The Potential for Plant-Based Meat in Africa - A Proposed New Approach using a System Design Methodology

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Abstract

This Thesis explores the potential application of new plant-based protein technologies to Sub-Saharan Africa. It demonstrates the use of a system design methodology to evaluate, assess and select a new approach to protein production.

This is an important topic, because global protein production systems are under pressure to reduce their environmental footprint. It is an interesting topic right now, because new protein technologies are emerging which have the potential to soon disrupt industrial livestock farming.

The system design approach means thinking in terms of protein production as a system consisting of individual parts (farms, value chain, retail outlets etc.) and their interactions, which together deliver value to the protein consumers. The stakeholders and users of the system are analyzed in order to understand and prioritize their needs in terms of the system goals. This approach allows us to creatively examine the individual parts for alternatives, whilst assessing expected system performance in terms of the overall value delivered over time.

The Thesis focuses on Africa's fast-growing and fast-urbanizing populations with their growing demand for protein. A common operating factor is malnourished populations, due to diets based on low-quality plant sources, and existing protein production systems which are inefficient, unsustainable and harming the environment. The work thoroughly analyses published research on the technical and operational aspects of new and old protein production. Interviews were conducted with experts in both protein and Africa. The comparison of new techniques for producing proteins suggest that new plant-based methods have the most immediate potential.

The proposed system is based upon three simple ideas, which together lead to an interesting outcome:

- Product Platform Architecture - firstly, a product should use a Platform Architecture in order to keep development costs low, and yet allow the product to be adapted to different local markets in Africa
- Franchise Model - the best way to achieve scale is to work with local entrepreneurs through franchising, an approach which enables allocating responsibilities and risks within the system hierarchy
- Lean Operating Model - finally, the operating entity has to be exceptionally lean by design, in order to ensure an affordable product for consumers – an idea known as a Base of the Pyramid (BOP) strategy

A case study of Southern Nigeria illustrates the concept.

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The idea of alternative proteins is still in its infancy, and their application to Africa is even more so. It will be interesting to watch the topic will evolve in interesting ways over the coming decades.

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Chapter 1

Introduction: The Challenge of Protein Production in Africa

New ways to produce meat but without livestock are emerging. Can they be used to meet the needs of a growing population in Africa? This thesis aims to answer that question, by using a System Design Methodology to proposes a potential new design of a system. It uses Nigeria's booming population and growing demand for meat, as an interesting case study for exploration.

Why is this interesting, and why now? Well if true, then Africa may be able to 'leapfrog' over developing an industrial livestock complex, and at the same time reduce malnutrition and environmental emissions. This type of technology 'leapfrog' has happened before – a couple of decades ago, Africa built a mobile phone network, without ever having invested in expensive fixed-line telephones. These cheap mobile communications accelerated development in fields far beyond telecoms.

1.1 The existing protein diet and the challenge of population growth

Most dietary protein in Africa today is low quality, and comes from starchy crops which are grown by smallholder farmers. These grains, such as maize, rice, or sorghum, are high in carbohydrate energy, but low in protein and are nutritionally incomplete. Some protein also comes from beans – a better source of protein but can be harder to grow. A limited amount of protein is available straight from nature - fish near water sources and bushmeat near forests. (Bushmeat is the term for wild animals which are caught or hunted for food.) Meanwhile, the wealthier people can afford nutritious proteins like farmed meat, milk, or eggs.

Even when population densities were much lower, these protein sources overall didn't provide sufficient nutrition. Now, Africa's population could quadruple by the end of the century, and incomes are rising, so the demand for protein is growing fast (United Nations DESA 2019). Production systems need to produce more to keep up, but today's systems are simply unscalable.

Being a small protein producer in Africa is tough. For example, small farmers face so many economic challenges, that it's no surprise that they don't progress out of poverty, and their youth are increasingly moving to the cities. The most familiar challenge is the rains, which every year seem to be getting less reliable, leading to low-level migration, for example increasing numbers of small farmers are moving from the dry South of Zambia to the wetter North. Another challenge is the highly acidic soils all over Africa, which really need a large application of agricultural lime to be productive – which is, alas, economically unviable. Perhaps the biggest challenge though is that the price of the commodities produced is really set by ultra-efficient production in the US or Brazil – meaning most small farmers never actually make a profit. To top it off, bigger families mean that small plots are continually being sub-divided between siblings, making plot size smaller and smaller.

Life is no better for small hunters and fishermen who are increasingly fighting over decreasing natural resources. The West Coast of Africa was once one of the most productive in the world is now under-controlled and over-fished to the point of collapse (BBC 2018). In some places, fishermen also have to compete with ultra-cheap frozen fish which is imported from China and can be sold below the costs of local production (Dijkstra 2019). It's a similar story with bushmeat hunters who are trying to make a living from increasingly empty forests and are facing increasing controls due to the risk of zoonotic diseases – viral diseases which can jump from animals to people, such as Covid-19.

Covid-19 has raised awareness of zoonotic diseases, but they are not new - there have been nearly twenty separate outbreaks of Ebola in and around the Congo Basin since 1976 (United States CDC 2020). The risks today though are much higher, as population densities increase, and the world is more globally mobile. A DNA testing study undertaken over the last fifteen years in the Congo Basin tested 3,561 wild mainly bats, rodents and primates, found 121 contained strains of coronavirus – some known and some new (Kumakamba et al. 2020).

In short, there are not any good sources of protein in Africa, and expanding any of the existing methods will have environmental impacts with global impact. So, why not simply adopt the commercial farming model which has been successful elsewhere? Well, the answer is not straightforward.

1.2 Around the world, livestock agriculture is being disrupted

Rightly or wrongly, consumers around the world are unhappy with livestock, and its environmental impact. The science is complicated, and the societal issues even more so, however the emerging consensus is that livestock produce too much greenhouse gases. Consumers are demanding 'cleaner' foods, better animal welfare and less water used. In response, food technologists are busy developing new alternative proteins – mostly which don't use animals. They aren't yet very convincing but every day they are improving. In my view, within 30 years, there will be a tipping point where these displace the majority of livestock protein.

But what are these new 'alternative' protein technologies? There is a vibrant research environment, and four distinct approaches have emerged:

1. Cellular Agriculture means growing meat cells in a laboratory. It's very new, very expensive and requires a lot of energy.

2. Fungi Proteins are selected strains of fungi, similar to yeast, which are grown in a bioreactor and fed on glucose – an industrial method which has been around for a long time.

3. Insect Protein – methods are being developed to farm insects safely, and cost-effectively. They are already widely consumed in Africa.

4. Plant-Based Meat (PBM) is an approach to mechanically transform plants into something which looks and tastes like meat. It's the current commercial success in the developed world.

Are they better than existing proteins? Figure 1 compares environmental cost (vertical) against a combined Desirability and Usefulness attribute (horizontal). This is based on my research and a scoring estimate, however it's clear that PBMs have the most potential and could even lead to a pareto shift.

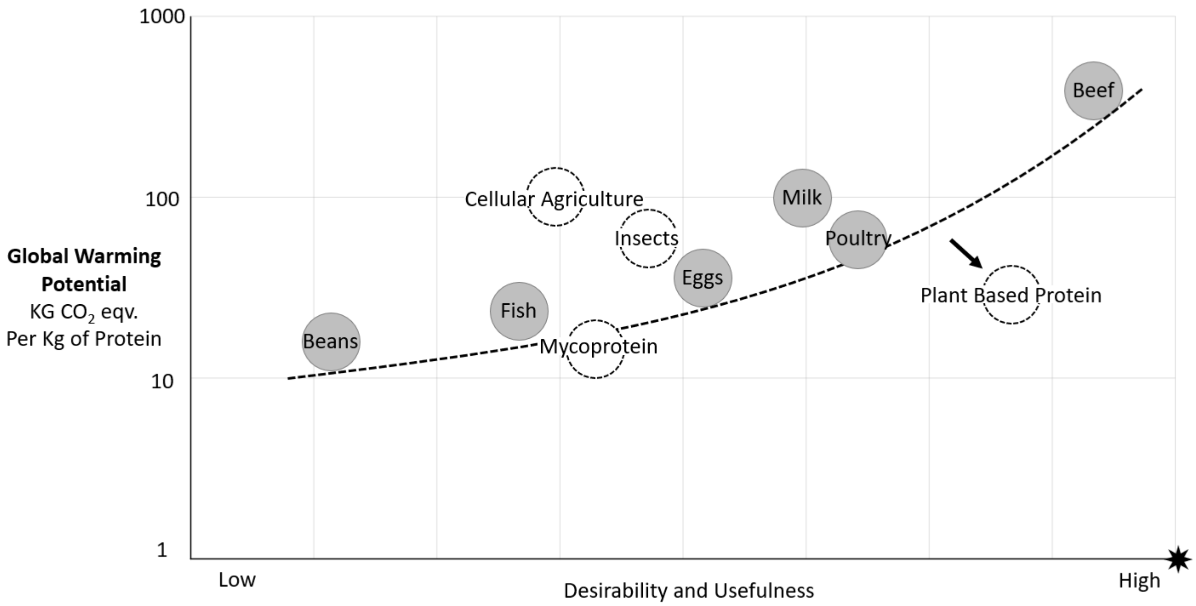

Figure 1 - Trade study below shows existing protein sources, plus four new types of protein.

Chapter One concludes by identifying the potential for plant-based meat (PBM) in Africa. Following chapters will explore the practicality of using PBMs In Africa, and consider a new system architecture for protein production which could both reduce environmental impact and increase nutritional outcomes:

- Chapter 2 – Protein and its Production – the background dietary protein and where it comes from, as well as the challenges with current methods and the need for change.
- Chapter 3 – Africa and its Growing Population, especially the challenge of feeding the population, and why Nigeria is an interesting use context to study.
- Chapter 4 – Finding the System Design Alternatives - analysis, through which system design considerations will be identified.
- Chapter 5 – Evaluating Major Design Options. What set of options will create a system most likely to meet user needs and achieve the best performance over the system lifetime?
- Chapter 6 – An Exploration of the new System Concept - how the selected architecture can be implemented and operated, and what value it should deliver to the stakeholders.

Chapter 2

Protein and its Production

This chapter presents the background to dietary protein, challenges with the current methods and the need for change as well as the new approaches. The chapter is presented in six parts:

- Protein in our diets – how protein moves from plants, to animals, to humans
- Protein malnutrition in Africa – a history and the state today
- Livestock agriculture, its impact on the environment and public perceptions
- Protein production as a system – including the pioneering of new methods of production
- The four new approaches to transforming protein
- The important value proposition of plant-based meats (PBMs)

2.1 Protein in our diets

Our bodies need protein to build and repair cells and carry out many other functions. Protein consumption is correlated with the body's growth and functioning. For example, between 1810 to 1890, the average height of western men grew from 5'6" to more than 5' 10" due to a better diet and greater meat consumption (Lauden and Pobiner 2020).

Protein are strings of amino acid molecules, which are fold up into specific forms to carry out different functions. The human body only uses about 20 specific amino acid molecules, but they are used in different sequences and folding patterns to make the approximately 75,000 different types of proteins that are needed for the human body to function (UniProt 2020).

These 20 amino acids are found in many plants and animals, and by eating them we acquire these amino acids for our bodies. The proteins are broken down by our livers, and the amino acids building blocks are carried by the bloodstream to wherever they are needed in our bodies. In effect, amino acids cycle between organisms. So how are amino acids originally made? Well, they're made by plants during the photosynthesis process, but we will discuss this later.

Humans need a balanced diet with all of the amino acids and in the right proportions, and if we don't get it then within a few days, our conative and physical ability declines dramatically. This was discovered in the 1950s by Professor William Rose who identified and categorized which amino acids are essential for humans, as well as the effects of not eating them. Rose concluded that only nine of the amino acids were really essential, as the human body could self-manufacture the others. During Rose's experiments, graduate students were fed diets that were engineered to eliminate one amino acid at a time. The experiments found that when an amino acid is missing, symptoms can occur very rapidly, in one experiment "*it became evident by the end of the 4th day of isoleucine deprivation, that the subjects were approaching the limit of their endurance, and that the missing amino acid must be returned to the food without further delay*" (Rose, Haines, and Warner 1951).

Key Insight: If we humans don't get a balanced diet with all of the amino acids, then within days we suffer under-performance of conative and physical ability, which will soon become lasting effects.

How do we measure protein in foods? For example, we know that eggs are rich in protein, but what metric will tell us this? Well, firstly, is the simple content of protein by mass, so for example, an egg contains about 13% protein. The second measure is less straightforward which is a measure of the protein's quality and accessibility to humans. To measure this, food technologists use a measure called PDCAAS (Protein Digestibility Corrected Amino Acid Score) which is on a scale of zero to one. So, for example, lard doesn't have any protein so the PDCAAS for lard = 0, whilst peanut = 0.5 and the excellent protein in egg = 1.

Key Insight: The protein usefulness of a food can be expressed by two attributes, firstly as percent (%) protein content, and secondly in terms of protein quality (PDCAAS) measured on a scale of 0 to 1.

