, can be placed at night. Thus, while less electricity is generated, less electricity is needed. In addition, the photovoltaic system can be coupled with a storage system to provide the required energy at night as well.

Another possibility to compensate for the deficits of photovoltaics at night or on days with weak sunlight is wind power. Especially on days with weak sunlight, stronger winds are often recorded, which argues for combining these technologies as much as possible. Compared to other renewable energies, wind power provides the largest amount of electricity per hectare used, while the costs per kilowatt hour generated are the lowest.[26]

Combined heat and power plants also offer the potential to be used for vertical farms. Care should be taken to use renewable fuels, such as wood or biogas derived from biomass, and to source these regionally if possible. Through cogeneration, energy is simultaneously converted into mechanical and electrical energy, resulting in a high overall efficiency. Thus, in addition to the electricity generated, the waste heat can also be used, for example, to heat the ambient air of the plants.

2.3.6 Pest control

As a closed system, a vertical farm is inherently better protected from external influences and pests than a conventional open-air field. Thus, the use of pesticides can be reduced, or better yet, avoided. Instead, new technologies can be used to ensure crop protection, despite lower risk. One such technology can be a camera system that uses artificial intelligence to detect pests and initiate targeted elimination.[27]

Micro-drones can also be used, which, like living insects, fly around independently among the plants and collect data. The data can be photos or videos, but also odors,

[26] (Solarcomplex, 2021)
[27] (Standard, 2021)

which are recorded by so-called e-noses using gas sensors. The data can then be uploaded to a cloud and evaluated by experts with regard to diseases or pest infestations. At the same time, artificial intelligence is to learn from this process in order to be able to independently assess the health of the plants.[28]

To eliminate the pests, beneficial insects can be used. These are the natural predators of the respective pests, which do not harm the plants themselves. Here, too, there is already the possibility of using drones, which drop biodegradable balls with pinpoint accuracy, in which the respective beneficial insects are located.[29]

Should the use of pesticides nevertheless be necessary, only natural active ingredients should be used. For example, biological insecticides such as neem or pyrethrum against insect infestation, or biological fungicides such as sulfur acetic acid against fungal infestation.[30]

2.3.7 Automation

Due to the artificially-created and closed ecosystem and the high level of standardization in structure and operation, vertical farming systems are particularly suitable for a high degree of automation. Automation is particularly essential for ensuring consistent quality of the products. The basis for this is a high availability of data on the various parameters in the ecosystem such as:[31]

- Temperature
- CO2 concentration
- Humidity
- Air pressure
- Air circulation
- Nutrient content
- Energy consumption
- Lighting conditions
- Picture photos of the plants

[28] (World Horticenter, 2021)
[29] (Pflanzenschützer, 2021)
[30] (Global2000, 2021)
[31] (Kozai, 2018)

Data is collected and stored via intelligent and networked sensors. In addition, the growth and condition of the plants can be monitored by installed cameras. By processing the data, the operator thus obtains automated monitoring and has knowledge of the conditions and parameters of the plants. Depending on the level of automation of the operation, the complete value creation can also run autonomously with the help of artificial intelligence and robotics. A distinction will be made between six degrees of automation, which cover the complete value creation from cultivation to distribution (see Figure 10). This includes purchasing, preparation of seedlings, cultivation of plants, harvesting, distribution, logistics, service and maintenance of the operation.[32]

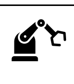
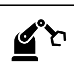
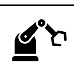
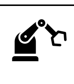
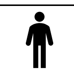
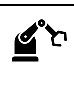
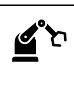
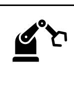
Level	Automation Capability	Core Cultivation	Pre- & Post-Growth	Logistics & Inspection	Maintenance & Service	Market Intelligence
0	No automation					
1	Basic growth automation					
2	Conveyor automation					
3	Adaptive automation					
4	System automation					
5	Full automation					

Figure 10: Automation level of Vertical Farms
Source: Own representation according to (Bertram, 2019)

In level 0 of the automation table, the operation of the vertical farm is exclusively manual with manual labor, and in addition, all decisions are made by humans. The experience values of the experts and workers serve as the basis for this; in addition, the data obtained from the monitoring of the plant conditions and parameters via the sensors and cameras support the human decision-making.

Level 1 of automation allows the plant that the parameters temperature, nutrient content, humidity, light intensity, etc. which directly affect the plants, are automatically adjusted to the target value according to predetermined rules and cycles. The basis for

[32] (Bertram, 2019)

this is automatic monitoring of the conditions and the link with the plant control system. This process takes place during regular operation without human influence.

In stage 2, the system is supplemented by the automation of operations related to the life cycle of the plant, including sowing, germination, harvesting and packaging. However, these operations are carried out with non-intelligent machines. Stage 2 represents the current state of the technologies for regular and commercial operation, and the following stages can be reached by further development of the technologies in the future.

To enable Stage 4, greater use of artificial intelligence and intelligent machines is required. This enables fully autonomous monitoring and inspection of plants via sensors and cameras to identify the exact needs of the plants and then, via the further automated processes, to provide them.

In the next stage, all processes are automated to such an extent that humans themselves only have to determine the quality and quantity of the output. All related process steps are taken over by machines, robots and software, including stock management with order actuation, refilling processes, service and maintenance of the machines.

In the final stage of automation, the human being exists only as a customer, every operation and process of the Vertical Farm is automated, the operation is thus completely autonomous and independent. In addition to analyzing the markets in terms of supply and demand, logistics between suppliers are also coordinated autonomously without human decisions or labor.[33]

2.4 Advantages and disadvantages of a vertical farm

The use of vertical farming technologies brings with it some advantages and disadvantages, which are explained in more detail in this section. In addition, a comparison is made with traditional cultivation methods in the greenhouse or in the open field.

A major advantage of producing food in vertical farms is the possibility of year-round production. Since the cultivation takes place in a closed and artificially created

[33] (Bertram, 2019)

environment, local conditions regarding local weather and other environmental conditions such as seasons, precipitation, soil quality and light intensity have no influence.[34]

Conditions can be precisely managed and controlled to create an optimal environment for plant growth, maximizing yield. Which also leads to the productivity per unit area of a vertical farm, which is 20up to10 a factor, mainly due to the use of smart technology and stacked levels (see figure11).[35]

Crops	Yield in VF due to Tech (tons/ha)	Field Yield (tons/ha)	Factor increase due to Tech	Factor increase due to Tech and Stacking
Carrots	58	30	1,9	347
Radish	23	15	1,5	829
Potatoes	150	28	5,4	552
Tomatoes	155	45	3,4	548
Pepper	133	30	4,4	704
Strawberry	69	30	2,3	368
Peas	9	6	1,5	283
Cabbage	67	50	1,3	215
Lettuce	37	25	1,5	709
Spinach	22	12	1,8	820
Total (average)	71	28	2,5	516

Figure 11: Productivity of a Vertical Farm compared to traditional farming methods.
Source: (Conrad Zeidler, 2017)

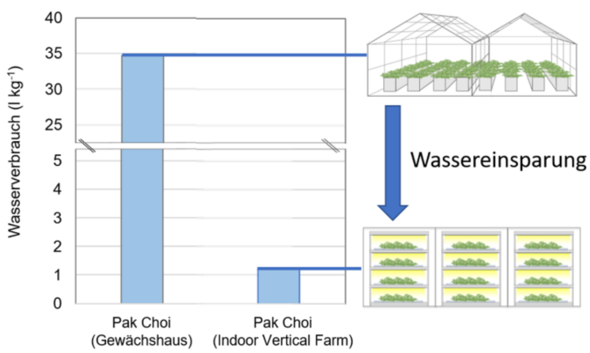


Figure 12: Water saving in the cultivation of pak choi
Source: (Mempel, 2020)

However, the closed and controlled system of a vertical farm brings even more advantages. These include the low water consumption resulting from the use of hydroponic cultivation systems, which in combination with a closed water circuit can reduce consumption. Thanks to the closed system, the water released by the plants into the air through transpiration can be recovered by condensers and reintroduced into the water cycle. These factors mean that, for example, only 1.2 liters of water are used to grow 1 kg of pak choi, whereas growing the same quantity

[34] (Birkby, 2016)
[35] (Adenaeuer, 2014)

in a greenhouse would consume 35 liters of water (see figure 12). However, the exact amount of water saved is highly dependent on the type of crop.[36]

In addition, the use of pesticides, herbicides and fungicides can be minimized or, in some cases, completely avoided through the plant's own ecosystem. As an alternative, certain insects are often used for pest control. So that, in principle, biodiversity and soils can be protected when substituting arable land. Due to the high flexibility and scalability, vertical farms can be established locally in places with high demand, for example in metropolitan areas or cities. This will shorten transport distances for the end customer, to the benefit of quality and carbon footprint of the produce. In addition, local jobs can be created, which also contributes to the overall security and independence of supply chains and food security.[37]

Despite the many advantages of the closed ecosystem, this type of cultivation also brings some disadvantages. In general, a high capital investment is necessary for the construction as well as for the operation of a vertical farm. Especially the buildings and the artificial lighting cause high fixed costs already during the construction (see figure 13).[38]

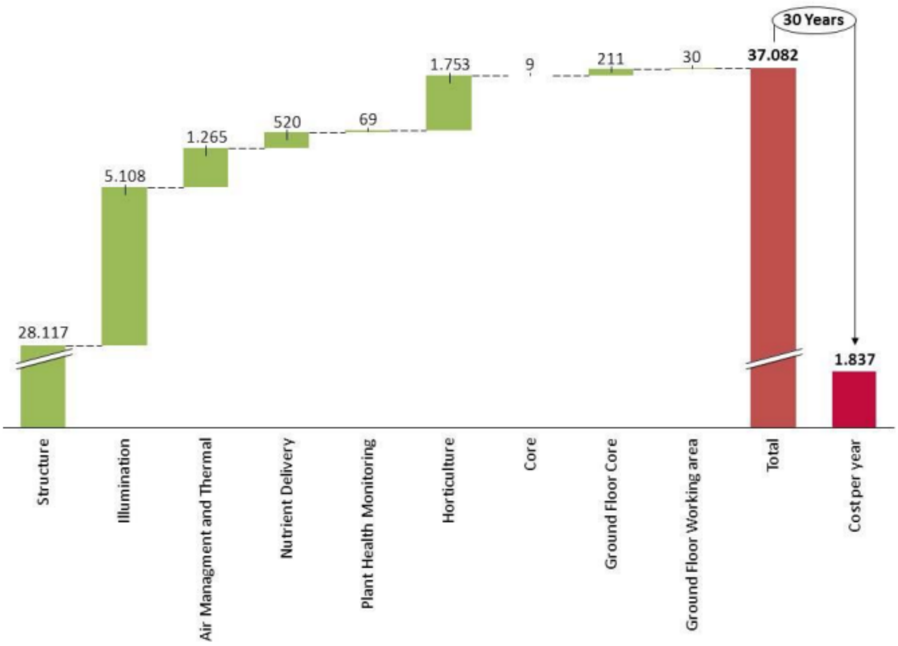


Figure 13: Total fixed costs with the yearly 30-year annuity cost in KEuro
Source: (Conrad Zeidler, 2017)

[36] (Mempel, 2020)
[37] (Fatemeh Kalantari, 2017)
[38] (Conrad Zeidler, 2017)

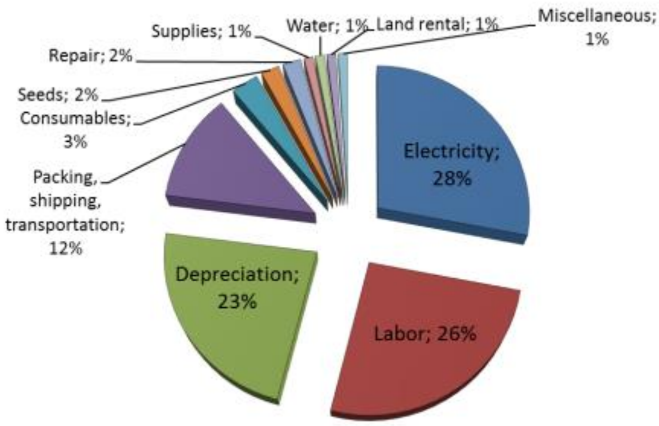


Figure 14: Operational Costs of Plant Factories
Source: (Conrad Zeidler, 2017)

Operating costs are mainly driven by high energy costs, depending on the location and type of energy supply (see figure 14). In addition, the operation of such a farm requires a workforce with a high level of education and training, especially highly automated farms require a large number of specialists in the fields of agricultural sciences, biology and IT, which further increases operating costs.[39] [40]

Another disadvantage is currently still the limitation to a small selection of crops suitable for highly automated and industrial production in a vertical farm.[41]

Compared to greenhouse and field food production, vertical indoor farming generally performs better for the European region in terms of resource use, quality, yield, environmental impact and automation (see Figure15). However, the result is highly dependent on the prevailing conditions and infrastructure.

		Indoor farm	Greenhouse	Outdoor
Climate/Weather	Independence	↑	→	↓
Resource consumption	Electrical energy consumption	↓	→	↑
	Heat	↑	↓	↑
	Water & Nutrients	↑	→	↓
	Plant protection products	↑	↑	↓
Quality	Targeted influence of secondary metabolites	↑	→	↓
	Just in Time Production	↑	→	↓
	Homogeneity (quality and quantity)	↑	→	↓
Yield	Yield maximization	↑	→	↓
	Year round production	↑	↑	↓
Environmental impact	Surface sealing/ land consumption	↑	↓	↑
	Carbon footprint	↓	→	↑
	Soil contamination/ nutrient leaching	↑	↑	↓
Automation	Potential for process automation	↑	→	→

Figure 15: Comparison of different cultivation methods for the region Europe
Source: Own representation based on (Mempel, 2020)

[39] (Conrad Zeidler, 2017)
[40] (Srikanta Patnaik, 2020)
[41] (Fatemeh Kalantari, 2017)

Thus, the vertical frame clearly stands out from the other methods, especially in the areas of independence from climate and weather, quality, yield and automation, but there are still deficits in resource consumption and environmental impact. The high energy consumption is particularly noticeable, depending on the available energy mix or independent renewable energy sources to varying degrees. Which also has a major impact on the carbon footprint of the entire farm.[42]

To ensure truly sustainable food production with a vertical farm, the impact of resource consumption and environmental impact must be reduced. There is no one-size-fits-all solution for these aspects; each vertical indoor farm must be precisely and specifically adapted to the selected location. Particular focus is placed on the existing infrastructure with regard to the availability of clean energy, heat and space, and the possibility of integrating or establishing a circular economy.

[42] (Mempel, 2020)

3. Botswana

The democratic Republic of Botswana is located in the southwestern part of Africa, bordering South Africa, Zimbabwe, Zambia and Namibia (see Figure 16). The independent country stretches over 582,000 km^2 and is home to approximately one 2,2million inhabitants. In 1966, the country was still one of the poorest countries in the world, but due to diamond discoveries and marketing, the country quickly developed into one of the richest and politically most stable states in Africa. Since independence in 1966, Botswana has been a stable democracy under the government of Head of State Mokgweetsi Masisi.

Figure 16: Map Botswana
Source: (Transafrika, 2009)

Large parts of the country consist of untouched nature, which offer home and protection to the large and unique animal kingdom. The largest part of the country is the Kalahari Desert with over 84% of the land area. Besides the Okavango Delta, the largest inland delta in the world, and the Makgadikgadi Pans, the largest salt pans in the world, the Kalahari Desert and the Okavango Delta are among the most famous areas of Botswana and are a magnet for tourists from all over the world.[43]

With an average of 4 inhabitants per square kilometer, the country is one of the most sparsely populated in the world. About 50% of the population lives in cities, almost 200,000 of them in the capital Gaborone and another 230,000 in the large cities such as Francistown (100,000), Molepolole (63,000) and Selebi-Phikwe (55,000) in the southwest of the country. This makes Botswana one of the African countries with the highest urbanization. The national language is English, but the native language Setswana is also widely spoken. The national average age of 24 years is average compared to the rest of the world, but with a population growth rate of 2.1% per year, the country is one of the African countries with the lowest percentage population growth. Another unique feature in Botswana is the high literacy rate, due to a

43 (Transafrika, 2009)

government initiative in which 25% of government spending is invested in education. Although there is no compulsory education in Botswana, the enrollment rate at universities is 27.5%, with many students completing their studies abroad (South Africa, the United Kingdom, the United States or Australia) rather than at home. In Botswana itself, there are two state universities specializing in mining, IT, manufacturing and production technology, materials science, biotechnology, civil infrastructure and agricultural sciences in order to make the country's development in the relevant areas less dependent on foreign specialists.[44]

3.1 Economy

After being one of the poorest nations in the world in 1966, the country has developed into one of the most prosperous countries on the African continent in recent years and is seen by many other African countries as a model of economic development. The origin of the strong economic growth is the discovery of large diamond deposits. Targeted investments by the stable government in the development of the country and the constant improvement of living conditions have increased the annual average economic growth to 9% (see figure 17).

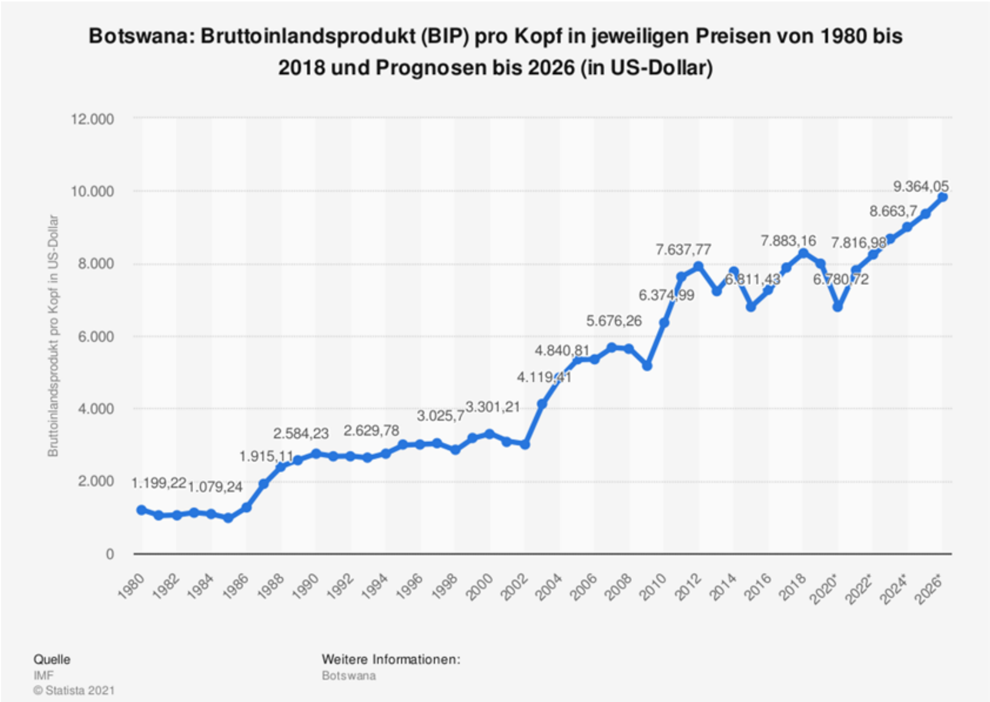


Figure 17GDP development per capita in Botswana (1980-2026)
Source: (Urmersbach, 2021)