What else do Proteins do? As well as providing nutrition, proteins also have useful functional characteristics as food ingredients, for example, eggs ability to foam when whipped comes from the ovalbumin protein, whilst the silky texture of dairy products comes from whey protein. These functional characteristics are hard to replicate, although scientists are trying to create synthetic versions of these functional characteristics. This thesis however focuses on the dietary aspects of protein.

2.2 Protein Malnutrition in Africa

Since the 1930s it has been known that protein deficiency is a problem across Africa. It commonly causes stunting and impaired cognitive ability (as found in Rose's experiments) and in extremis leads to a disease called Kwashiorkor, which is recognizable from the children with a swollen belly as seen on TV. Protein deficiency is largely caused by poor diets that rely on a single plant (e.g. maize) and the fact that any one plant is an 'incomplete' source of protein and so deficient in some amino acids – for example, maize is deficient in the amino acids lysine and tryptophan (Lunven 1992). One solution is to combine plant types to create a complete amino acid profile, for example, combining beans and maize creates a complete protein profile. This sounds simple but is surprisingly hard to do practically in much of Africa.

This plant-mix approach is that taken by humanitarian organizations which have developed many porridge-like products, the most common of which is corn-soy-blend (CSB). These products were pre-mixed, pre-cooked, and have added vitamins, and usually contain a fat too. Sometimes they would contain milk powder, or groundnuts or wheat protein, and often based on commodities that the donor country produces in excess. Some of these complete-protein blended foods have also had commercial success as consumer products, especially for use to feed young children, whilst many have failed (Shurtleff 2004).

It appears that these formulated food products can only be successful in the long run and commercially if they are desirable (e.g. taste, texture). It is a monumental task to convince consumers about the health benefits of something which is unfamiliar, as market development consultant Erik Simanis explains in a 2018 Washington Post article "*larger companies, including DuPont®, Pepsi® and Danone®, have attempted to launch dozens of these formulated protein foods in low-income markets. Almost all failed so completely that the companies never publicized them — a casualty of the marketers' inability to* *persuade low-income consumers, including many who can't read, to switch to unfamiliar products with unclear health benefits*" (Dewey 2018)

Key Insight: In Africa, people may get most protein from a single plant source, typically lacking in amino acids. Porridge-like corn-soy-blends have been a humanitarian approach to improving this.

2.3 Livestock Agriculture; environmental impacts and public perception

A decade ago a UN report 'Livestock's Long Shadow' criticized livestock's greenhouse gas emissions and triggered todays negative public sentiment. The report claimed that livestock was accountable for 18% of greenhouse gas emissions (Steinfeld et al. 2006). This was later revised down to 14.5% (Gerber 2013) but still, the widely-quoted comparison "*more greenhouse gas emissions than all transport combined*" really shocked public opinion, triggered demand for environmentally friendly protein and created the motivation for the new alternative protein technology companies.

How are emissions measured? Greenhouse gasses (GHG) are measured in terms of 'Global Warming Potential measured in CO_2 Equivalent' or sometimes shortened to GWP in CO_2e. The reason that it has to be converted to 'CO_2 equivalent' is that actually there are three different greenhouse gasses: Carbon dioxide (CO_2), Methane (CH_4) which has a x25 potential to warm the atmosphere and Nitrous oxide(N_2O) which has a x298 potential to warm the atmosphere (Brander 2012). All three gasses are created by livestock, but enteric methane (cow burps) is the worst. Land Use Pasture Change is also significant – this comes from carbon released by cutting down trees to make new pastures.

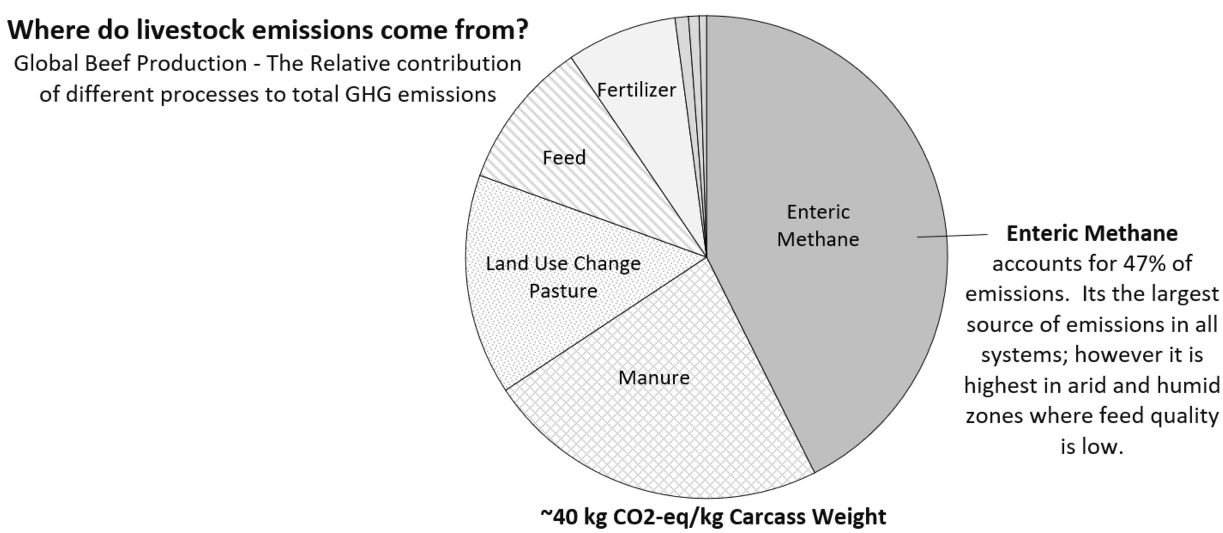

Figure 2 - Enteric Methane is the cause of most livestock emissions (Opio and Gerber 2012).

Recent studies that have compared the emissions from different types of farming systems, for example, feedlot, pastoral, mixed, smallholder etc. It has been found that smallholder production (the dominant system in Africa) is the worst culprit. In smallholder production, livestock are not fed intensively and so take many years to reach maturity, creating a lot of methane in the process.

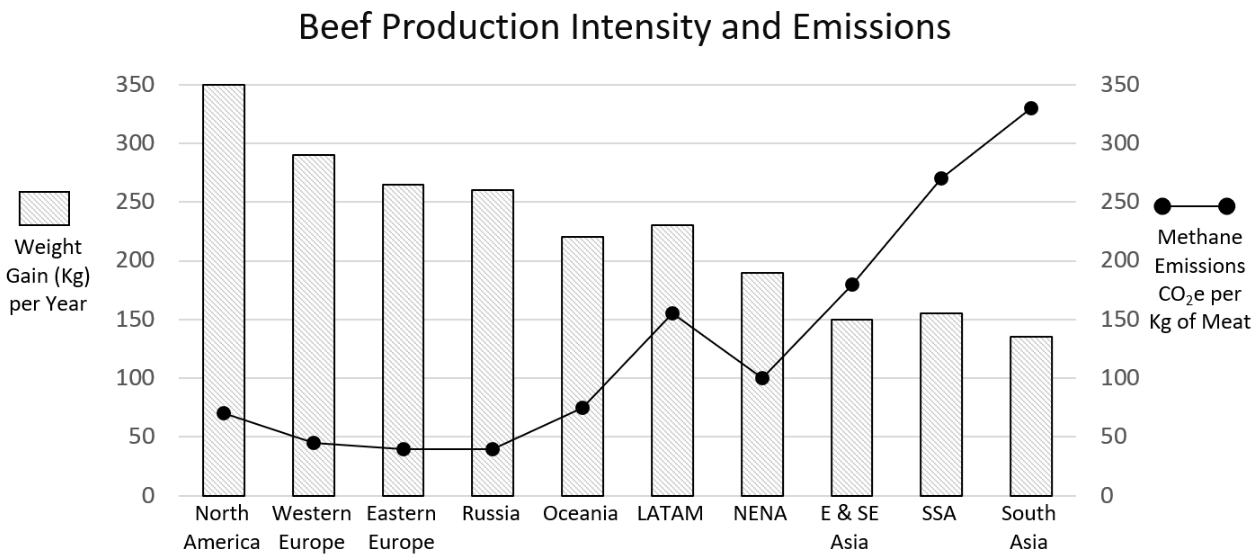

Figure 3 - Sub-Saharan Africa (SSA) creates the most methane (Opio and Gerber 2012 Figure 25a).

Key Insight: Public opinion has turned against livestock due to emissions, and smallholder livestock in Africa, is the worst form of production with the most emissions on a per unit of production basis.

So, do the new plant-based meats (PMBs) have a better environmental profile? Yes, a beefburger has a foot print of about 3Kg of CO2 Eq. whilst the equivalent plant-based burger has 1/10 of that (Heller and Keoleian 2018).

2.4 Protein production as a system

Making protein for humans to eat generally consists of two stages – firstly synthesizing the amino acids, and then secondly transforming the amino acids into useful forms of protein that we can eat. Figure 4 maps these functional steps.

The first step is synthesis of amino acids happens naturally by plants during photosynthesis using oxygen, carbon, nitrogen and hydrogen. It's also possible to artificially manufacture amino acids in industrial processes for use as ingredients, animal feed or for other uses, although this method is less common than more efficient plant production. The second step is transforming the amino acids into proteins which we can eat. This is done by plants who turn amino acids into proteins stored in the plant's seeds, leaves, stalks and roots, which we can eat. Sometimes these plants are eaten by animals and metabolized into animal protein, which we generally find tastier and more useful.

Some people in the developed world choose to eat a plant-only diet (vegetarians) but it's easy to do when supermarkets stock a huge variety of plants all year round. In Sub-Saharan Africa it's a very different story – it would be technically hard, expensive, and time-consuming for most of rural Africa to grow a balanced, year-round, plant-only diet. Therefore, most people in Africa don't have the luxury of dietary choice, and so they survive on a single crop (e.g. maize) and supplement with any other protein when they can afford it (Schönfeldt and Hall 2012).

Animal proteins have been part of our diet forever – earliest evidence suggests that 3.4M years ago our ancestors started to eat large mammals, whilst 1M years ago we first started to cook meat and then about 15,000 years ago is the first evidence of domesticating animals for meat (Lauden and Pobiner 2020). Consuming animal proteins is advantageous as it is a complete amino acid profile, and also allows us to store proteins for the winter, or move them around with us. Animal protein also tastes better, is satiating and has useful cooking properties.

Key Idea: A healthy plant-only diet is a developed world luxury, and only possible when you can access many plants year-round. This is too hard and expensive for most people to achieve in Africa.

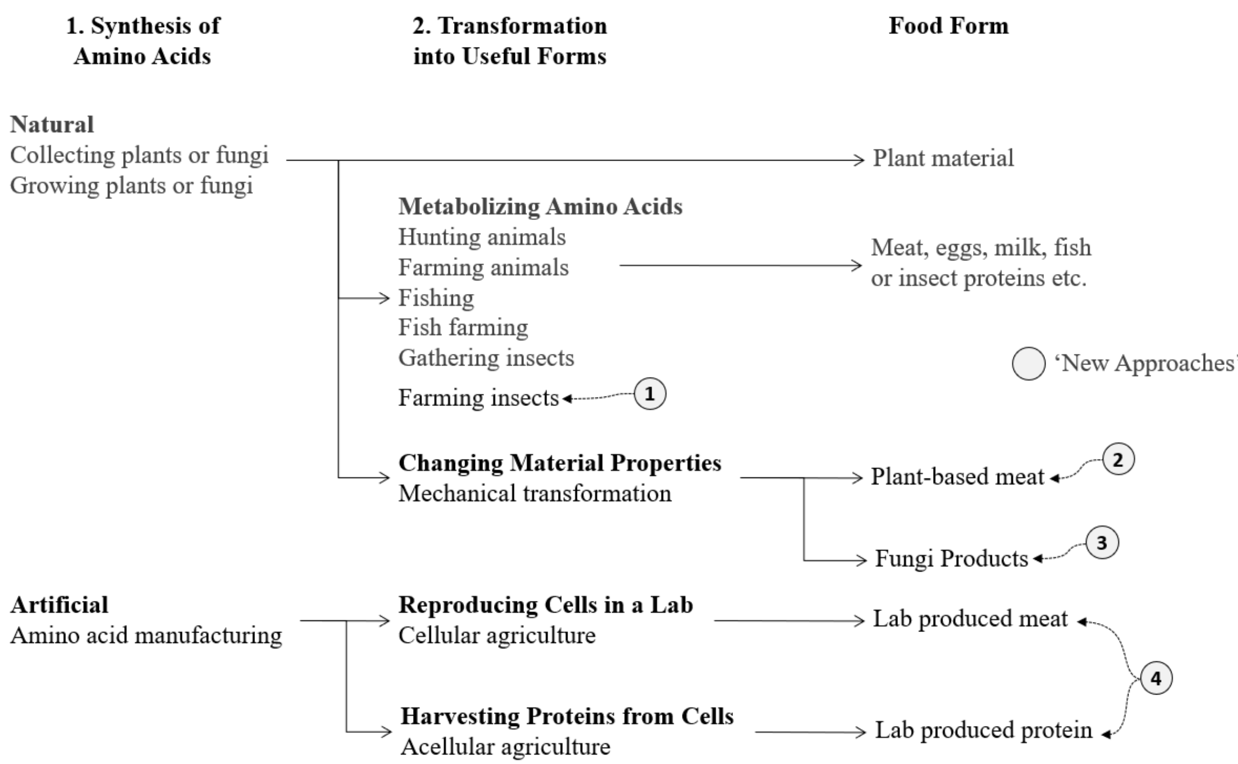

Figure 4 - Different ways of Synthesizing Protein, and then Transforming it into useful forms.