[44] (DAAD, 2017)

In addition to diamond mining and mining, which account for about 20% of GDP tourism and financial services are other important pillars of the economy.[45] The diamond trade alone accounts for 70%-80% of the country's export volume. Nevertheless, Botswana faces major economic challenges such as high dependence on diamonds and trading partners, limited infrastructure and widespread poverty. Moreover, despite its comparatively high GDP per capita, Botswana ranks among the countries with the highest social inequality.[46]

3.2 Agriculture and food supply

National agriculture covers only a small portion of the population's food needs and therefore contributes only about 2% of GDP. Over 90% of food is imported from surrounding countries, mainly from South Africa, resulting in a high dependence on trading partners and international markets. Nevertheless, subsistence agriculture and animal husbandry are of high importance, especially for the population in rural areas, which accounts for more than half of the total population.[47]

Livestock accounts for about 80% of agricultural GDP, and cattle farming in particular is very important in Botswana. Livestock production exceeds domestic demand, making beef exports one of the most important agricultural exports. However, the livestock sector has experienced a continuing decline in recent years.[48]

The crop agriculture sector, is mainly dominated by cereal crops. The main cereals include sorghum, maize and millet. However, cultivation, which is mainly located in the eastern region of the country, is severely constrained by unreliable water supply due to frequent dry spells, poor soil quality and low productivity (see figure18).[49]

[45] (Africa, 2021)
[46] (Worldbank, 2021)
[47] (OEC, 2021)
[48] (International Trade Administration, 2021)
[49] (Nkgowe, 2021)

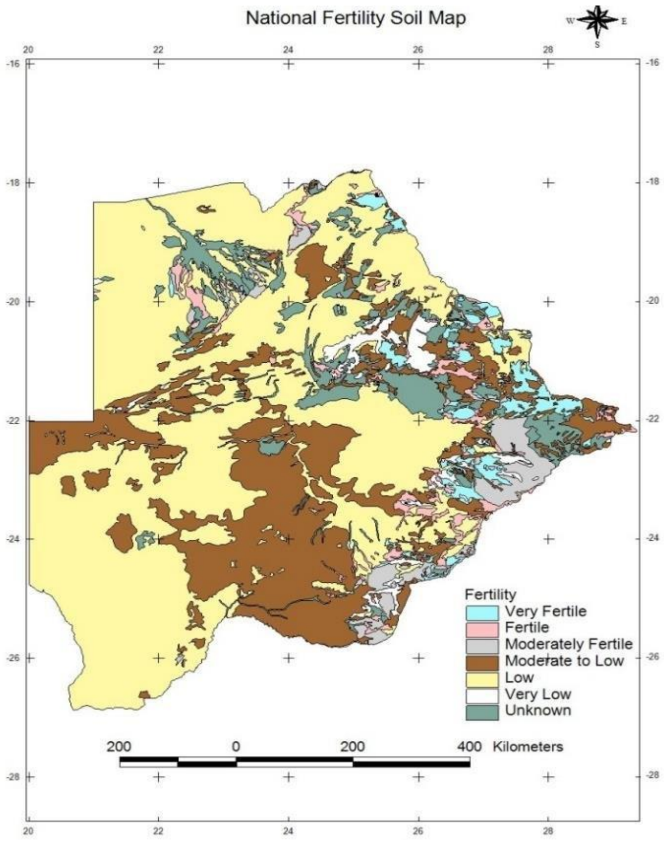


Figure 188: National Soil Fertility Map of Botswana. Source: (Kashe, Kolawole, Moroke, & Mogobe, 2019)

As agriculture in Botswana is predominantly rain-fed, the country is also particularly vulnerable to climate variability and change, which greatly increases the risk of crop failure and loss. Only 0.5% of the land in Botswana is suitable for growing crops.[50] This problem is exacerbated by the ongoing urbanization and development of the country, which means that fertile land is used for the construction of buildings and infrastructure.[51]

Projected climate change trends threaten regional grain production and imports of key staple crops. Given the expected increase in temperatures and decrease in rainfall, particularly in key agricultural areas in the eastern part of the country, maize and sorghum yields are expected to decline by 10% to 35% by mid-century and also pose a major challenge to livestock production.[52] Already in 2018, 75% of the cultivated area was reduced in the short term due to a two-year drought, posing problems for food supply.[53] According to a study by the UN's Food and Agriculture Organization, there is malnutrition in large parts of the country. For example, between 2016 and 2018, about 41.3% of the population was already struggling with severe malnutrition and 70% with moderate malnutrition.[54] Due to the poor outlook in terms of climatic conditions, which further complicate arable farming, this percentage will continue to increase in the future without measures.

[50] (World Bank Group, 2021) [50] (World Bank Group, 2021)
[51] (Henssen, 2021) [51] (Henssen, 2021)
[52] (World Bank Group, 2020) [52] (World Bank Group, 2020)
[53] (Staff, 2018)
[54] (United Nations World Food Programme World Hunger Map, 2019)

A large proportion of farms are smallholders in the country's rural regions. Due to the difficult climatic conditions and lack of infrastructure, they are particularly dependent on policy assistance and support for operations to increase field productivity and resilience to market changes and climatic conditions. [55][56] In addition, the lack of support makes it difficult for local smallholder farmers to access markets, creating a large market imbalance with the large food importers in the country.[57] Farms are also in need of support for infrastructure development, with only 45% of farmers having access to roads, 17% having access to electricity, 22% having access to telecommunications, 64% having access to water for livestock, 66% having access to water for domestic use, 43% having access to water for field irrigation, and only 52% having access to markets (as of 2010).[58] In addition, there is a great need for financing of new agricultural projects by public institutions.[59]

Women play an important role in food security in Botswana; especially in rural areas, women are the main contributors to food security. Although women often face greater challenges when it comes to accessing land, labor, and financial services, in Botswana the percentage of female labor in agriculture is about 60-80% and the percentage of women with agricultural property is about 30%, a high figure compared to other African countries such as Malawi with about 5% female ownership when it comes to land.[60]

3.2.1 Vertical and Indoor Farming Projects in Botswana

Regarding the challenges in agriculture, there are already projects and companies in Botswana in the context of indoor farming. First pilot projects and companies are working with the technology, but the implementation faces some challenges. These include customer acceptance, as he majority of the population has a meat-rich diet with a lot of cereals and root vegetables, the needs of these needs cannot be met with the current cultivation options in vertical farming. In addition, policy regulations such as earmarking for existing buildings hinder the widespread implementation of vertical farms in central locations in cities, for example. In addition, the operation and development

[55] (Sirak Bahta, 2017)
[56] (Moseley, 2016)
[57] (Nkgowe, 2021)
[58] (National Institute of Agricultural Extension Management India)
[59] (Nkgowe, 2021)
[60] (UNICEF, 2019)

of a vertical farm requires a high level of education and skills in the use of modern technologies. However, the technology offers great opportunities, for example, for the supply of the catering and hotel industry, which often have a different target group with different eating habits (e.g. tourists from Europe, etc.).[61]

One of the largest indoor farming companies in Botswana is *Go Fresh Botswana*, which produces vegetables at its two locations in Maun and Gaborone using the concept of hydroponics. Customers mainly include regional restaurants and hotels, but also fast food chains and selected households in the area. No information is available on the size and production capacities of the operations in Maun and Gaborone.[62]

In addition to *Go Fresh Botswana*, *Veggieland* is another company in the indoor farming sector that also relies on the concept of hydroponics. Through a collaboration with *Capital Hill (Pty) Ltd, which is* responsible for groundwater pumping, the company operates a 15.5 hectare cultivation area for growing various vegetable and fruit crops in the Gaborone area. In addition to operating the indoor farm facility, *Veggieland* acts as a general trader and importer of vegetables and fruits from Botswana and South Africa. And supplies vegetables and fruits to the leading supermarkets in Botswana in addition to the catering industry.[63]

In collaboration with the government of Botswana, *PFL* and the company *Green Gems,* a vertical farming project is being created for ten villages in rural areas. This will involve smallholder farmers being trained by *Green Gems in* a pilot project on how to grow vegetables and run a farm using hydroponics. Later, the project will be rolled out to up to six districts.[64]

In addition, there are other projects in the context of urban farming for growing crops in cities and rural areas, but these projects are not based on the concept of vertical or indoor farming.

[61] (Nkgowe, 2021)
[62] (go fresh!, 2021)
[63] (Veggieland, 2021)
[64] (Botswana On, 2021)

3.3 Energy supply

Access to electricity is an important driver and indicator of economic growth in developing countries. This effect can also be observed in Botswana; in addition to GDP, energy demand and consumption in the country is also steadily increasing at similar rates (see figure19).[65] While consumption in 1990 was about 1TWh, it quadrupled in about 30 years to almost 4 TWh.