2.5 The four new approaches to transforming protein

① Farming Insects. New techniques are being developed to farm insects (like crickets, mealworm or black soldier-fly larvae) which can be eaten whole or more commonly ground up into flour. The main advantage of farmed insects over traditional livestock is low-emissions and high feed-conversion ratio –

crickets have an excellent feed-ratio of 1.7 compared to 10 for beef (Oonincx et al. 2015). Another attraction is that insects can be fed on agricultural or food waste.

Whilst insect farming is being researched around the world, including in Kenya and South Africa, it is not yet possible to achieve an economical product. The main challenge is that feeding insects on biological waste leads to a highly variable product, including anti-nutrient properties (compounds that interfere with nutrient absorption in humans) which can negatively affect human health. Therefore, today producing safe insect protein can only be done using expensive feed, which makes the whole process uneconomical. (McClements 2019)

② Plant-based Meats (PBM). The goal here is to produce convincing meat-like material by transforming the material properties of plants directly using mechanical technologies. Several impressive products have been brought to market in the last couple of years. The predominant form is ground-meat-like products (i.e. burgers) but the longer-term goal is to produce whole-form meat-like products (i.e. steak) but this is still in research.

It should be recognized that basic approaches to this have been around for a while, but without much commercial success. For example, Textured Vegetable Protein (TVP) is a cardboard-like ground-meat product made of extruded soy, but as I learned from a food entrepreneur in Africa, this produce is almost taboo across Africa due to its terrible taste. The recent commercial success has come from similar, but much improved techniques.

③ Fungi Products. These are tiny fungi microorganisms which are high in protein and can be grown in bio-rector tanks, and fed on glucose. The end product can be shaped to look like different types of meat. So far, there has only been one commercially successful product - mycoprotein (marketed as Quorn™). It was developed by Rank Hovis McDougall (RHM) in the 1960s during a period of (mistaken) Malthusian belief that the world was about to undergo a massive protein shortage. It's a highly fibrous strain (*Fusarium venenatum*) which eventually found a small but loyal customer base of vegetarian lifestyle consumers (Trinci 1992). Sales have been growing since the 1970s and by 2018, the company had the capacity to produce 40,000 MT/Year. Today, the search is on for newer or more efficient strains which can be more efficient in their production.

The main challenge of fungi as a protein source is that it requires a large and specialist industrial manufacturing facility. Another challenge is that the existing product Mycoprotein needs to be refrigerated. Neither of these make it suitable for Africa today, nevertheless it has future potential.

④ Cellular Agriculture. Over the last decade, scientists have developed the ability to grow meat cells artificially in a laboratory. It's not a new idea, in 1931 Churchill proclaimed *"...we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium…".* Whilst the whole approach sounds futuristic, insulin and rennet have been produced this way for decades. There are two variations, firstly, 'Cellular Agriculture' aims to grow meat cells, whilst 'Acellular Agriculture' aims to grow animal cells, but then harvest functional proteins which are produced by the cells (e.g. milk casein or egg albumin).

However, it's still very early days for cellular agriculture; whilst it has been proven in the lab, it is still too expensive. Some very expensive hamburgers have been produced, but only really for publicity reasons. In an interview in February 2020, an industry expert told me that most CEOs are saying "*5 years to market and 10 years to cost parity with animal meat*". The reason for the holdup is that the process uses a product called fetal bovine serum (FBS) as a growth medium. This FBS can only be sourced from a cow fetus collected at the slaughterhouse, so is cost-prohibitive (van der Valk et al. 2018). Researchers are searching for a cheaper synthetic FBS, and in the meantime, this technology clearly has no place in Africa.

Key Insight: Despite some very active research, it seems that cellular agriculture, fungi and insect protein are currently impractical or too expensive for commercial use, especially in Africa.

2.6 The important value proposition of plant-based meats (PBMs)

The reason why PBMs have suddenly been successful is the coming together of three simple ideas, which together produce something more powerful than the parts. In the systems world, it is called 'emergent value'. These three ideas which underpin the success of PBMs are:

- **Nutritional Profile**: PBMs combine plant proteins to create a complete profile – this is the same idea as the corn-soy-blend (CSB) used for humanitarian purposes. For example, BeyondMeat® combines wheat, soy and potato to achieve a PDCAAS score of 0.95 so higher than beef which is 0.92 (Impossible Foods 2020).
- **Meat Texture:** PBMs use twin-screw extrusion machines to extrude protein powder and form a texture like ground-meat. This is a well-known idea - textured vegetable protein (TVP) has been made by extruding soy for decades, but how come todays product is so much better? Well, it's the use of the twin-screw extruder, rather than the traditional single-screw extruder machine, as well as a carefully planned protocols of heat, moisture and pressure during machine operation (interview with food science graduate student students June 2020). Figure 5 shows the interesting nano-scale protein transformation which happens during the extrusion process.
- **Meaty Taste:** This final attribute has been achieved by Stanford Professor Patrick Brown and his Impossible Foods® company. He identified an iron molecule called heme as being responsible for the meaty taste in meat, and developed a recombinant DNA biomanufacturing protocol so it could be used in the Impossible Burger®. Interestingly, recombinant DNA has been used for decades in foods and has Generally Regarded as Safe (GRAS) status, meaning it doesn't need FDA approval. Regardless, to be sure, Brown submitted extensive safety studies for approval to the FDA who raised no concerns (United States FDA 2019) meaning it can be freely manufactured and sold in the US (other countries will likely follow).

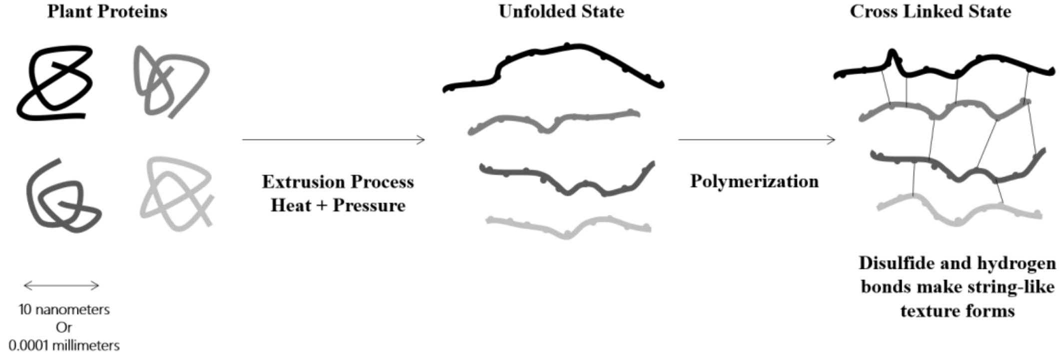

Figure 5 - The extruder re-aligns the plant proteins at a nano-scale to give a linear form to PBMs

The ultimate goal of plant-based technologists is 'whole meat forms' (such as steak) and likely to be achieved with 3D printing or layering technology. I undertook an interview with a strategist at Nova Meats in Barcelona which is on the leading edge of 3D printing of plant-based foods to create realistic whole-form meat products. Their approach effectively uses a desktop 3D printer, and can be used for pork, seafood etc. It's still several years away from even the high-value markets – in Africa it will be likely on the medium-term horizon only.

Key Insight: Plant-based meats have been successful by focusing on the texture, taste and nutritional value of meat. This approach shows the most potential for use in an Africa context.

Table 1 - Summary Protein Sources Data (McKinsey Global Institute 2019)

	Cost $ per Kg Protein	Protein Quality PDCAAS	Environmental Impact
Beef	40	0.92	High
Poultry	30	0.91	Medium
Insect Protein	41	0.73	Low
Soy Protein Isolate	2	0.96	Low
Mycoprotein	13	1	Medium
Cellular Meat	300	0.92	High

Summary of Key Insights from this Chapter

- If humans are missing any one of the nine essential amino acids, within days they will suffer a dramatic under-performance of conative and physical ability.
- The protein content of any food can be expressed by two attributes, firstly as percent protein content, and secondly in terms of dietary availability (PDCAAS) measured on a scale of 0 to 1.
- In Africa, people may get most protein from a single plant source, typically lacking in amino acids. Porridge-like corn-soy-blends have been a humanitarian approach to improving this.
- Public opinion has turned against livestock due to emissions. Smallholder livestock in Africa is the method of production with the most emissions on a per unit of production basis.
- A healthy plant-only diet is a developed world luxury, and only possible when you can access many plants all year round. This is too hard and expensive for most people to achieve in Africa.
- In Africa, people may get most protein from a single plant, which may be lacking in amino acids. Humanitarian approaches to protein-energy malnutrition have led to porridge-like products.
- Despite some very active research, it seems that cellular agriculture, fungi and insect protein are currently impractical or too expensive for commercial use, especially in Africa.
- Plant-based meats have been successful by recreating the nutritional value, texture and taste of ground-meat. <u>This approach shows the most potential for use in an Africa context</u>.

Chapter 3

Africa and Nigeria

This chapter provides explores Africa and it's growing population, especially the challenge of feeding its growing population, and why Nigeria is an interesting use context to study. The chapter consists of:

- Africa, and the coming population growth – one to four billion people in the rest of this century
- A Proposed segmentation to describe the population
- Nigeria, and why feeding the fast-growing population is a particular challenge
- Agroecological and Demographic Profile of Nigeria
- The Nutritional Situation in Nigeria

3.1 Africa and the coming population growth

Africa will account for most of the world's population growth over the coming decades. The present population of Africa is just over one billion, and mainly young people - sixty percent under the age of twenty-five. By 2050 the population will double and by the end of the century, the population of Africa will have doubled again to four billion (United Nations DESA 2019).

Just less than half of Sub-Saharan Africa's population live in cities, but the continent is rapidly urbanizing. This move to the cities is not planned by any government, but instead a movement of people who realize that they are economically better off living in a city than living in a rural area. It is believed that the urbanization rate is correlated with GDP – a study in 2016 showed that urban GDP/head was $8,200 versus $3,300 for rural (McKinsey Global Institute 2016). People who move to the cities participate in low-level economic activity which pays cash such as being day-laborers or security guards. They live-in low-cost housing and lack the space to grow food as they could when home in rural areas.

Key Insight: During the rest of this century, Africa's population will continue its transition to become larger, wealthier and more urban. It will move from traditional, towards consumer lifestyles.

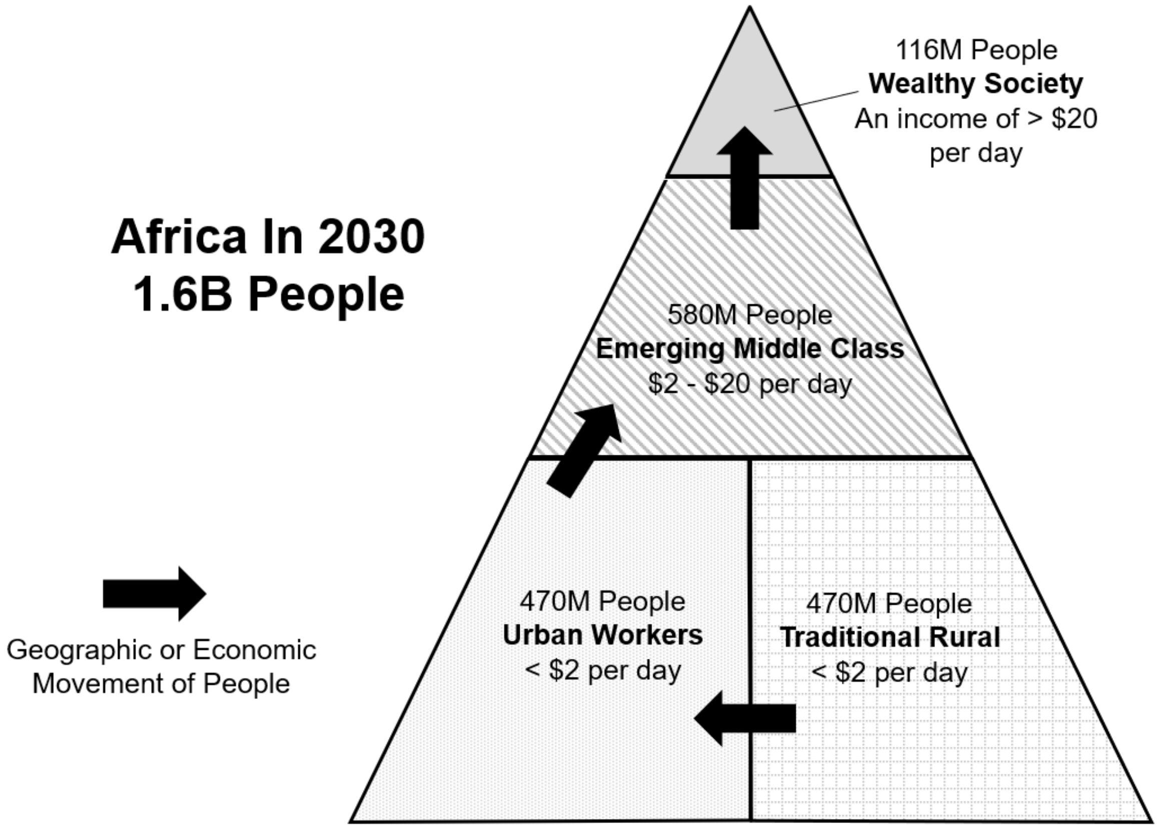

Figure 6 - My expectation of socio-economic drift to cities and higher income (Deloitte 2016)

3.2 A Proposed segmentation to describe the population

It may help to understand the demographics of Africa through the simple segmentation in Figure 6. Please note that the segmentation descriptions below are based on the author's experiences of living and working in Africa and serve only as a basic representation to support discussion later in the thesis.