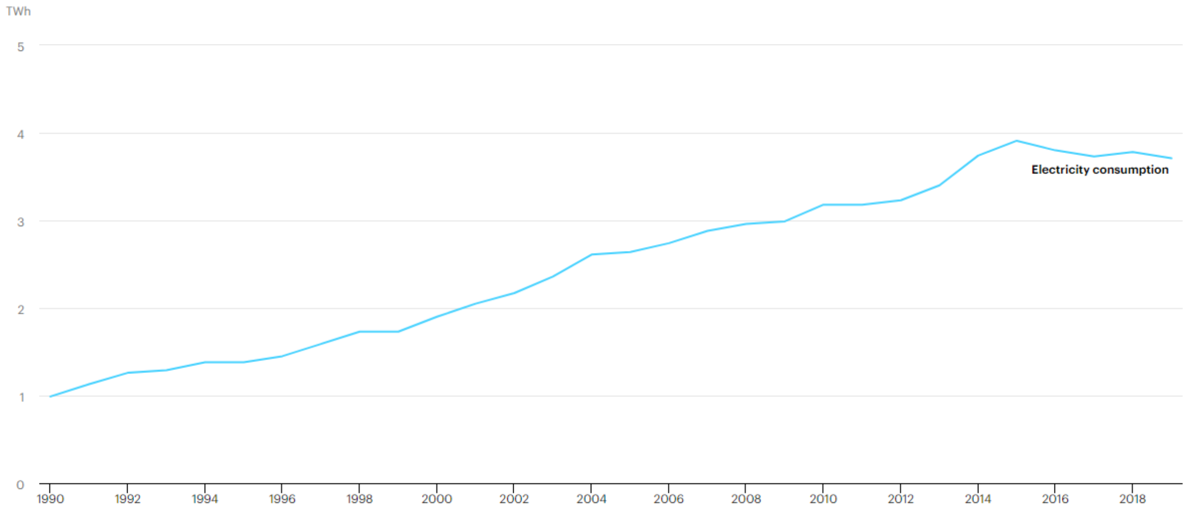


Figure 19: Energy consumption of Botswana (1990-2019)
Source: (International Energy Agency, 2021)

In 2018, approximately 64.9% of Botswana's population had access to electricity, placing the country in the top third of Southern African countries in terms of electricity access rates. In urban areas of Botswana, 80.4% of the population has access to electricity, while in rural areas only 24.2% do. Through various programs, the government aims to provide everyone in the population with access to electricity by 2030.[66]

To meet its energy needs, Botswana relies primarily on coal, oil and biomass generation. Botswana is thus heavily dependent on fossil fuels. For example, coal-fired power generation has a share of about 40%, oil-fired generation about 40%, and biomass generation such as wood and waste about 20% (see figure20). The share of wind and solar energy is not relevant at <1% (as of 2018).[67]

[65] (IEA, 2021)
[66] (International Renewable Energy Agency, 2021)
[67] (IEA, 2021)

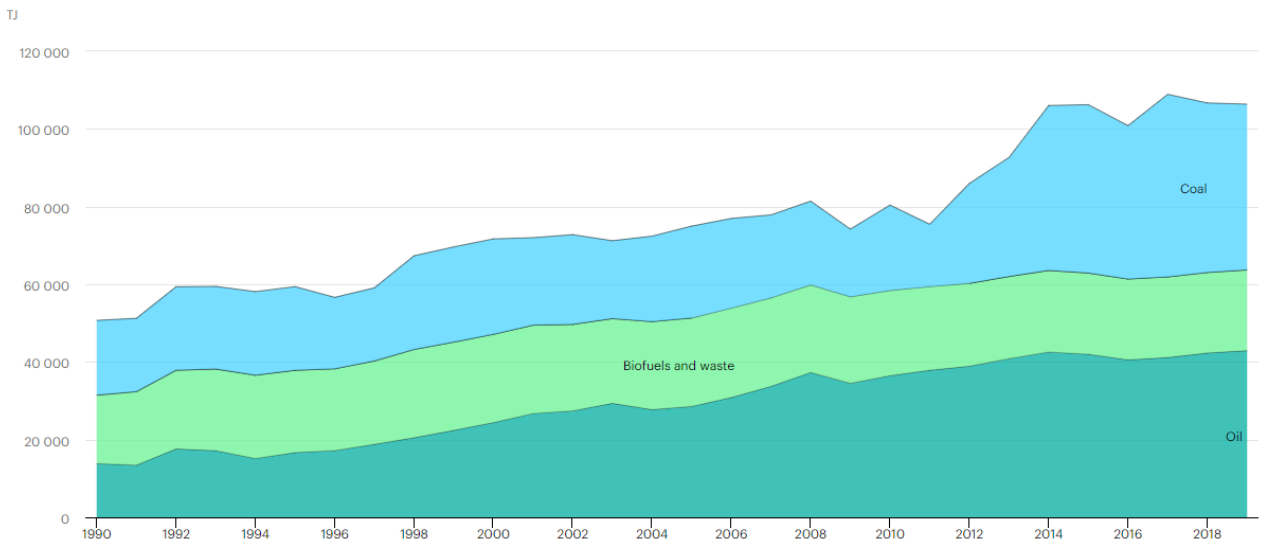


Figure 20: Energy production by energy source 1990-2019 in Botswana.
Source: (International Energy Agency, 2021)

In addition, the country relies on imports from surrounding countries; imports account for about 45% of total demand.[68]

In order to make the energy supply more sustainable and to reduce greenhouse gas emissions by -15% by 2030, Botswana is focusing on the development of renewable energies in the future.[69] According to a study by the International Renewable Energy Agency, the country has great technical potential for the production of clean energy due to its geographical location and climatic conditions, so can be generated by solar thermal 130.7 TWh, photovoltaic 137.6 TWh, biomass 10MW and wind turbines 1152 MW energy. In addition, the power grid is to be further expanded and supplemented with so-called off-grid systems. [70]

3.4 Water supply

Botswana obtains its water from groundwater as well as from surface water, e.g. from rivers. In Botswana, 48% of the water is extracted by the water supply industry and 52% by self-suppliers. So that about 95% of the population has access to drinking water.[71] The country has an annual demand of 245millions of cubic meters of water,

[68] (Internationa Renewable Energy Agency, 2021)
[69] (International Trade Administration, 2021)
[70] (International Renewable Energy Agency, 2021)
[71] (Statistics Botswana, 2016)

with the agricultural sector being the largest consumer of water in the country at 48%, along with households at 18% and the mining industry at 16%. [72]

In the past, the country relied mainly on groundwater resources, which were tapped through drilled wells or boreholes.[73] Another water resource are the rivers (Limpopo, Chobe, Zambezi and Okavango[74] and 94 reservoirs (surface water) in Botswana.[75] However, these sources are quantitatively and qualitatively limited and are also very unevenly distributed across the country. Thus, the largest usable deposits of groundwater and surface water are located in the eastern and northeastern parts of the country, while most of the population lives in the southeastern part of the country.

Botswana's renewable water resources are 50% dependent on other countries, so Botswana has to share most of its surface water resources with neighboring countries. The main sources are the Limpopo, Chobe, Zambezi and Okavango rivers in the north of the country.[76] Due to climatic factors such as the high evaporation rates in the interior wetlands and reservoirs, low general rainfall, and the high temporal and local variability of rainfall, the amount of water leaving the country is less than the amount flowing into the country. Which significantly limits the amount of available water resources. It is expected that the influence of these factors will be further exacerbated by climate change (see Chapter 3.5) and that the annual water demand of 340 million cubic meters in 2035 will exceed the expected available water resources in the country in the future, so Botswana will have to make its water use more efficient in the future and negotiate the use of water resources shared with neighboring countries.[77]

3.5 Climate

Botswana, like all countries near the equator, has a tropical climate. The average daily maximum temperatures are at a constant level between 24-32°C throughout the year and at night at an average of about 20°C, although in the colder months (May to August) night temperatures can drop to as low as 9°C (see figure 21). During the rainy season (October to March), the salt pans, dried up river beds and the Okavango Delta

[72] (Ministry of Land Management, Water and Sanitation Services, 2017)
[73] (Rahm, Swatuk, & Matheny, 2006)
[74] (Centre for Applied Research and Aurecon Botswana, 2013)
[75] (African Development Bank, 2011)
[76] (FAO, 2013)
[77] (World Bank Group, 2020)

fill with water, supplying the land and nature with water. Throughout the year, only the Okavango River and the Chobe River system have permanent water. The vegetation is characterized by its diversity of flora and fauna, depending on the time of year in different forms.[78]

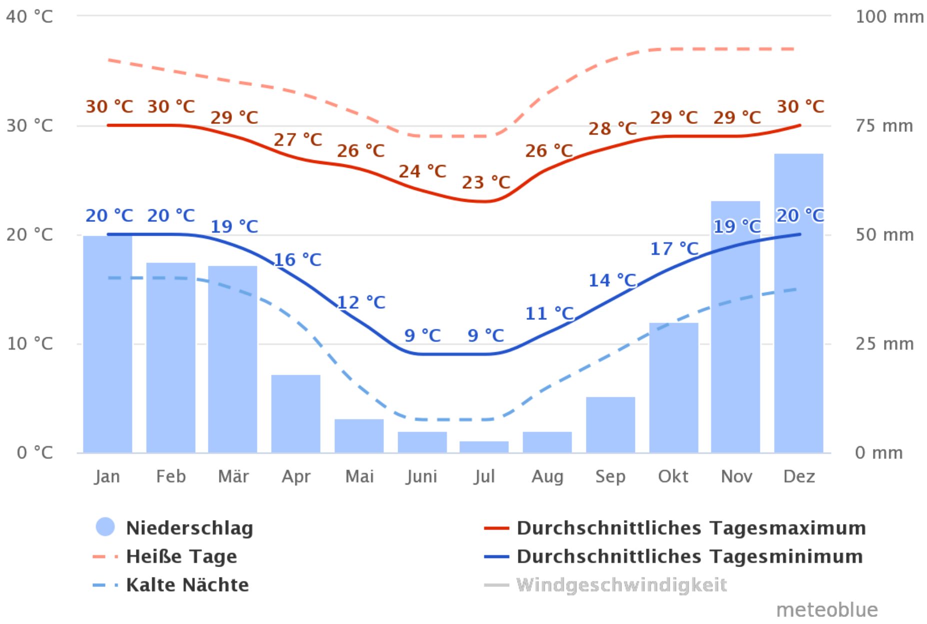


Figure 191: Climate diagram for Botswana
Source: (Meteoblue, 2021)

The global climate change hits the region around Botswana particularly hard and makes the effects clear and are a direct threat to the nature and population in Botswana. According to a study by the World Bank Group, average monthly temperatures are expected to increase by +5.0°C by 2099, and at the same time average monthly rainfall is expected to decrease by -9.5mm (see figure 22), leading to major impacts on agriculture and water supply.[79]

CMIP5 Ensemble Projection	2020–2039	2040–2059	2060–2079	2080–2099
Monthly Temperature Anomaly (°C)	**+0.6 to +2.2** (+1.4°C)	**+1.6 to +3.5** (+2.5°C)	**+2.8 to +5.2** (+3.8°C)	**+3.9 to +7.1** (+5.0°C)
Monthly Precipitation Anomaly (mm)	**−18.8 to +11.9** (−2.4 mm)	**−24.9 to +9.5** (−5.3 mm)	**−25.6 to +9.3** (−7.1 mm)	**−32.1 to +6.1** (−9.5 mm)

Note: The table shows CMIP5 ensemble projection under RCP8.5. Bold value is the range (10th-90th Percentile) and values in parentheses show the median (or 50th Percentile).