The first segment is the **Wealthy Society**, characterized by earning over $20 per day, and by 2030 this segment will consist of about 116M people across Africa. The Wealthy Society segment earn a salary which is paid on a monthly cycle, probably own a house and lead a consumer lifestyle similar to the developed world. This segment will buy food through restaurants or supermarkets, and will likely buy branded goods. They are able to eat animal protein whenever they like. Food will be prepared at home in a modern kitchen with refrigeration, and may be prepared in traditional or global forms. Their values and concerns may reflect global issues such as global warming, income inequality or animal welfare. Their aspirations would be familiar to any global consumer, such as children's education or homeownership.

The **Emerging Middle Class** is a segment of consumers with an income of between $2 and $20 per day and will consist of about 580M people by 2030. This is an exciting segment that is driving economic growth across Africa. The people in this segment may be paid on a monthly cycle, may rent or own a small modern house and own a car. They will likely buy food from supermarkets or retail shops and may choose packaged or processed foods. They frequently consume animal protein and likely have refrigeration at home They may remit cash back to relatives in a rural village. They will aspire to lead a modern consumer lifestyle, and get a good education for their children.

The **Urban Workforce** is my name for a fast-growing segment of first-generation immigrants to cities and who are responsible for the huge growth in urbanization, and by 2030 will represent 470M people. This new Urban Workforce segment earns less than $2 per day and likely live on a daily cash cycle. They will live in large areas of basic housing. Spending on food will depend on cash earnt that day, and they may buy street food, or basic ingredients to prepare at home. This segment will be faced every day with consumer lifestyles, and this forms the basis of their aspirations. Their concerns are focused on a daily rhythm – will they find work today. They may send any spare cash back to relatives in rural areas. This segment will have much more immediate concerns than worry about the impact of global warming.

The **Rural Traditional** Segment represents the traditional village base in Africa, and by 2030 will consist of 470M people. The segment will earn the equivalent of $1-2 per day from mainly farming or fishing activity, and so income will be tied to seasons of nature. They may also earn cash income from remittances from relatives in the city, although a lot of their consumption will be outside of the cash economy. Most food will be grown or traded locally, and diet will heavily depend upon local factors, for example, farmers will eat maize or sorghum, whilst fishermen will eat a lot of fish, so likely to lack nutritional variety. Their concerns will be seasonal, for example a failed harvest and insufficient food, or a fishing source drying up. This segment may have values based on traditional culture or beliefs, which may include values or beliefs about food and meat.

Key Insight: The newly-urban population is a fast-growing segment with cash and who appears to have an unmet demand for protein. This thesis should focus on this segment as protein consumers.

3.3 Nigeria – an interesting case study for this thesis

Nigeria's population is expected to double in 30 years from 200M to 400M, so becoming the World's third most populous nation (United Nations DESA 2019). 70% of the population is below the poverty line (Nigerian National Bureau of Statistics 2019) and quickly urbanizing. The economy is diverse and buoyant, with oil consisting of 10% of GDP, but the majority of exports.

In Nigeria, protein consumption on average meets recommended levels, although is unequally distributed so a significant part of the population is protein-malnourished. Figure 7 shows most protein comes from sorghum and maize, but these three cereal crops are deficient in the amino acids tryptophan lysine and threonine (three amino acids which are all found in legumes). Fish provide 3.3MT of protein annually, partially from fish farming, but mostly from fishing of the coast of West Africa where stocks are near collapse (BBC 2018). The North of the country has traditional pastoral livestock, and in the south, commercial poultry and pig enterprises are growing fast due to demand from wealthy urbanites.

Bushmeat is an interesting case, but not much is known about it. It is hunted and consumed each year near to rainforest areas, and the volume is estimated at between 1MT and 5MT each year (Fa, Peres, and Meeuwig 2002) and this is consumed both by the poorest, but increasingly as a luxury food. As a WWF bushmeat expert explained to me in an interview in May 2020 "*there is growing huge demand for it from urban areas, and mining camps - basically anywhere there is money, as bushmeat is seen as a luxury, and supplying this can be lucrative, although driving increased extraction from the forests*".

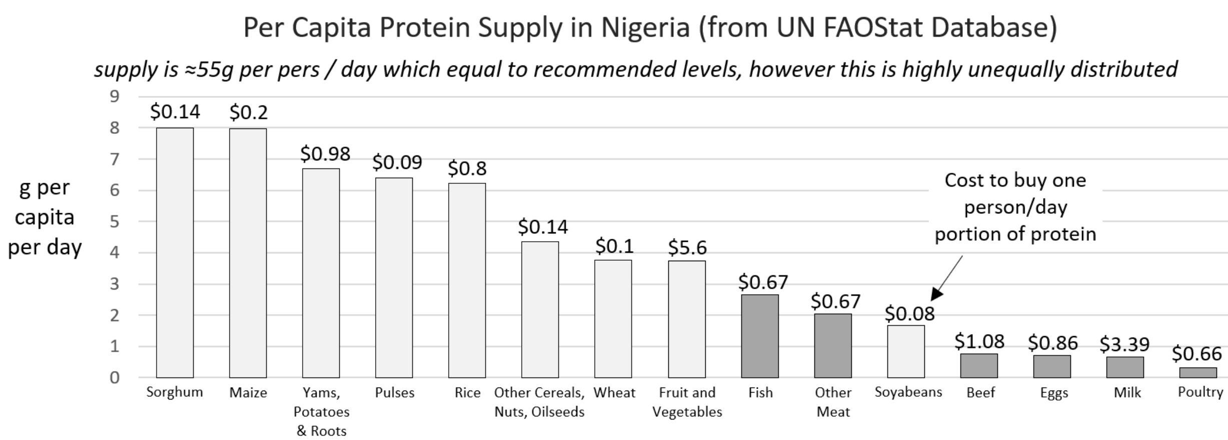

Figure 7 - Protein Sources in Nigeria - note that it mostly comes from low-quality plant sources

Key Insight: Nigeria has a high level of malnutrition, caused by the high reliance on cereals like maize and sorghum for protein – a low-quality protein, but which could be offset by protein in legumes.

3.4 Agroecological and Demographic Profile

Figure 8 shows Nigeria as a vast country that is over 1,000Km from east to west and the same from north to south. The four zones get progressively wetter, wealthier and urbanized as you move South:

- **Arid North** is a vast zone of dry-land farming and pastoralism, with the worst security, as it is Boko Haram's heartland. The population is rural, poor and sparse, with more than 50% of children being stunted (Murphey 2013).
- **Dry Savannah** is the next agroecological band, and the productive heartland with some of the best agriculture, including the productive soybean. The administrative capital Abuja is here.
- **Humid Savannah** is also agriculturally productive, and the center of maize production.
- **Humid South** is populous and rich, with the coastline and oil-rich Delta. However still 20% of children are stunted (Murphey 2013). The landscape is rainforest with industrial palm oil and cocoa plantations. It's 80M people mainly live in cities and are packed into an area the size of South Carolina (pop. 5M).

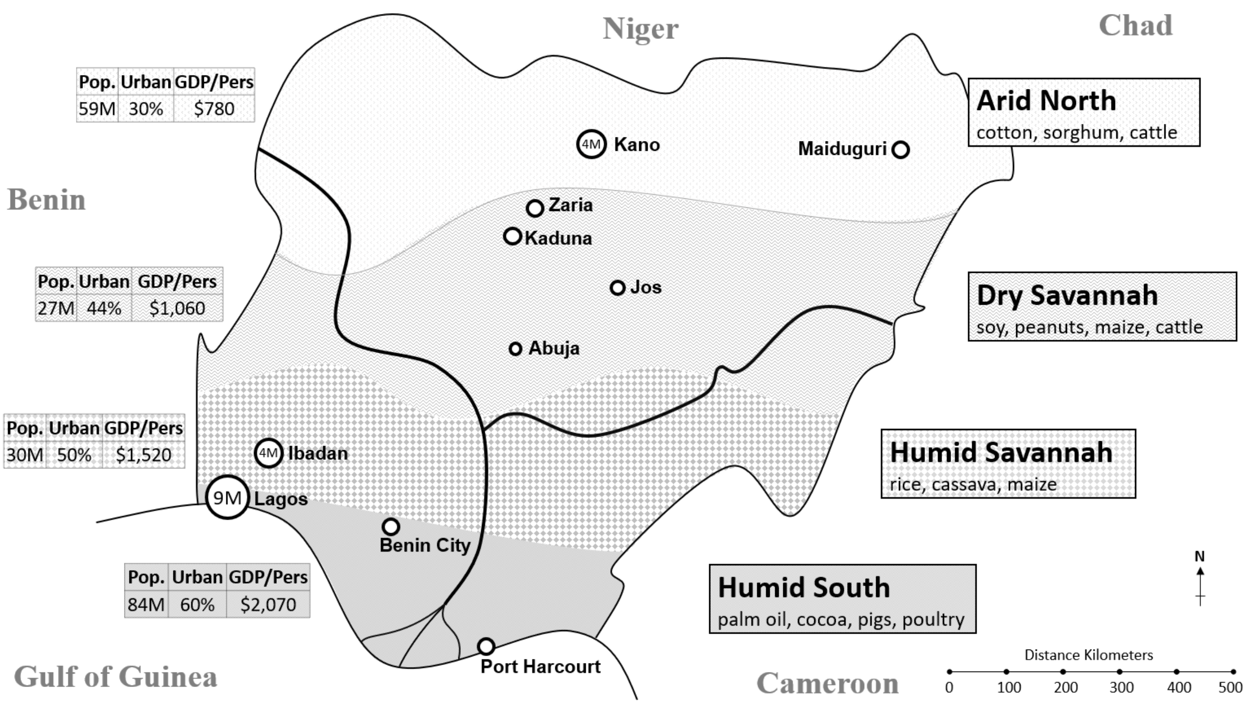

Figure 8 - Agroecological and Demo-geographic Profile of Nigeria

Key Insight: The sparse, arid North is malnourished, but challenging to operate in. The populous South is more addressable and has clear protein demand, and should be the focus of this thesis.

3.5 The nutritional situation in Nigeria

Across Nigeria, 32% of children under five are stunted due to malnutrition – the second highest burden in the world, due to inadequate protein as well as other nutrients. An estimated 2M children suffer from severe acute malnutrition (SAM), but only two out of ten children affected are reached with treatment (Ngerian National Bureau of Statistics 2018). Seven percent of women of childbearing age suffer from acute malnutrition.

"*To further complicate matters, the worst and most irreversible health effects of malnutrition occur between birth and age two, when children need particularly high doses of micronutrients such as Vitamin A, zinc and iron. That means a product designed for the general population would not adequately address issues like stunting and wasting*" said Marie Ruel, director of the poverty, health and nutrition division at the International Food Policy Research Institute (Dewey 2018). This insight implies that in order to address the worst effects of protein deficiency, any new protein product should be suitable for use as soon as children can eat solid foods – usually at 4-5 months.

Food security is a strategic issue, and the government is heavily invested in the challenges of feeding its fast-growing population. Nigeria maintains a large but underfunded agricultural research and extension network of 7,000 agents which were initially set up by the World Bank (Huber 2017). Nigeria's priority seems to be increasing rice production and setting up poultry farms with the aim of reducing imports.

I was fortunate to interview a young Nigerian student at MIT, who grew up in a teaching family and moved around different towns in rural Nigeria. She explained to me the cultural importance of meat in Nigeria "*When I was growing up, meat was expensive, but we had it at almost every meal. It is seen as essential, and at a meal, it was typically a fist-sized portion, although this may be shared among children. It's definitely expensive, someone who is rich would have five pieces of meat, whilst poor people may not eat it as often and will eat the less desirable parts of the animal. Many people would raise chickens in their back yard for meat. One common saying that we have in Nigeria is 'there is no meat on this' – it shows how meat is part of our culture*."