Figure 202: Development of average monthly temperatures and precipitation until 2099.
Source: (World Bank Group, 2020)

[78] (Meteoblue, 2021)
[79] (World Bank Group, 2020)

Agriculture in Botswana is predominantly rain-fed, which makes the country vulnerable to climate variability and change and will increase the number of crop failures in the future. The population in rural areas is particularly dependent on subsistence agriculture and livestock. To meet demand in Botswana, a total of 90% of food is imported, making local agriculture a small contributor to GDP. Climate change, which is also severely affecting Botswana's main importers, further threatens Botswana's supply and food security.[80]

The water supply in Botswana is also threatened by climate change. Rising temperatures and stagnating precipitation inhibit the recharge of groundwater, which is currently the main source of drinking water supply in villages. In urban areas, the supply is mainly covered by surface water, e.g. from rivers (see chapter 3.4).[81]

Botswana is generally considered to be highly vulnerable to climate variability and change, as the country is heavily dependent on rainfall and natural resources. The resulting major challenges will be water availability and changing rainfall cycles. Especially the impact on agriculture and the general supply of the population, as well as the dependencies on other countries, make the country vulnerable to food insecurity and unstable livelihoods.[82]

[80] (OEC, 2021)
[81] (Centre for Applied Research and Aurecon Botswana, 2013)
[82] (World Bank Group, 2020)

4 Maun

The city of Maun is located in the north of Botswana on a spur of the Okavango Delta and, with a population of around 60,000, is the fifth largest city in the country (see Figure 23).[83] Maun serves as an important tourist hub for connections to the surrounding Okavango Delta and Moremi Game Reserve national parks. And also has a science center, with the University of Botswana and the Okavango Research Center, in addition to an airport, and serves as the site for the realization of the Maun Science Park.

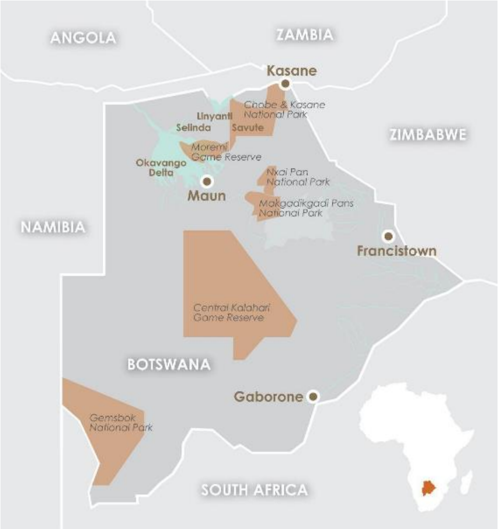


Figure 213: Location of the city of Maun
Source: (Maps Botswana, 2021)

4.1 Maun Science Park

With the Maun Science Park, a future-oriented project is to be realized in Maun, it is to meet the emerging challenges such as demography, governance and climate change and to become a best-practice model for a symbiotic coexistence of humans, animals and the environment for the whole of Africa and the whole world. The vision is to develop a self-sufficient district, the Maun Science Park. Equipped with state-of-the-art technology and infrastructure as well as research and educational facilities, it will become a habitat for humans and animals.

The project has an impact on many areas in the lives of the population and on the infrastructure of the city of Maun, these include:

- **Energy**: Sustainable energy production and efficient energy use
- **Construction**: Development of housing units from natural and local resources
- **Water**: Ensuring access to drinking water and reuse of wastewater.
- **Waste management**: recycling and minimizing waste
- **Transport/Logistics**: Establishment of a multimodal transport system
- **Digital connectivity**: developing best practices and creating added value through networking

[83] (Maps Botswana, 2021)

- **Agriculture**: Ensuring a self-sufficient food supply under the given climatic and structural conditions.
- **Healthcare**: Preventing disease and ensuring quality health care.
- **Education**: ensuring lifelong learning and developing a knowledge-based economy
- **Governance**: creating an environment conducive to innovation and transparency
- **Social cohesion**: Holistic approach that puts people at the center and promotes cooperation

On a 250 hectare site, south of the airport on the Thamalakane River, the various facilities of the MSP are to be set up in the future in the form of a real laboratory.[84]

This includes the so-called **Maun Smart Living Lab**, a real laboratory consisting of 25 smart homes, in which smart technology for the supply of water, electricity and food is tested. The buildings are part of the sustainable concept and are constructed from natural and local materials.[85]

Another element will be the **Maun Science School for Design and Technology**, which will serve as a hub for the national and international research community. The university concept is tailored to the local problem areas and is intended to promote the development of know-how in the areas of sustainability and new technologies in order to work together with scientists and companies to develop technological solutions for coping with the consequences of climate change and demographic change.[86]

In addition, the **Maun Science Park business incubator** aims to attract startups and companies in the field of sustainability and new technologies to enable knowledge transfer and support the process of digital transformation. Together with the Maun Science School, this will create local jobs and build wealth in the future.[87]

Initiator of the MSP is Prof. Vasilis Koulolias, together with his team from inRes the project is developed and built. The MSP project has been approved by the cabinet in Botswana as part of the national digital transformation strategy and is supported by

[84] (Bühler & Koulolias, 2021)
[85] (Maun Science Park, 2021)
[86] (Maun Science Park, 2021)
[87] (Maun Science Park, 2021)

various universities and institutions worldwide e.g. Microsoft, World Economic Forum, TU Munich, HTWG Konstanz etc. [88] [89]

[88] (Maun Science Park, 2021)
[89] (Bühler & Koulolias, 2021)

5. Challenges for projects in Africa

The implementation of complex projects like the Maun Science Park or the realization of a Vertical Farm in Africa, requires overcoming some obstacles.

The basic rule is that every project needs to be financed. Thus, especially for the implementation of complex projects in Africa, the financial resources must be made available and the necessary investors must be convinced.

A major obstacle in Africa is the lack of infrastructure and technology on site. The energy supply plays a decisive role here, which should be realized as cleanly as possible in order not to disregard the sustainability concept of the project. Currently, however, hardly any renewable energies are used in Africa, but this should change in the future thanks to the recognized great potential of the continent, especially in the field of photovoltaics. The electrical energy generated in turn requires an intact power grid, which is still poorly developed, especially in rural areas of Africa. In addition to electrical energy, water supply is another obstacle. While in rural areas it is often necessary to walk for kilometers to the next water point, more urban areas are supplied with water and often also running water. However, this water is polluted and cannot be used without treatment.[90]

Once the hurdle of infrastructure has been overcome and a sufficient supply of electricity, water and the required technology has been ensured, it must also be installed and operated professionally.[91][92] The lack of local skilled workers is a further obstacle here. If the technologies cannot be used and maintained properly due to a lack of skills, the project risks collapsing. In addition to the sometimes low level of education, the local work ethic can also lead to problems, as it differs from the way of working that is customary in Western culture. The cultural differences can lead to further problems, such as a lack of customer acceptance. Especially in nutrition, which directly affects the local population, there may be a lack of interest in food from vertical farms due to different eating habits. [93] [94]

[90] (Karlheinz Böhm Äthiopienhilfe, 2021)
[91] (Nkgowe, 2021)
[92] (Henssen, 2021)
[93] (Henssen, 2021)
[94] (Stakeholder, 2021)

Political regulations such as building codes and local authority regulations are another obstacle. For example, vacant industrial buildings may not be used for agricultural purposes, as the building code does not allow this. In addition, locals often find it difficult to start new projects as they receive little to no support from the state and have to take a very high financial risk to get a project off the ground due to a lack of security.[95]

[95] (Nkgowe, 2021)

6. Conclusion

The aim of this project was to show how vertical farming can be used to ensure sustainable food security and how this concept can be implemented in the Maun Science Park in Botswana. So that the future nutrition of the emerging self-sufficient district can be achieved. From the literature review, it was found that vertical farming in principle has the potential to sustainably produce more food with less resource input than traditional farming methods, using state-of-the-art greenhouse methods and technologies.

Considering the prevailing conditions in terms of infrastructure, education, environment and climatic conditions, this conclusion cannot be directly applied to Botswana. While the concept of vertical farming addresses a lot of problems in Botswana on the one hand, on the other hand these technologies bring many new challenges. For example, Vertical Farming provides high food security through year-round production of food through the self-contained ecosystem and creates independence from current and future climatic conditions, poor conditions for traditional agriculture (e.g., infertile soils), and foreign imports. In addition, water consumption in agriculture can be reduced while increasing productivity per unit area.

However, vertical farming does not address the main problems of agriculture and food security in Botswana. While the country is one of the most prosperous in Africa due to its strong economic development in recent decades, it still lacks basic structures. For agriculture, these include, regardless of the prevailing climatic conditions, the lack of infrastructure for the operation, cultivation and sale of agricultural products, as well as the lack of support for agricultural projects and innovations by politicians. In addition, there is currently a lack of know-how and capital among the population, which is needed for the establishment and operation of a vertical farm. Another challenge is the meat-rich diet that is widespread among the population, to which the possible crops do not fit at the current stage of development of vertical farming. Thus, the scope of application and market is limited compared to Europe. In addition, the sustainable operation in Botswana is currently questionable, as the high energy consumption during operation is mainly covered by fossil raw materials due to the current electricity mix.

Despite the challenges, the concept also offers opportunities for useful applications, for example, through concepts based on aquaponics, whereby fish cultures are grown in addition to the plant cultures, so that the meat-rich diet of the population can be served. Another possibility is production of animal feed through vertical farming for the existing livestock industry in Botswana, which accounts for 90% of the agricultural GDP in the country. However, the exact potentials and feasibility would need to be evaluated in a separate project.

But with the ongoing development in Botswana and in the field of vertical farming, these problems can be partially solved. The Maun Science Park can play a key role in this, especially in Maun. Through this forward-looking project, the conditions and prerequisites for sustainable food security in the form of Vertical Farming can be created. Through the establishment of the Maun Science School for Design and Technology, the necessary know-how for Vertical Farming can be built up and international knowledge carriers can be attracted. In addition, the Maun Science Park Business Incubator provides access to capital and support from international investors and institutions. The development of a circular economy and the expansion and use of Botswana's potential in terms of renewable energy sources can also ensure the sustainability of a vertical farm in Botswana.

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IV. Appendix

Appendix 1: Interview transcripts

1.1 Qualitative Interview with Interviewpartner 1, Smart City Specialist on 05/11/2021 (Zoom):

Hannes Borgwardt

So, as you can see here, our project thesis is about vertical farming as you know, already. And our thesis is part of the Maun Science Park project. Our aim is to identify the requirements for vertical farming and to show the ways in which these can be met using innovative technologies. We will ask you some open and some close questions as part of our research. So, let us start with the first open question: What are currently the biggest challenges for agriculture and food security in Botswana? What is your view or your opinion on this question?

Interviewpartner 1

Um, the biggest challenge specifically for agriculture and food security in Botswana, okay. I think we cannot ignore the fact that we have very large landmass with very few people. We have 2.4 million people, so we are spread. So, to address something as important as agriculture, which is labor intensive, you obviously must consider arable land. A lot of the farmland in Botswana, funnily enough, was originally used for agriculture, but as the country developed and industrialized, the community settled around the farmland, and a lot of it was then concreted over to build towns, to make housing. So, it is funny, we have few people who need arable land, but cities have been developed over the land that was left and available. And so now it becomes an issue of what is available, um, looking at food security as well in terms of agriculture. Now it is not really seen as progressive. I mean, it is seen as something for our grandparents because you only ever see a picture of old people working in rural areas, very uneducated, literal people. So, they are not seen as a, this is like accounting or banking or anything like that. Another issue is that there is not a lot of infrastructure that is supporting. So, the infrastructure to support commercialization. And I think now, lastly, and most importantly, it is not an issue of capacitation, like people's skills development. Farmers or any potential farmer is not enabled with the mechanisms to start. So that first issue of seed funding, or, um, you have an idea, but then let us work to help you now develop this idea further. So that first step you cannot start the business with a loan. So, you need to struggle first. And if you get lucky enough to get started, that is when they come in. But no one helps you with the start to prototyping, getting a few orders in. No one helps you that. So, the issue here is around that seed funding or seed that initial capacitation at the beginning stage. Yes. Specifically, for those who want to go into commercial farming, initial food security.

Hannes Borgwardt

Okay. All right. That is interesting. Thank you. I think we will go over to our second question. So, the second question would be: what are the current impacts of climate change and agriculture of food security in Botswana? So, is the climate change a big problem now, or will it be a problem in the future?

Interviewpartner 1

It is a problem. It is a problem threefold. It is threefold because currently we are an importing country. We are not a producing country. So, from a food security perspective, we are importing almost 95% of our produce from South Africa. So, we are importing. So, I do not know how much an import bill currently stands there, but I thought it was somewhere around the form of food perspective around the three, four billion marks, but I am not sure of the current figures, but that is a lot of food to be importing, for so few people. And now you can say, but then why do not you produce to offset this food importing. Well then it comes back to the issue of how do your capacity the farmers. If your capacity is the farmers, to be able to take up the commercial opportunity, so that they can meet the capacity scale. If they have not started in getting the first steps right and then feel comfortable enough to now start improving the quality of the input materials, or the operation material and machinery that they use, then that is going to be a problem. Then the issue becomes, thirdly, if you have not started, how do you then start even addressing issues of, value addition, which is now addressing issues of the value chain of the sector. So even if you are talking about things like vertical farming, for example, if you are just doing strawberries, there must be a lot of core inputs and skills that you need. Whether it is machinery, bio scientists for the pH meters and everything else, you need scientists. Then how are you addressing the issues of water, where you are getting this water from, the hydrologists who are helping you, the people creating the digitalization or ICT tools to do the monitoring and all that. Then I will say lastly, point four, the issue of climate change is only relevant because we have been rain fed.

So, we are waiting for the rains, and we are out in the fields. So, this is not very effective. You should be able to intensify production a bit like the Israelis have done very well. You know, water, very little land mass, which is not very good, but somehow improve the nutrient quality. They use low number of square meters or acreage and they've intensified to produce. So, you need to intensify food production, but also you need to now focus on an intense irrigation, not rain fed. So that is the only impact of climate change really has based on our model for production, that is the problem. And the capacity of people themselves. And I would also like to say over and above the model, because we are now a water scarce environment. And agriculture depends on rain, but now because of the heat coming from climate change, our underground water is now being affected. So, the boreholes are becoming deeper and deeper because the waters are dissipating lower and lower. So, you must go deeper to get access to the water itself. So, this is a huge risk, and therefore government is focused on water importation.

Jannik Endress

If you go back to the import problem. Would you say the small farmers in Botswana are fighting against the big farmers in South Africa?

Interviewpartner 1

No, I do not think it is a fight. They do not have a chance because they are not being helped with the start. Government is saying very clearly that they want to do economic inclusion, citizen, economic empowerment, but then it is not putting in place. For example, saying if you are going to commercialization right before you even take a loan at national development bank or Cedar, we want to focus on food security. So, because you want to focus on food security, those who want to start a, not just youth or women or whatever, those who want to start, we are looking to create a technical assistance facility, so that we want to help those who are the top five hundred commercial farmers to come. And then we will help capacitate you for a two, three-year period so that you are ready now to get started. So, if you have almost liked a pitch deck, and you can show what your vision is, we are going to help you to start and grow. Whether it is with technical assistance and then capacitation then connects you with those who can help you scale. So, getting infrastructure in place and everything else. And then now you are, we make your investment ready through our procurement capacity. Nobody helps you develop the commercialization model. So that you can start the show first, that I have hit some milestones, that I can basically be a commercial farmer, that I'm creating jobs and tapping into the value chain that sits underneath me.

Hannes Borgwardt

Okay, thank you. Let us go to the next question: So, what do you see as the biggest challenges and disadvantages of vertical farming, especially in Botswana.

Interviewpartner 1

Yeah, in a Botswana context it is twofold. This is a very Western ideology, vertical farming. And I know it started off like Japan, where they build plant factories and things like that. But also, vertical farming itself, is big in the Northern hemisphere. I know the us and Europe its huge for them. The reality also around this, apart from the perception, is our diet. We are meat eaters. So really, vertical farming also does not compliment root-based crops. So, for example, can you grow carrots? Can you grow maize? Can you grow, uh, I do not know, beetroot? You know, things that complement our diet. The vertical farming, yes, it looks great, it is wonderful. But the reality in Botswana is, somebody will look at the plate after you have done your leafy vegetables and they say, okay, um, I like the salad, but where is the food? That will be the first question. The food is the meat and the Maize.

Hannes Borgwardt

Okay so maybe it could be a way to produce the food for the animals?

Interviewpartner 1

Yes, it is what are you going to use the vertical farming for? A takeaway for you is the question, what are you going to produce in the vertical farm? Do not think Botswana. It is looking like a cool thing because we have seen it being done somewhere else and it is seen to be modern, but the reality of it when you are facing the people themselves in the community's view, you are not going to get anywhere, feeding them salad. They want their crops that they know, and they also want the meat. So do not come with the perception that now we want to change their diets from meat to leafy vegetables. It might be necessary for those suffering from diabetes and for those who need to lose weight cause of hypertension or too much fat. But this is about starting it in Botswana, but it is also around the market size. This could be an opportunity if you look at it from a regional perspective. So that is not to say it is not possible from a regional perspective but using Botswana as the base so that it creates a job. And Maun is a very interestingly well-planned location simply because it is the second busiest airport in the whole of the region. So, it lends itself like Kenya. Kenya is the world's largest, if I am not mistaken the second largest, grower of flowers. And from Kenya, they exporting flowers from there. So, they just like the Dutch, they are just producing all sorts of flowers in shaded and covered greenhouses. So, it is an opportunity, but you must look at it from a regional perspective.

Hannes Borgwardt

Okay, thank you. The next question is: Where do you see the biggest opportunities and benefits of vertical farming?