Key Insight: In order to address the worst malnutrition, a new composite protein product should also provide the nutritional and functional properties suitable for children as soon as able to eat solids.

Summary of Key Insights from this Chapter

- During the rest of this century, Africa's population will continue its transition to become larger, wealthier and more urban, and will move from traditional towards consumer lifestyles.
- The newly-urban population is a fast-growing segment with cash and who appears to have an unmet demand for protein. <u>This thesis should focus on this segment as protein consumers</u>.
- Nigeria has a high level of malnutrition, caused by the high reliance on cereals like maize and sorghum for protein – a low-quality protein, but which could be offset by protein in legumes.
- The sparse, arid North is malnourished but challenging to operate in. <u>The populous South has clear, immediate demand for protein demand and should be the focus of this thesis</u>.
- In order to address the worst malnutrition, a new composite protein product should also provide the nutritional and functional properties suitable for children.

Chapter 4

Finding the System Design Alternatives

At this point, it's worth noting how the research has already shaped the design of the system, set boundaries, and informed the requirements and constraints of the system. In short, the system should:

- use a plant-based approach, with modern techniques, as it has been successful elsewhere
- target fast-growing urban populations as they have cash, need protein and can't produce it
- focus on Nigeria's southern area which is densely-packed, urban and malnourished
- complement a heavy maize/sorghum diet, and specifically its amino acid deficiencies

Other system constraints have started to become apparent, such as the need for a non-refrigerated product and low price, but these will be refined through the system design process. The chapter will analyze a series of factors and their implications, in order to inform the system design process.

4.1 Environment and Context of the System

<u>Political</u>. Nigeria's President Buhari's power base is in the poor North, but his popular deputy is from the South. He has made investing in agriculture a key policy in order to reduce dependence on oil exports. Recently, he shut down borders with neighboring Benin, Niger, and Cameroon in an effort to stem flows of rice and tomatoes, and promote food self-sufficiency. He also urged the Central Bank to stop providing foreign exchange for food importation saying 'foreign reserves are strictly for economic diversification, and not foreign food imports' (Smith 2019). **Design Implication → most protein is produced internally today; it would be politically challenging to base any new system on imports.**

<u>Economic</u>. Until recently, Nigeria was one of the fastest-growing economies in Africa, but the economy has not kept up with population growth and since 2014 per capita GDP has declined, in other words, people are becoming poorer even as the economy grows (Campbell 2012). Foreign debt is a record $27B largely denominated in euros and it's not clear how it will be paid back, so the debt rating is at a 20-year low. The President has refusal to devalue the Naira, means that foreign currency is often in short supply. **Design Implication → Local credit would be hard to obtain. Imports will be expensive in local currency, therefore better to source local ingredients.**

Nigeria still relies on oil for 90% of export earnings (but the oil price remains low), while the remaining exports consist of low-value commodities like sesame, cashew, and cocoa. In general, whilst it runs a trade surplus, it remains food insecure and dependent upon food imports (Matemiola and Elegbede 2017). **Design Implication → The system should reduce dependence on imports and even aspire to value addition exports.**

Interestingly, whilst Nigeria is the largest producers of soybean in Africa, it still relies on soybean imports for 2/3 of its consumption. **Design Implication → Soybeans are imported anyway, so importing soybean isolate (ISP) would do no additional harm to economy in short term.**

Legal. Nigeria has four legal systems, the most important of which is Common Law, which governs most commercial and organizational activity(Efobi and Ehima 2019). Common Law was revised in 2018 to bring Nigeria in line with global best practices. Now, Nigeria ranks 131 out of 190 countries in terms of ease of business (World Bank 2019), but is named as one of the fast-improving countries. **Design Implication → doesn't appear to be any legal impediments or considerations to the system design process.**

The other legal systems are interesting, but less relevant; English law is a hold-over from the colonial days, Sharia Law is practiced in the Islamic North and finally, Customary Law will be used in some traditional communities. There may be aspects of Customary or Sharia law relating to food that impact the system however, these will be hard to identify in advance and will not impact system design at this stage. **Design Implication → customary legal factors maybe locally impactful in different regions; should be identified early.**

Societal. What do Nigerians think of vegetarianism? Answer: Not much. There appears to be just one vegetarian restaurant in Lagos, and when the staff were asked in an interview if they were vegetarian they said "*No - we're Nigerian!*". In the same interview, the restaurants founder explains "*in Nigeria, meat represents wealth. Those who can't afford to eat meat aspire to it. So, Nigerians are trying to eat more meat and it's hard to imagine someone giving up meat voluntarily*." (Daldorph 2019) He later explains that the restaurant's (few) customers are looking for a healthier lifestyle. **Design Implication → don't position product as vegetarian; product has to appeal on meat-like food attributes alone. Note: this enables a design freedom - animal-products, or by-products such as milk whey could be used.**

His wife adds "*People are curious about a healthy lifestyle, and people are curious about climate change*" (George 2020). My research leads me to conclude that climate awareness isn't widespread in Nigeria, which is surprising given that Lagos is a low-lying, coastal city and at high risk. **Design Implication → Environmental product positioning may be only slightly effective in some segments.**

Technological. As described earlier, the two technologies used in the plant-based industry are recombinant DNA biomanufacturing and twin-screw extruders. The biomanufacturing step is used to produce heme and is owned by Impossible Foods® in the US. It would be complicated and unnecessary to establish local biomanufacturing in Nigeria, and anyway, many PBM products are successful even without using heme as an ingredient.

More critical technical questions relate to the twin-screw extruder although fortunately, these machines are readily available. The bigger concern is the availability of the input material for the extrusion machine: concentrated, isolate powder-form soy, pea or whey protein (SPI, PPI or IWP). Nigeria doesn't manufacture these inputs, so will need to be imported. If the system is successful, it would be possible and maybe economical to manufacture these locally in the future. **Design Implication → core protein input will need to be imported, but if the system is successful should aim to manufacture locally.**

4.2 Stakeholders and their Needs

Table 2 - Segment Data in Southern Nigeria (authors calcs, data from Deloitte 2016).

			Nigeria		Southern Nigeria	
	Income	Protein Spend	Pop.	Protein Annual Value	Pop.	Protein Annual Value
The Four Segments	**$ / day**	**$ / day**		**$ / Year**		**$ / Year**
Wealthy	>$20	$1-3	5M	$2-5B	4M	$1-4B
Emerging Middle Class	$2-20	<$1	40M	$8B	20M	$4B
Urban Workforce	<$2	$0.20	55M	$4B	30M	$2B
Rural Traditional	<$2	$0.20	100M	$7B	26M	$2B
Total			**200M**	**$20-25B**	**80M**	**$9-13B**

Needs of Target Consumers. From Table 3, the two target segments together consist of 50M people who spend $6B per year on protein:

In Southern Nigeria, the 20M **Emerging Middle Class** spend $4B on protein, live in areas like the Lagos Metropolis and lead a basic consumerist lifestyle. They need a product to look and feel like meat, and which supports their growing societal status, perhaps even to signal a concern for the environment.

The 30M **Urban Workforce** spends $2B on protein. Many will be first-generation economic migrants from rural areas and working as laborers or security guards, who will earn when they can, on a daily basis. They will buy protein when income allows on a daily cycle; packaging needs to be cheap, and allow the purchasing of single-day portions. In fact, a food manufacturing entrepreneur who I interviewed told me that this segment needs "*to be able to buy the smallest amount possible, even 1 or 2 cents at a time*". They will be under-nourished, so the product could include fat, sugar, or salt, and should be engineered to contain the vitamins and nutrients needed when eaten just with maize. **Implication → Both segments need a meat-like, nutritionally dense and protein complete product to support a maize-sorghum diet, but with segment-specific finished forms and packaging.**

Needs of Non-Target Consumers. It's worth mentioning the two non-target segments which the product will not be designed to satisfy. Firstly, the Wealthy Segment – several-million rich folk living a consumer lifestyle two-thirds of whom are overweight (Akarolo-Anthony et al. 2014). The product will not have any of the healthy-lifestyle properties which they need. The second non-target segment are the Rural Traditional who are outside of the cash economy but need an ultra-cheap nutritious protein may be similar to a humanitarian product – again the system will not meet this need.

Needs of the Nigerian Government. Their interests include maintaining legitimacy and ensure re-election by showing improving quality of life for its citizens. Therefore, they will be interested in anything which creates jobs, and generates tax revenue. Also, they will be interested in any initiative which reducing costs of living for citizens, for example by keeping food costs low. The government also has an interest in reducing food imports. **Design Implication → Government will support if the system can increase government tax revenues, create jobs, and reduce food costs.**

Needs of Protein Producers.   These are the fishermen, farmers or hunters who are involved in protein production. Their livelihood and assets will be in the natural resources or experience which they use to produce protein. Their needs including having the skills to be able to produce things, and a market to sell them too. They also need to maintain access to natural resources like fish or forest stocks. **Design Implication → system should consider profitable livelihoods for local producers.**

Needs of Protein Value Chain.   The traders, processors, transporters, retailers and foodservice industry will have a strong interest in the protein production system. They will be especially concerned with any changes, as it will impact their income. They need a way to be involved in the value chain, and in particular low-costs raw materials, as well as the ability to add value such as transporting, storing, and processing. The more entrepreneurial-minded of this group are aware of alternative proteins, but may need to develop the skills, understanding, and be supported if they are to create new products. **Design Implication → the existing value chain may be able to carry out functions for the system.**

Needs of Other Stakeholders.   Less critical but worth considering are 'Local Communities' who are interested in the sustainability of shared resources such as fish or forest stocks. Another stakeholder group are the global 'Technology Owners' who have developed plant-based meat technology. They may want to expand into the developing world.

4.3 Tension between system goals and stakeholder needs

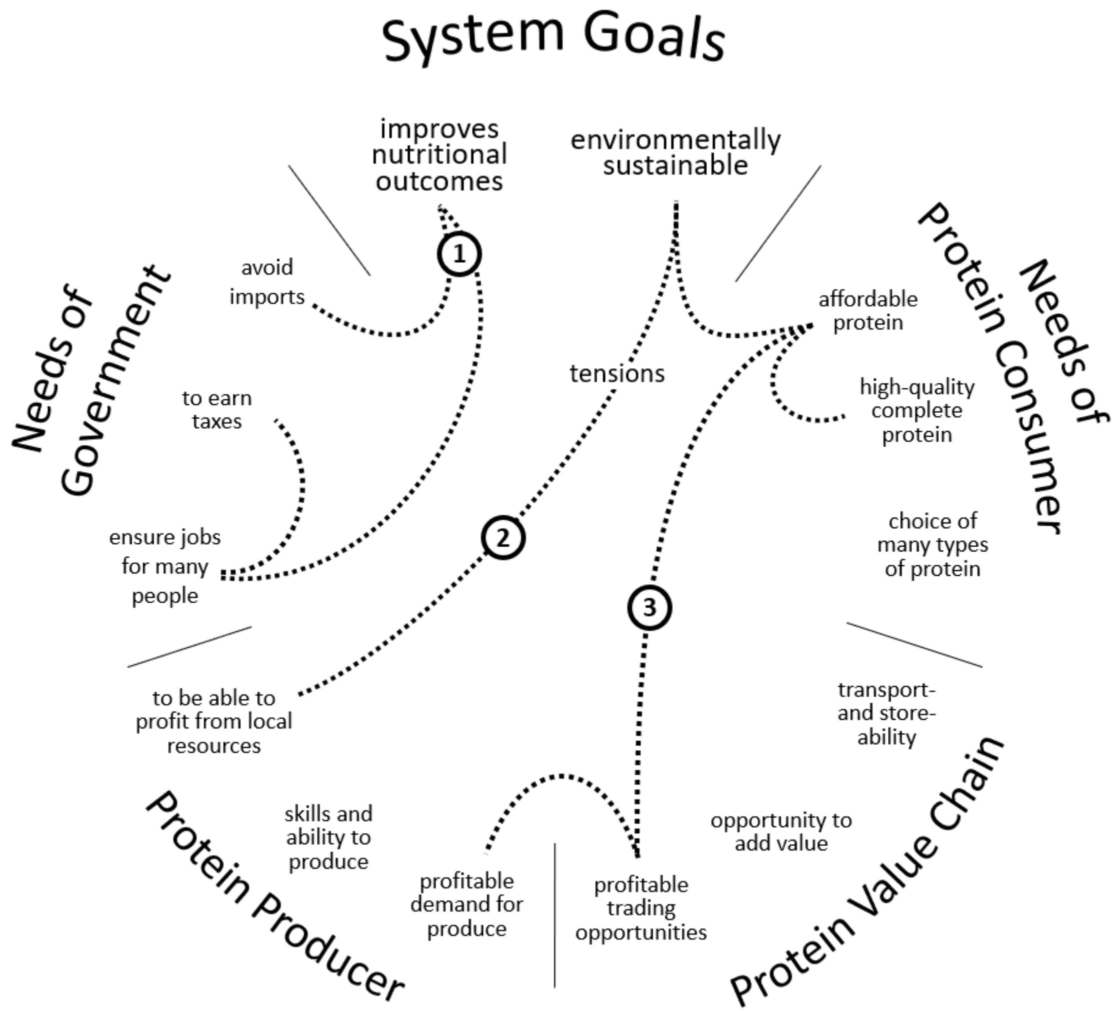

Figure 9 - The tensions (dotted lines) should be managed or resolved through system design