Interviewpartner 1

I think I have touched on that, for example, from a Maun perspective, Maun is the second busiest airport in the whole region. So even if you say, okay fine, In Botswana they do not eat leafy vegetables or fruits, you can still grow them here. But if these are grown here, you going to use issues of freight to get the produce out for looking at the region, because obviously Africa wants to connect it is a transport. I think if you are being shown that it is possible at the special deliveries of COVID medicine. But also, the issue is connecting the region by delivery freight and logistics. So, Maun is a very good position if you're looking at producing. But now saying, okay, fine, what are the opportunities for the product for people in the region? That is one. And then the second one, like, I think you have just mentioned is issues of looking at it as an input producing input, more efficiently through vertical farming. You know, how do you produce food more efficiently. So, the goats and sheep and pork production, chickens are also could benefit in this regard. I think not many people know about snail farming, but the leafy vegetables are an input for snail farming. So, these are things that you can look at. Um, but critically for me, vertical farming also could be another way of, transforming perceptions of smart agriculture. It is just another way of showing the market that they are more intensive. So that people can see this as just another opportunity. It can be a catalyst for unlocking a value chain.

Hannes Borgwardt

Okay. Interesting. So, we will go to the next question: What other approaches do you think can solve the challenges in agriculture?

Interviewpartner 1

I think here really, you have the issues of design thinking. You are familiar with that; people must solve this start to solve problems. So, agriculture is a way to be creating issues of now addressing issues of regenerative agriculture. So, you can look at agriculture as a climate adaptation too. Everyone is talking nature-based solutions. So, agriculture does play a role here. And here specifically I am talking about urban food systems. So how do you now use agriculture as a vehicle to now start to create more use of more nature-based solutions for addressing urbanization. So, you take out the boundaries of open spaces, for example. So, the, the job creation vehicle in that respect and obviously nature base opportunities. But also, it is a vehicle for now addressing waste in the circular economy space, uh, water wastewater issues of waste from other things. And then now cleaning that up to now be used agriculture as a vehicle for now addressing some specularity. So, it is an input, whatever the, whatever you reuse redesigned from another industry, you can now become an input and use agriculture is that vehicle to now start to make use of the input material. Um, so it is a good vehicle for that. But I think the last thing would really be how do you now start to address the issues of irrigation? So, you need to now start to look at more intensified production so that you must look at how do you improve in a water scarce environment with the renewable energy, for example. So how do you use less water, renewable energy, and now use less square area to actually be more commercial in your production. So, it is yes. Irrigation needs to be addressed.

Jannik Endress

Okay. So, you think the classic agricultural has much unused potential?

Interviewpartner 1

It is not efficient, yes. It is too inefficient, waiting for the rain. It rains some day and then it can be cold at night and then the sun comes out. So, your crops can get destroyed then because it is open fields. Here we are coexisting with nature. So, a lot of people are suffering from wild animals coming in at night, and then just basically cleaning out the crops. So, it is not secure for the farm itself because for example, there is no insurance. So, you very high risk. So, farmers are not getting the benefit of insurance in regard. The farmers must secure their houses, you know, and that is how they do it. They produce, and this is very inefficient. There are no payment systems, micro insurance using e-wallets in their production, you know, where the farmer can show that they are selling, they are benefiting from evidence from trading and that evidence is the deposits in their wallets. And then the bank would say, oh, look at how much your banking, your wallet. We now creating a pay as you go model for covering your insurance. If your annual insurance is 1,200 pula, how do you pay let us say 60 pula a month or a hundred per month. And then you can now pay as you go. They are not creating those kinds of models. There is no innovation in this space, you know. So, that is also a huge problem. One last thing I would say in terms of approaches the clustering, we do not have industrial clusters in Botswana, so there is no agroprocessing classes. So that is another approach that is not even here. Cluster development is not even here in Botswana.

Hannes Borgwardt

Okay. Then we will get to the next question: What challenges do you see in the possible deployment of vertical farming in Botswana?

Interviewpartner 1

I think we have covered it previously. It is a very Western, I am sorry to say this again, it is a very Western ideology. So, I think it does not take into consideration for the local context. So, it is almost coming with something that is foreign and trying to plant it in and say, you must adapt rather than looking at what you both want to do. What are they good at? How do you design new systems or new solutions with the communities, you know, address their current challenges based on what they want to do? And then possibly now start to look for new opportunities for taking advantage of what is possible from the local context. And then technology comes in because the vertical farm is just the technology. That is all it is. So, but now you are imposing the technology and the community. So, this for me, uh, I would say that it is a nice to have, but it does not address the issue here, which is on a need to be more intensive, more intentional in the commercialization. And they need to be helped with now, addressing the core problem, which is how are they assisted to start and grow? So that does not necessarily mean vertical farming is the way to do it. It could be that they need help with even just how they transition to becoming commercial farmers and create solutions that address actual problems. So therefore, they are using agriculture as a vehicle to do that. And then, creating through clustering, whatever the model is, service models, whatever I am packing value chains to create job creation, create economic opportunity, and start to grow the industry. Agriculture has any input into GDP or the economy, as a driver. Yes. That is not to say it is not a good thing, but I just would like to say that is what I see as the biggest challenge here.

Jannik Endress

Another question: are you currently aware of any research projects or companies in the field of vertical farming in Botswana?

Interviewpartner 1

Um, yes, I am familiar with about four. There is a project in a village called (?Gumakwane). Somewhere in the eighties, some German came here, and he started doing a community project, but then over time the community stopped being involved. They wanted him to lead it. So, I do not know what the company name is, but when you are in the village of (?Gumakwane), as you are leaving the village, there's a vertical farming project, right there. There are also other projects. I think, through the layer incubated Len valley. Uh, so they have done a very good job on creating shade netting. And they started with shade netting, but they shifted to green houses. So, I do not know if they already moved into vertical farms, but they are moving in that direction. Um, there is also, I believe if I am not mistaken, there is a fish farmer in, in Casani. So, this fish farm is also now doing like an integrated farming, and vertical farming is part of that process. So, it is more into hydroponics. So, the wastewater from the fish production is coming in. They are doing tunnels and, a vertical farm is part of this process. And lastly, there is a lady, she is doing a vertical farming project in (? Sirueh). So, she is very well progressed. She is at the stage of launching. I do not know who our partners are, but she works as an agricultural policy specialist now, working with the government and the ministry of agriculture. So, she is also in very well-advanced and getting close to launching a vertical farm. It is installing now that she is installing and ready to launch. Oh, sorry. Last one. There is a company called go fresh. They are running a very impressive, I would call vertical farming project. They supply, I think most of the large retailers in Gaborone. And they also had a project where they are using vertical farming to do to show the farmers that you can create food through a shipping container. Yes. But again, it came back to the issue of you need electricity. You need water. So, all those input costs, no one helps you with.

Jannik Endress

Okay. And then to the last open question: Do you know other persons or stakeholders for whom the topic of vertical farming is interesting, or you can offer us a federal perspective for our project work?

Interviewpartner 1

Uh, persons or stakeholders here. Government is trying to address the issue of youth unemployment. So, there is a huge contingent of youth, especially women, young women who now are moving this direction of looking for using their talents. Somebody who was in was an accountant when their parents now are getting older, that they have farms and they, they need this. This is a job creator. They use the, the accounting program to take advantage of the opportunity that the parents have had, you know, and now they want to take it to the next level, because this is the inheritance. You have issues around people who are ready to retire. So, for example, somebody is working in a bank or within this work and now they want to exit and create like this. They want to take advantage of a farm that they have. So, women empowerment is a huge, huge, huge issue here. So, I think the likes of an NDB would be best placed. See, there will be the space to see who are the women who are working in industry, whether they could be working anywhere, but who now are looking to transition out, um, a huge aspect of stakeholders here in Botswana, the informal, the informal sector itself. Government wants to make sure that the informal sector is supported. So, I know UNDP assisted the ministry of trade within the informal sector recovery plan. And I know that agriculture sector is a huge focus of this. I know the ministry of environment, wildlife and trade is also looking at supporting because obviously agriculture affects environment is part and parcel. You are taking up wild land to create opportunity for, for agriculture. So, they want to make agriculture balanced with the environment. So, they made sure environment is also a key stakeholder, but I will say the informal sector. They have been traditionally seen as dependence looking for menial jobs, one thousand pula per month, but why they not being assisted to become self-employed. Um, I think the key last stakeholder here, which is quite interesting from a vertical farming perspective, I think would be local authorities. The issue is that building codes do not necessarily comply. You cannot use an industrial building for farming because the building control code does not allow you to. Which begs the question, if we are going to make more in addressing issues of urban spaces and buildings that are lying around cities and towns, why are you not addressing the issues of using buildings now as farm production? So, the building control code must change. So, the local authorities, the town, the town council, the city council, they are huge, huge stakeholders. You talk about food security in an urban context.

Jannik Endress

That is helpful and interesting. So, we will come to the last seven questions. These are closed questions, so you only must answer with a number. How would you rate the impact of climate change on agriculture and food security? One is low and 10 s high.

Interviewpartner 1

I would say eight. It is very high. Eight out of ten, but again, the only reason it is so high is simply because of the way we are doing it, it is eight, but it does not have to be that way. We should be taking advantage of the challenge to say, how do we transition this an opportunity? So, it is eight because agriculture has been affected.

Jannik Endress

Okay. Thank you. How would you rate food security in Botswana?

Interviewpartner 1

Uh, we are very insecure. It is going far as a three or four. I think three, because we do not produce anything, this is a huge risk. All the money went to importing food and buying medicine and things, but, you know, so we are very food insecure. So, I would say three.

Jannik Endress

Um, how would you rate the feasibility of a self-sufficient vertical farm in Botswana?

Interviewpartner 1

I would say five, simply because of the reason that it is a very foreign concept, so this is not necessarily the technology that is best suited for our climate. But again, the self-sufficiency comes in for the reasons of special economic zones looking at the region. And so, I will just sit in the middle and say five.

Jannik Endress

How effective do you think vertical farming is in a fight against climate change?

Interviewpartner 1

Um, I would say four. Simply because you cannot produce very much in it. People have crops that they are more interested in. So, it is limited in terms of what can be produced in vertical farms. Uh, if you cannot grow carrots, if you cannot grow all these other things. For me, I do not see it as very effective. So, I would go as slow as even three.

Jannik Endress

How sustainable do you think vertical farming is?

Interviewpartner 1

I would say a seven, but you would have to address the energy and the water. So, on itself is sustainable. So, I would say seven, but the reason I cannot go any higher is simply because you need to bring the power line to where you are, or you must install solar. So, the cost entry point of starting is high, but once you have started and you have the money, you good to go. You are very, so it is a seven, but yes, input costs and starting is the problem.

Jannik Endress

How sustainable do you think is the classical agriculture in Botswana?

Interviewpartner 1

It is not very sustainable, simply because of the climate action so I would even go as far as two, it is not very sustainable.

Jannik Endress

How effective do you think vertical farming is in securing food supply?

Interviewpartner 1

I would say a four again, I will come back to our diet. They can only address certain components, but overall looking at what people eat here. It is very different from Europe. I think you have been in our supermarkets, you see what we are eating, when you are at the side of the road, you will see what the person is ordering. And if you are not supplying that, then the vertical farm does not deliver. So, therefore I come back to the irrigation issue. If irrigation was the tool, technology that enables the super intensive irrigation, low water, that is what you need to be addressing and enabling people to participate in production, you know, as it is very simple in a box solar power, water, digital technology. And this little box can now make you super-efficient. It is connected to a smartphone. That will be the tool. The vertical farm is super, but I would dare say, not for our context, it may work in a regional context, but not necessarily based on what Botswana eat here and what they prefer.

Jannik Endress

How do you estimate the acceptance of customers for new types of cultivation such as vertical farming?

Interviewpartner 1

The acceptance of new types of cultivation will be high. We will be an eight or nine. The problem is what your question says, which is vertical farming. Then it goes even low. It goes to a four. If you said that estimate customers for new types of cultivation, that will be eight or nine, but vertical farming specifically, uh, high input costs. Uh, the local value chain, is really aligned supporting vertical farming as, as a vehicle. So even vertical farming, they, people creating the PVC pipes. Are they people doing the design or the so, I mean, there's whole value chain sitting here? So, if you can address that as well, that will be a huge issue. That will be huge opportunity. So, uh, but otherwise as a cultivation method and to address food security, uh, I would say four or five.

Jannik Endress

How do you rate the competitiveness of vertical farming compared to other types of farming?

Interviewpartner 1

I would rate it as a six, simply because once you have past the input costs and you would know what you are growing and you have your market, you are good to go. It is very, self-sustaining, low maintenance, everything else, but it's the start. The starting point is very, very high. Well once you have it, you are running. So, it is very competitive, but only once you start. And no one's helping. So, I hope you see the challenge of answering the question, because if you cannot get started, then it is not very competitive, but once you start, it is very competitive.

1.2 Qualitative interview with Interviewpartner 2, farmer in Botswana (from Europe) on 11/15/2021 in Maun, Botswana:

Jannik Endress

What are currently the biggest challenges for agriculture and food security in Botswana?

Interviewpartner 2

The first one is Water and the second one is the state of soil. I read the article from the university of Arkansas. They are big into agriculture. And I did research in Chobe, 10 years ago. And that conclusion was that the soil in Botswana was not suited for farming at all. These are the challenges: the water and the soil. And for me, what I also see is the old-fashioned way of farming. They cut all the trees and they remove all the grass. There is sand and they just put the seeds in it and wait till the rain comes. That is not productive. And, you know, after two or three years there's desert. On a small scale it works, but on a bigger scale, it is difficult. We have a lot of Bush. We have a lot of sand. Botswana is no agricultural country. Water is the biggest problem. We have water, but it is dried a long time and then it rains a lot. There is a lot of water in the grounds. I do not know how deep it is. I wonder why there is no investment in pumping water and give it to the locals. Because in our farm, we have a borehole which provides us with good water. But I have no idea why the government is not supporting this. Because people are still going to the river to get their water if there is water.

Jannik Endress

So where do you see the biggest problem that should be addressed?

Interviewpartner 2

I will think, but that is a guess, that it is the lack of education. So, to really know how to farm on this land and how to do it in a way, which is not a bad for nature. But for me, also a bit of a challenge is that the traditional Botswana people eat a lot of meat. But more and more people are getting to know different food like we did in Europe. You know, when we walk into a market, you can buy everything all over the world. This will happen when people get introduced to new fields, new greens and so on.

Hannes Borgwardt

What are the current impacts of climate change on agriculture/food security in Botswana?

Interviewpartner 2

What's going through my head as I am thinking of climate change, and everybody is seeing it is getting warm. I do not believe that it is getting warm. Because what we saw the last two years, you had a lot of rain. Also, this year we had already had rain. So, it has a positive impact, because if the rain comes the rivers get full, the ground gets more wet. I think it could be good for us, because the whole thing of getting warmer...I am not there yet.

Hannes Borgwardt

What do you see as the biggest challenges and disadvantages of vertical farming?

Interviewpartner 2

The initial investments and the return on investment. And the problem is still the education. Did you ever look at a world economic forum research that they do compare every country on several objects? So, Botswana is on the bottom of happiness, they are the bottom of education, and they are on the bottom of work ethics. So, work ethics is translated into laziness, which I do not believe, but it is about the culture of the way they look at work and being on time and how to work and finish things.

Jannik Endress Where do you see the biggest opportunities and benefits of vertical farming?

Interviewpartner 2

I think it could be helping us not to have to import everything from other countries and it could help us to grow more different vegetables and to farm on a bigger scale.
In rural communities where there is a lot of people and you have less land to grow your vegetables, it is a good thing. But in Botswana, I do not know.
Even if the money would be there. I doubt that the local people will adapt it.

Jannik Endress

What other approaches do you think can solve the challenges in agriculture?

Interviewpartner 2

You know, first, I think the government should look differently at agriculture. For example, they have incentives for farmers if they plow the fields. So, if you plow you get money, but you do not have to put anything in there. So, incentives are good. But if the incentives would be, if you grow that much of maize, then you would get that much money. But no, it is about plowing your fields. So, after it, nothing happens, so the incentives of the government are strange.
Another thing is that Botswana is not an agricultural country. We have other great things, but not agriculture.

Hannes Borgwardt

What do you think are the key technologies for a Vertical Farm?

Interviewpartner 2

What do you mean by that, the key technologies?

Hannes Borgwardt

The technologies needed to build a vertical farm

Interviewpartner 2

It would be great if you use sustainable materials. One thing we have enough and that's sun, so solar would be great if we have the right batteries to store all that energy. What would be interesting is how to provide clean water, so that you can use it for this technology, because we also have a lot of salty water in the soil. So, it would be interesting how you can turn salty water into usable water.

Hannes Borgwardt

What challenges do you see in the possible deployment of Vertical Farming in Botswana?

Interviewpartner 2

(talked about it before) education, money, work ethic – mindset. Vertical farming would be an opportunity to jump from old fashioned farming directly to a new way, without all the steps to take in between.

2. Quantitative interview on vertical farming in Maun, Botswana:

Interviews with 27 stakeholders from the following sectors: smart city, agriculture, university, gastronomy and hotel industry

Questionnaire:

1. How would you rate the impact of climate change on agriculture/food security?
2. How would you rate food security in Botswana?
3. How would you rate the feasibility of a self-sufficient Vertical Farm in Botswana?
4. How effective do you think Vertical Farming is in combating climate change?
5. How sustainable do you think vertical farming is?
6. How effective do you consider Vertical Farming in securing food supply?
7. How do you estimate customer acceptance of new farming methods such as Vertical Farming?
8. How do you assess the competitiveness of vertical farming compared to other types of cultivation?

Answer (Scale 0 -10)	How would you rate the impact of climate change on agriculture/food security?	How would you rate food security in Botswana?	How would you rate the feasibility of a self-sufficient Vertical Farm in Botswana?	How effective do you think Vertical Farming is in combating climate change?	How sustainable do you think vertical farming is?	How effective do you consider Vertical Farming in securing food supply?	How do you estimate customer acceptance of new farming methods such as Vertical Farming?	How do you assess the competitiveness of vertical farming compared to other types of cultivation
Scale	1 = low 10 = high	1 = insecure 10 = secure	1 = low 10 = high	1 = not effective 10 = very effective	1 = not sustainable 10 = very sustainable	1 = not effective 10 = very effective	1 = low acceptance 10 = high acceptance	1 = not competitive 10 = very competitive
1	0%	0%	5%	0%	0%	0%	5%	0%
2	0%	15%	5%	0%	0%	10%	20%	0%
3	0%	35%	30%	10%	0%	15%	25%	10%
4	0%	30%	10%	30%	15%	45%	25%	10%
5	5%	15%	30%	25%	30%	10%	10%	25%
6	0%	0%	15%	15%	20%	10%	5%	20%
7	10%	0%	5%	15%	20%	0%	5%	15%
8	50%	5%	0%	5%	5%	0%	5%	15%
9	20%	0%	0%	0%	0%	0%	0%	5%
10	15%	0%	0%	0%	0%	0%	0%	0%
Average	**8,3**	**3,7**	**4,2**	**5,1**	**5,7**	**3,9**	**7,7**	**5,9**