The tensions between system goals and stakeholder's needs are presented in Figure 9. System design should make trade-of decisions to mitigate or eliminate these tensions. The major tensions are:

① The cheapest way to meet nutritional needs would be to allow cheap imports (e.g. frozen chicken and fish) but this hurts local farming, and currency. The price of cheap imports should be considered a price target for the system (Sahel Partners Consulting 2015). **Design Implication → price constraint of $1.75-2/Kg**

② Local farmers, fishermen, and hunters need to access natural resources to produce or harvest protein; however in doing so they invariably cause harm in competing for a limited resource base. **Design Implication → system should enable livelihoods, whilst protecting forests, soil, and fish stocks**

③ Consumers need low-cost protein, whilst the producers and suppliers need profitable business. Market forces mean that those who can afford protein get it, and supply will continue to expand so long as it is profitable to do so. **Design Implication → system should enable protein supply for the poorest in society, the 'base of the pyramid' consumers**

4.4 System operation explained through use cases

Descriptive Use Cases of users interacting with the system can be helpful to illustrate and inform on the system operation meeting the needs of specific user groups:

Use Case 1: Applies to the **Emerging Middle-Class** Consumer Segment.
A modern consumer in Lagos sees a television advert which promotes a product as better for the environment but doesn't pay much attention. A few days later, he goes to their local supermarket, to do a weekly shop and notices the product, so buys to try it out. It's a refrigerated product and claims to be an alternative to meat. A few days later, the product is prepared as part of an evening meal and all family members are satisfied with it as a meat-like product, and are also happy as it is better for the environment. The sensory attributes of product form must meet the family's expectations. The activity would lead to a permanent change in purchasing behavior based on awareness of the environmental impact of animal agriculture. The long-term effect should be that the same consumer makes a permanent behavior change and include the alternative protein product as part of their diet.

Use Case 2: Applies to the **Urban-Worker** Consumer Segment.
The consumer is the wife of a security guard who lives in a coastal town. As part of her daily activity, she travels to the market to buy rice, vegetables, and meat in her local market. A shop keeper convinces her to but a new packaged dry food which is a replacement for meat, but is cheaper. It can be stored dry but can be prepared simply in the kitchen to resemble, smell and taste like meat. The parents and children feel like they are eating meat and it fills them up, although it is not clear if they know that it is not actually meat. By using this product, the family is able to afford protein three times per week instead of once per week. The product must meet the needs of the family and at a lower cost. The successful outcome would be a permanent change to the family's diet and the nutritional state over time.

4.5 Summary of System Design Parameters

Mission: To limit environmental the environmental harm of feeding a growing population.

Value: The value is created if the system can produce a product that is more accessible and preferable to the consumer in place of meat, fish, or bushmeat, but which has a lower cost to the environment.

Goals: To better nourish a growing population and look after the environment in Southern Nigeria by creating alternatives to meat using new plant-based forms of protein.

System Attributes: In order to achieve the Goal, the system design needs to enable operation which is:

- Affordable - the product has to be lower cost than existing protein sources. **Design Implication → Lean organization, Low-cost, profitability through scale**
- Accessible – in the right place and unit pack quantity for consumers where and when they have cash **Design Implication → Small pack sizes**

- Desirable – appeal, based on 'meaty' taste and characteristics **Design Principle → Meaty**
- Nutritional – has to exceed protein and nutritional quality of livestock protein sources **Design Implication → Complete protein**
- Stable – able to be ambiently and safely transported, stored and handled in challenging environment **Design Principle → Robust**

Key Performance Attributes: Clearly these are the nutritional and environmental performance, as the value is delivered by meeting both of these. They are measurable through two metrics:

Metric 1: Nutritional Improvement. The first important outcome to measure is the 'change in the nutritional state of the population' due to the system, relative to a counterfactual situation (assumed to be the existing average diet of the consumer segment).

- Key Metric. To do this, the key metric is the change in Protein Malnourished of Population in percent, which is caused by the system.
- How to measure? By modeling nutrition in the protein, versus an existing average diet.
- Supporting Metrics. (1) Volume (Kg), (2) Number of People Reached, and (2) Price relative to existing options, will all be measurable leading indicators.

Metric 2: Environmental Protection. The other outcome to measure is 'reduction in greenhouse gas emissions due to the system'. Again, this should be measured relative to a counterfactual situation which is assumed to be a continuation of the existing system.

- Key Metric. To do this, the key metric is the CO_2 Emissions Displaced in CO_2e which is attributable to the system.
- How to measure? By modeling the emissions of the protein in CO_2e produced by the system compared to an equivalent amount of emissions with existing methods.
- Supporting Metrics. (1) Volume (Kg) and Market Share Percent of Protein Market (2) Unit Emissions in Kg CO_2e per Kg of protein product are leading indicators.

4.6 Emerging System Design Decisions

The diagram below represents the system as a series of major decisions, and three of these choices which I will specifically examine.

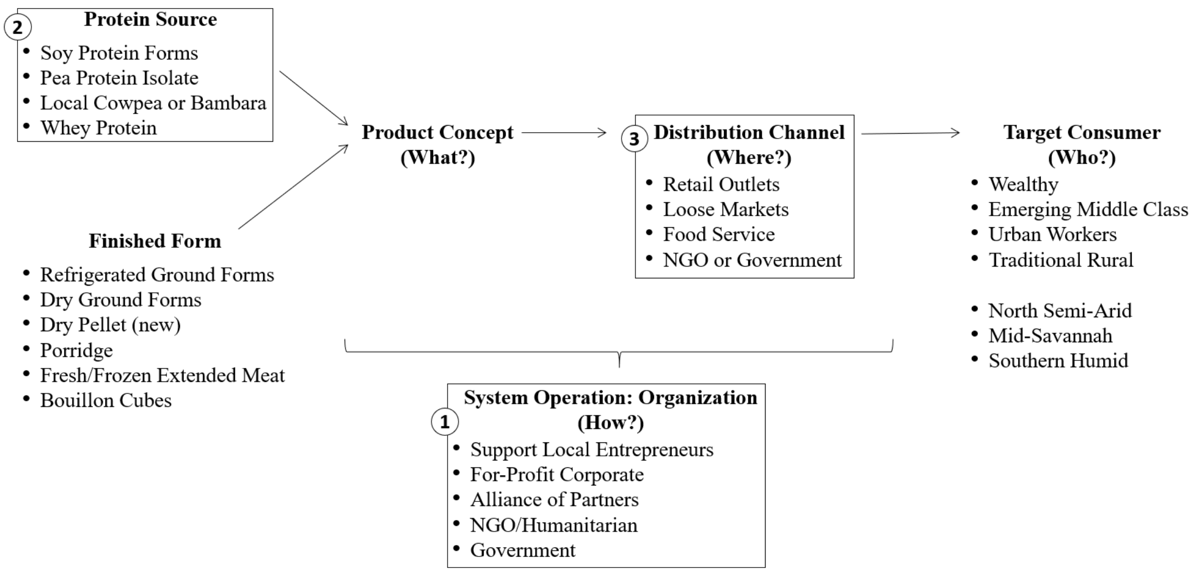

Figure 10 - The Major System Design Decisions and their Associated Options.

In the next chapter, I will systematically explore these system design decisions and options. I will highlight the costs and benefits of the possible option and later evaluate the combination of options when operating together as a system. Through this evaluation process, its possible to determine the design which best meets the system goals.

Chapter 5

Evaluating Major Design Options

What set of design options will create a system most likely meet user needs and achieve the best performance over the system lifetime?

5.1 Design Choice 1: System Operation and Organization

How is the system going to be 'operationalized'? Who or what is going to actually do the value-adding functions, such as: buying inputs, manufacturing products, packaging, sales, and distribution, etc.? Clearly some means of organizing capital and labor will be needed. Historically, governments are bad at operating food systems, but the private sector is better, motivated usually by profit, or sometimes driven by other motivating missions. Four different System Operation options are evaluated:

<u>Option 1 - Support Local Entrepreneurs</u>. Nigeria is highly entrepreneurial and many people are looking for opportunity. But, technical challenges and upfront investment costs make it hard for entrepreneurs to start in alternative proteins. Therefore, there is an opportunity to operationalize the system by providing support to willing entrepreneurs with guidance, technical help and financing. This entrepreneur-first approach could even one day lead to a domestic alternative protein industry ecosystem, a local knowledge base and even competition and choice for consumers. On the other hand, there are risks in relying on cash-limited entrepreneurs to operationalize the system - entrepreneurs may drift away from the system goals, for example, to just focus on the most profitable activities.

<u>Option 2 - For-Profit Corporate</u>. This would be the most straight forward approach and is the standard model driving the plant-based meat industry elsewhere. A for-profit entity could be set up to operationalize the system, either by investing in and operating capacity directly or by contracting-out functions to third parties. However, a for-profit corporate entity may attract suspicion when operating in an area of public interest such as new types of food, and if successful may even attract competition.

<u>Option 3 - Alliance of Partners</u>. One approach could be to form an alliance of existing food manufacturers, traders, transporters or retailers who already have operating expertise, but may not have the breadth, expertise, or bandwidth to enter this market. By providing technical support and incentives, it may be possible to create a partnership network to operationalize the system. The advantage is that this building on existing expertise and so reduces risk and costs as many of the business functions will be in place. The downside is that commitment may be limited, and partners distracted by other more profitable activities. There is also a risk of partners falling out.

<u>Option 4 - Not-For-Profit / Humanitarian</u>. A humanitarian mission to operationalize the system could be another approach, but it depends upon finding an aligned source of funding. Such an organization could either undertake the system functions itself directly, or partner-outsource with specialists. This approach could cover issues such as malnutrition, animal welfare or global warming. The challenge of this approach is long-term sustainability – requiring indefinite funding or a self-sustaining model.

Table 3 - Design Options for System Operation: Organization against System Goals and Needs

	Choice Options			
	Support Local Entrepreneurs	**For-Profit Corporate**	**Alliance of Partners**	**NGO or Humanitarian**
Goals + Needs	*Do they support (✓) or conflict (×) with Goals?*			
1.System-Level Goals				
Improves overall nutritional outcome	× profit-focus may conflict with nutrition goal	✓ can control quality × profit-focus may conflict with nutrition as goal	× profit-focus may conflict with nutrition as goal	✓ could be mission-driven around nutritional outcomes
Sustainable for environment and society	✓ could kick start an industry			✓ could be mission-driven around protecting the environmental
Operationally viable and low risk	✓ supporting Nigeria's dynamic entrepreneurs will be seen positively × control may be hard	✓ability to execute × perception of 'corporate' brings some risks	✓ motivations between partners should align × disagreements may be catastrophic	× a mission-driven operating model may not be sustainable
2.Consumer Needs Low-cost meat-like protein, with choices for different segments	✓ a competitive ecosystem may lower prices and increase variety × profitable activities may be counter to system goals	✓ should enable lowest cost manufacture and can engineer a full product portfolio		× serving wealthy market segments may appear to conflict with 'mission-related' donor funding
3.Government Needs Earn taxes, create jobs and avoid imports	✓ creates jobs and businesses × low tax earning potential (initially)	✓ earn taxes × may not create many jobs	✓ potential for taxes as partners grow	✓ may help with government nutritional goals × no tax earnings
4.Producer Needs Opportunity to supply protein profitably and sustainably	✓ multiple buyers mean a buoyant market for producers	× single buyer can exert pricing power on producers		✓ may be more price sympathetic to producers
5.Value Chain Needs Opportunity to trade, and value-addition	✓ opportunity for entrepreneurial value chain players	× corporate dominates – less opportunity for local value chain	✓ opportunity to partner in a combined value chain	✓ opportunity to provide services

Design Choice → A For-Profit Corporate approach is the most controllable way to achieve system goals, but Supporting Local Entrepreneurs could create a creative, dynamic and sustainable new industry.

5.2 Design Choice 2: Protein Source

The extrusion machine will require some sort of protein in a concentrated, powdered form. The selected protein should be economical and be nutritionally complementary to Nigeria' cereal-heavy diet. Ideally, this would be locally sourced, but Nigeria doesn't yet have any manufacturing capability for these high-quality isolate powders.

<u>Option 1 - Soybean Protein Forms</u>. Soybean protein is very cheap and has an excellent amino acid profile, which is why it's sometimes called a 'superfood'. It's traded in three different qualities of refinement: firstly, simple de-fatted flour which is available in Nigeria, secondly concentrates (SPC), and finally high-quality isolates (SPI) neither of which are available locally. About 1M tons of high-quality soy isolate are traded globally each year - a market worth $2-3B. It costs around $2,000 per ton and has a 90% concentration which equates to 10 cents for man-day of protein.

SPI is widely used in meat analogs and well understood, however, there are mild off-flavors in particular, a beany flavor that is caused by oxidation of the fatty acids and which can be hard to manage. There has also been a perception of safety issues relating to estrogens in soy; whilst scientific consensus has now dispelled these (Harvard TH Chan School 2018), there is a possibility of reputation risks from their use in Africa. Another drawback is the need to import, however with sufficient demand, in time it may be possible to develop industrial fractionalization capability manufacture locally.

<u>Option 2 - Pea Protein Forms</u>. After soy, pea was the second legume to have its protein isolated and the powder isolate form has been around for just around 10 years. It's about twice as expensive as soy, so a protein-day portion would cost around 20cents. Whilst it's a less complete protein than soy this shouldn't matter in Nigeria as the cereal rich diet should compensate. Pea protein forms have only a mild beany off-flavor, and there are no perceived health issues. The yellow pea varieties used are not native to Nigeria so will need to be imported, but supply is volatile due to the current global high demand.

<u>Option 3 - Develop Local Proteins</u>. One creative approach could be to invest in the research and science needed to identify native crops and isolate and extract protein as a protein source for PBMs. This isn't cheap nor easy – as explained to me in an interview with some Food Science graduate students, the research took 50 years to create SPI from soy, and then 10 years to do the same for pea. An obvious target would be cowpea, which shows potential for protein quality and functional attributes (Rangel et al. 2003) and which is the most widely grown legume in Nigeria. Bambara nut is a local high-protein but which is gathered in forests, and is being studied as a protein source (N'Dri Yao et al. 2015). Whilst it's high in protein, it appears to be like maize also limited by tryptophan, and unlikely to be cost-competitive at scale. Africa's native moringa tree has highly-functional, but as yet little understood protein.

<u>Option 4 - Whey Protein</u>. Whilst not a plant-based source, this is a highly functional by-product of the dairy industry with form and function similar to soy and pea protein powders. It has a perfect amino acid profile, is very usable and has no off-flavors. It's about three times more expensive than soy protein isolate. It's uncertain is there is a whey manufacturing capability in Nigeria, so would likely need to be imported. However, there is a possibility to develop local production in order to complement the growing dairy sector in Nigeria.

Table 4 - Design Options for Protein Source against System Goals and Needs

	Choice Options			
	Soy Protein Isolate	**Pea Protein Isolate**	**Develop Local Protein**	**Whey Protein Isolate**
Goals + Needs	*Do they support (✓) or conflict (×) with Goals?*			
1.System-Level Goals				
Improves overall nutritional outcome	✓ cheap, complete and widely available protein	× suited to high-end products only	× the nutritional profile of any new source is an uncertainty	✓ excellent protein source, although expensive
Sustainable for environment and society	✓ highly efficient with potential for local production × perception of health issues (although untrue)		✓ potential for local production and food sovereignty	× relies on dairy industry
Operationally viable and low risk	✓ most commonly used plant protein type	× supply challenges	× risky – needs scientific research	✓ functional and versatile protein
2.Consumer Needs Low-cost meat-like protein, with choices for different segments	✓low-cost and useful for variety of products × off-flavors need to be managed	× suited really to high-end products only		× probably better suited to high-end products due to costs
3.Government Needs Earn taxes, create jobs and avoid imports	✓ imports could be taxable × likely need to be imported so won't create jobs	✓ imports could be taxable × imported so doesn't create jobs	✓ potential for local industry	✓ potential to develop a complementary local industry
4.Producer Needs Opportunity to supply protein profitably and sustainably	✓ in time, local production may be developed × unlikely to source locally	× no opportunity to supply locally	✓all supply will be local, although will take time to develop	✓potential for local supply
5.Value Chain Needs Opportunity to trade, and value-addition	✓ opportunity to develop a local supply chain of soy protein	× this will always be imported	✓all local supply and large opportunity to add value	✓ local sourcing will need investments in value addition

Design Choice → Soy Protein Isolate is a cheap, nutritious and well-understood protein source, the main downside of which is that it needs to be imported, although in time this could change.

5.3 Design Choice 3: Channel of Distribution

How will the product reach the consumer? Who is going to move it from the factory to the point of consumption? The Channel of Distribution may be the part of the system with most cost and risk, due to the logistical challenges of Nigeria and is a major factor in system design. It is highly coupled to decisions about product form – for example, ambient or refrigerated, as well as the type of packaging. Within Nigeria, as the rest of Africa, there is a hierarchy of retail outlets which generally map to the social hierarchy, ranging from the street market trade, all the way up to modern supermarket-style retail outlets (Igwe and Chukwu 2016).

Option 1 - Supermarkets. These are common-place in large cities but absent from rural areas. It's a fragmented industry, with no chain having more than 50 outlets, and led by international chains Spar and Shoprite, but with local contenders such as Addide. Stock is predominantly packaged goods, and all have refrigeration. This channel would reach the Wealthy Segment, and some of the Emerging Middle-Class. Supermarkets would be the best outlet for a high-value, but subsequently low-volume product.

Option 2 - Small Retail Outlets. These are ubiquitous in Nigeria's urban and to a lesser extent rural areas. A high volume of packaged, traded products passes through them. Most products are dry, ambient packaged goods, as well as some bulk. The retail shops sell a limited range of refrigerated goods – with a small kitchen fridge generally stocked with soda drinks. It's a scalable channel, with robust distribution networks. It would suit a low-cost, packaged-branded product aiming for large-scale.

Option 3 - Market Loose-Form Trade. In both rural and urban areas, small markets service the trade in non-packaged, loose-form goods such as fruit, vegetables, meat, fish, nuts, rice as well as loose-form manufactured goods such as pasta. They may range in size from a tiny village market with a couple of housewives selling goods, up to central city markets with thousands of traders. They will be serviced by nationwide informal-but-efficient distribution networks which include a well-established bulk-break function. Products in this distribution channel will need to be shelf-stable during ambient conditions, all weather conditions, and be safe for trade when in bulk.

Option 4 - Foodservice Providers. Cafes, restaurants or street food vendors who account for a significant volume of protein, and is especially important to Urban Workers on a daily wage. This channel would need bulk buying formats, which may be a way to reach scale quickly and cheaply. The challenge is the need to convince two convince two layers of user – both Foodservice Provide and the end consumer.

Option 5 - Humanitarian Distribution. Governments or NGOs often distribute food to the needy. Sometimes this is in the form of a financed distribution of basic goods (typically known as a Public Distribution System or PDS) or otherwise humanitarian distribution in times of famine (often in conjunction with WFP). These channels may be an interesting use case of plant-based meats, but won't be considered in this analysis as it is a special case.

Table 5 - Design Options for Distribution Channel against System Goals and Needs

	Supermarkets	Choice Options Retail Outlets	Loose-Form Market Trade	Foodservice Providers
Goals + Needs	*Do they support (✓) or conflict (×) with Goals?*			
1.System-Level Goals				
Improves overall nutritional outcome	× very low reach and only to high-end consumers	✓ reaches all segments apart from wealthy	✓ reaches the poorest segments	✓ reaches the most impactful Urban Workers
Sustainable for environment and society				
Operationally viable and low risk	× volatile segment with buying power	✓ well established channel	✓ well established channel	✓ well established channel
2.Consumer Needs Low-cost meat-like protein, with choices for all segments	✓ high-end consumers × doesn't reach most people	✓ reaches most consumers	✓ reaches poorest × not as impactful reach as the retail outlets	✓ reaches the important Urban Workers segment
3.Government Needs Earn taxes, create jobs and avoid imports	✓ taxable channel × doesn't create many jobs	✓ creates jobs and trade × hard to tax	✓ creates jobs and trade × no taxes	✓ creates jobs and trade × no taxes
4.Producer Needs Opportunity to supply protein profitably and sustainably				
5.Value Chain Needs Opportunity to trade, and value-addition	× concentrated supermarkets are bad for most small traders	✓ many retail outlets involved	✓ significant number of traders involved	✓ foodservice is value add activity

Design Choice → To reach both the Emerging Middle Class and the Urban Worker segments, then a combination of both the Retail Channel and the Loose Form Market Trade needs to be used.

The analysis so far has only considered the parts. What really matters though is system performance when the parts are combined into whole new architectures. This table evaluates six variations of the system which emerge from combinations of decision options.

5.4 Assessment of complete concepts against User Needs and System Goals

Table 6 - Evaluation of Selected System Concepts against User Needs and System Goals

System Design Choices			What Concept Emerges? *Will it deliver value and meet performance goals? Will it meet the user needs? How feasible is it?* **Overall System Performance Score**
① System Operation +	**② Protein Source** +	**③ Distribution Channel**	
Support Local Entrepreneurs	Soy Protein Forms	Retail outlets and Loose Form Market Trade	Support Local Entrepreneurs. Tap dynamic ecosystems of local entrepreneurs to create competition to bring cheap, soy-based products thus creating choice for hungry urban markets. Government will support due to local empowerment and job creation. **Score: 8/10**
Corporate	Pea Protein	Supermarkets	Corporate FMCG. Developed-world model with a high-end product (exists elsewhere - no need for product development) which would satisfy rich consumers, and offset some environmental impact, but fail on other goals such as nutritional improvement. **Score: 3/10**
NGO	Soy Protein Forms	NGO	NGO focused on Improving Nutrition. Could use cheap soy protein to develop meat-like humanitarian products which could be distributed to the most nutritionally challenged. Can meet nutritional/ environment goals, but may struggle with sustained funding. **Score: 5/10**
NGO	Local Plant Types	NGO	NGO Focused on Localism. A huge investment would be needed to develop protein isolate from local plants such as cowpea. Value is created through opportunities for local farming, but is hugely risky and has little impact on near term goals. **Score: 3/10**
Corporate	Soy Protein Forms	Retail outlets and Loose Form Market Trade	Base of Pyramid Corporate. A BOP strategy requires a lean-corporates achieving huge scale through high-volumes of very low-cost products. The single corporate approach is attractive as it is controllable and can capture all profits. Risks emerge from corporates operating in sensitive food production. **Score: 7/10**
Alliance of Partners	Soy Protein Forms	Retail Outlets	Local Production Alliance. Existing food-chain actors have the skills to quickly launch new products, but the category is new, technical and needs a level of investment that requires cooperation to spread costs and risks – this may be unfeasible. S**core: 6/10**

5.5 A Proposed System Concept: 'Support Local Entrepreneurs'

The preferred concept is a protein production system which ① provides technical support to local entrepreneurs in order to ② manufacture products based on Soybean Protein Isolate (SPI) that are then ③ distributed through local markets and retail outlets.

Chapter 6

A New System Concept Emerges

The chapter provides the supporting details for the Support Local Entrepreneurs concept. The concept naturally leads to Franchising - a well-proven concept which is most well known in fast food retail. Therefore, the new system can be described in terms of a combination of three ideas:

<u>Product Platform Architecture</u>. The product is based on a platform of interchangeable ingredients which can be adapted for local markets. This means that whilst the production process may be similar, the ingredients or finished form could be adapted to what makes most sense locally.

<u>Franchised Operations</u>. The system operations are based on local franchises, in order to enable modularity, adaptability and scalability. Thus, local operations can be adapted for different local markets.

<u>Lean Organization</u>. The overall system is based on a lean organization, in order to keep the product affordable. This comes from an idea in business called a Base of the Pyramid (BOP) strategy. The product would be unviable in the target markets if it was burdened with high overheads.

6.1 Architecture of the System

The System Architecture in Figure 11, shows how responsibilities and risks can be allocated to the parts of the system where they can best be managed or mitigated. The system's main elements of form are:

① **System** means the high-level entity responsible for value-delivery; lean to ensure affordability.

② **Product** is a food product which is based on soy, with a meat-like form, and with attributes affordability and shelf-stability. It uses a platform-architecture in order to adapt to create local variants.

③ **System Operations** is the operating entity which delivers value by organizing the entrepreneurs and delivering the functions that would be challenging for local entrepreneurs.

④ **Product Local Form** is a variant which has been adapted to a particular geography, by adapting three product design attributes: nutritional profile, ingredients base, and taste/texture.

⑤ **Entrepreneur** is the local agent (the 'franchisee') responsible for execution functions that require local knowledge. They share in some of the reward, but also take the burden of the local execution risk.

⑥ **Value Chain** are local providers of non-core local activities, for example sourcing within local channels or running distribution networks – these are best done by local specialists.

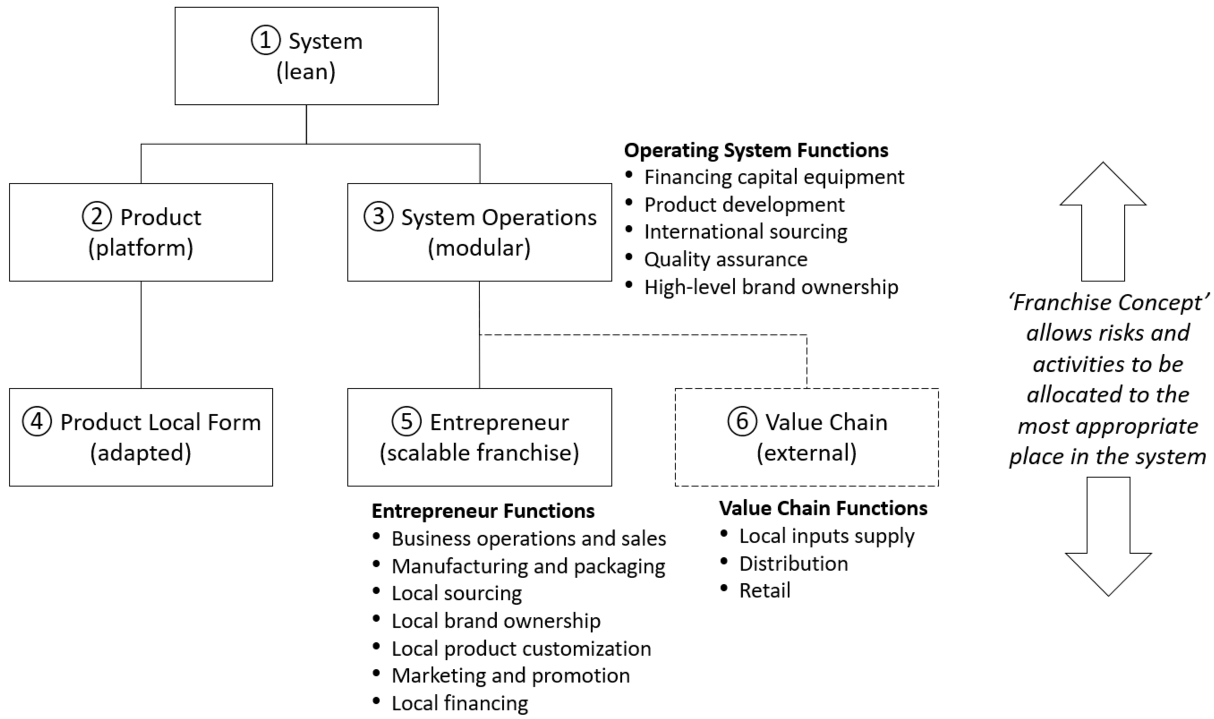

Figure 11 - Selected System Architecture – effectively a 'Franchise Architecture'

6.2 The Product Delivered by the System

Africa is a continent of small diverse markets, including Southern Nigeria. In order to achieve scale, a product platform approach is proposed, which means that a standard product, can be adapted for local markets. It's a well-known approach in say, automobiles (most cars use a platform architecture) but the idea is less common when applied to foods.

In this platform strategy, the 'base' product would be designed to meet a common-requirements set, for example being shelf-stable outside of the refrigerated chain, meanwhile local variants would be created by morphing design features such as flavor between markets. The morphable design features are:

<u>Morphable Design Feature 1: Product Components</u>. Most popular PBMs in market today have a fairly standard list of ingredients. Firstly, there is a main protein source (say soy or pea protein) but sometimes other proteins which help to achieve a balance of amino acids to make the product more 'complete'. In the case of Southern Nigeria, a protein combination would need to make up for the AA deficiencies in the predominant maize/sorghum diet - tryptophan, lysine and threonine. Other nutritional ingredients, say vitamins and minerals could be added to support this maize/sorghum diet. The product also needs to contain fiber, and fat, such as local palm oil, and some imported ingredients such as the fat-binder methylcellulose, colorants, preservatives, vitamins, and minerals.

<u>Morphable Design Feature 2: Product Finished Form</u>. The form of the finished product (independent of ingredients) is an important design choice which depends upon local cultural and cuisine factors. In the

US today, most PBMs (e.g. BeyondMeat®) are sold as ground-meat products such as burgers, and always in the freezer section. In fact, most meat in the US is sold as ground-meat, meanwhile in Africa 90% of meat is sold in whole-form meat (interview with local protein entrepreneur April 2020). In fact, it's only really possible today to sell PBMs as ground-meat, but fortunately there seem to be many ground-meat dishes in Nigeria. This suggests that there would be sufficient market (at least initially) for a ground-meat form product.

Taste also need to be understood and adapted locally, and fortunately flavor profiling is well understood by food scientists, and so the favors of popular local bushmeats could even be created. Textures could also be morphed depending on local preferences.

The system should also consider future flexibility to include new technology. For example, 3D printing could soon be used to create realistic whole meat forms. Could the product platform absorb this new technology without a whole new re-design?

<u>Morphable Design Feature 3: Product Positioning</u>. Finally, the local variants need to be positioned for each market segment within a market – another morphable design factor. In the case of Southern Nigeria, there are two local macro segments. Firstly, the Emerging Middle Class require a consumer-packaged goods product which is cheap but aspirational and branded. The secondly, the Urban Workers segment needs ultra-cheap protein, but which give them an ability and feeling of eating meat every day.

The platforming strategy also needs to account for the fact that new techniques may emerge. A future scenario is that cellular agriculture suddenly became cost competitive – could a platform strategy be designed so that this new architecture could be implemented within the existing platform?

<u>Product Development Process (PDP)</u>. Protein impacts a food's texture and flavor, and so protein food development is technically challenging and requires a specialist food lab. In this case, there is an additional challenge which is uncertainty, and so the PDP will need to be iterative in order to allow for testing. But, how to achieve a PDP like this when the markets are all dispersed across Africa? Probably the PDP will need to be dispersed, with R&D undertaken centrally in a specialist lab, and then transport samples by courier into markets so that a local team can carry out consumer testing, and report back.

Such a PDP will need to consist of the following steps in order to develop the platform and local variants:

- Cost analysis to ensure product variable costs enable the important cost requirement
- Environmental assessment of supply chain to inform the product stability requirement
- Sample testing of local ingredients to inform the ingredient formulation
- Profiling flavors and cuisine locally to understand what taste, texture and form are acceptable
- Lifecycle analysis to ensure that the environmental goals can be reached
- Branding and positioning research to understand local buying behaviors and positioning
- Rapid prototyping iterative blind taste testing to optimize the product and ensure desirability
- Verification that the product and its parts and combined entity meet requirements
- Validation that the system meets system goals

6.3 System Operating Strategy

There are two emerging strategy themes; Franchising, and 'Base of the Pyramid' marketing:

Franchising. This is a very well-known operating model, which took off in the US mainly since the end of WW2. Today the most well-known example is McDonald's - a very slick operation. Franchising enables the system to scale across the locally-diverse operating environments of sub-Saharan Africa. The model differentiates between global and others local business functions. Global functions include things such as branding, which benefits from the wider recognition and trust between countries, and also global commodity sourcing, which again is better done globally. On the other hand, local functions consist of things better done locally, for example local supply chain, marketing and sales operations. The franchise model works well when there is a common business model, which just needs to be repeated with a small amount of local customization - exactly the conditions of our protein system.

McDonalds provides an interesting case which we can learn from. McDonalds has over 38,000 restaurants worldwide – 30% are in the US and 90% are franchised. Carefully-selected franchisees are required to attend McDonald's University, and agree to very strict operating criteria - all of which helps to achieve the global branding and recognition needed to grow the business worldwide. In return the franchisees are supported to operate a local business which is almost certain to succeed (Vignali 2001).

This model could apply to our case in Southern Nigeria. Franchisees could signal commitment by making an appropriate upfront financial investment, as well as giving up a share of their operating profits. In return, they could receive the training and equipment needed to produce a PBM product, as well as rights to a brand, technical advice, and a supply of ingredients. Their responsibilities would be to undertake all of the local functions needed to make the product a success, which in our case include local product adaptation, and manufacturing. In short, franchisee would be given the means to manufacture and sell, but would need to provide local management and 'hustle' to make the system work.

Base of the Pyramid. The second theme of this system concept is a 'Base of the Pyramid' (BOP) business strategy. This was made famous through a 2002 paper (Prahalad and Hart 2002) that argues that there is a massive, untapped, and growing opportunity in serving the world's poorest 4Bn people. The idea is that serving these markets can be both profitable, and also serve to lift people out of poverty. The paper trys to dispel past assumptions, like the poor can't afford new technology, or that you can't find talented managers in these markets. Many of the well-known BOP ideas also apply to our system concept:

Firstly, BOP says that you need to 're-invent organizational cost structures' so that you protect poor consumers from high corporate overheads. In other words, don't add expensive HQ costs onto a BOP business – keep BOP operations lean, and mostly variable costs. In our case, this means keep the system level entity lean. This is one reason why large corporate probably couldn't operate this system.

The BOP strategy also says to conduct dedicated R&D for poor markets. Again, an important part of the proposed system is to run a dedicated product development process (PDP), specifically to meet the technical requirements of these markets.

Another BOP idea is maximizing affordability for consumers, rather than specifically minimizing costs. For example, by using the loose-form market channels, our system could allow consumers to buy any quantity product - even for a few cents if that's all that they have in their pocket when then buy.

Finally, BOP also emphasizes forming alliances in order to reduce costs and maximize reach. In our case, our systems consist of a network of entrepreneurs and other value chain partners to do local functions.

6.4 System Operation as a Fictious Case Study

Imagine several years hence, what might a successful system look like? Let's go on an (imaginary) trip to Port Harcourt – a fast-growing city of 1M people in Southern Nigeria to see the system operating.

When we arrive in Port Harcourt, we meet an (imaginary) character called Dorcas Okeke. Dorcas has recently graduated from a local university and desperately wants to be an entrepreneur. Last year, Dorcas managed to raise enough money from friends and family to buy the Port Harcourt 'system franchise' for New Protein Systems (NPS). The franchise cost $40,000 which is a significant amount of money for Dorcas and certainly demonstrates her commitment to the project.

Once the contract was signed, Dorcas received several weeks of technical and business training through the New Protein System's 'Protein University' – an online training course which both trains, but also tests that the franchisee has the skills and integrity needed to make the system work in their geography.

On graduation, Dorcas acquired the lease on a food-grade factory in Port Harcourt. Then, the imported manufacturing equipment was installed, consisting of a twin-screw extruder and other manufacturing and packaging equipment. The machinery costs $2M but is owned by NPS and Dorcas pays for the equipment as a variable cost, based upon throughput volume. Raising money for capital equipment in Nigeria would be hard for Dorcas as a new entrepreneur, and so this financing function happens at the higher NPS level.

Also, at the start, Dorcas worked with NPSs International Product Development Team (IPDT) to help them to run a Product Development Process (PDP). The goal of the PDP was to develop two initial product variants that will be suited to the Port Harcourt market. The technical adaptations included using local coconut as a source of fat, although the core protein ingredient remains Soybean Protein Isolate (ISP). The recipe added vitamins and minerals in order to complements the rice-heavy local diet. Dorcas's role during the iterative PDP was to run local blind taste tests on samples that were couriered into Nigeria by FedEx. Dorcas also took responsibility for working with a local marketing agency to develop local packaging and a local brand.

The two products in Dorcas's range include: firstly, a high-end packaged branded burger which sells in local retail stores, sometimes in the refrigerated section for effect although it doesn't need to be. This high-end product is positioned as convenient, better for the environment, and is promoted heavily. The second product is ultra-cheap meat-like 'chunks' which are sold loose in 50Kg sacks for the local market trade. This ultra-cheap product accounts for most of Dorcas's volume, but the margins are very thin.

Dorcas's factor foreman oversees the ten workers running the production line. Dorcas has to manage the inbound supply chain, which consists of the monthly containers of inputs, including ISP – the powder used to make the protein form. The international ingredients are often delayed due to the congestion in the Port in Lagos, so NPS has to finance considerable buffer stock. She also has to procure and manage the deliveries of local inputs, including packaging materials. Dorcas also manages the sales and distribution of finished goods which happens through distribution partners. In short, Dorcas provides the local operation and entrepreneurial 'hustle' whilst NPS takes care of the higher-level business financing, sourcing, and product development – things which are challenging for a young entrepreneur in Nigeria.

This year, Dorcas's target is to sell over 500 tons of PBMs which will displace 1.5% of the meat and fish market in Port Harcourt. Dorcas is able to achieve an average of $2 per Kg ex-works which means that her revenues will be $1M. The 120 tons of ISP costs $250K, whilst other inputs and manufacturing expenses also cost $250k. Finally, another $250K is used to pay to NPS for use of the manufacturing equipment. This leaves the final $250K for company overheads, and Dorcas's profit.

So far, the sales have gone well in Port Harcourt and the growing population means that demand is strong. If Dorcas achieves this year's target, then she will plan to expand the production capacity, and even introduce a new product variant next year. She may even apply for a franchise to operate in a neighboring city. All of these options are easy as the system is designed to be modular and scalable.

Does the system create value? In Dorcas's case, she has sold 500 tons of PBM product in her first year, which (let's suppose) displaces an equal (protein volume) of chicken, fish, bushmeat and sorghum, so it:

- Displaced **100T of chicken** and in doing so saved 600T of carbon emissions (FAO 2013 Fig 29. Chicken ~6kg CO2-eq.kg CW) which is the same as removing 130 cars from the road (US EPA 2016 Car Produces about 4.6MT of CO2e/Year)
- Also, saved **100T of fish** caught from the Gulf of Guinea, where fish stocks are near-collapse.
- And, saved **125T of bushmeat** which is the same as extracted from about 200Km^2 of rainforest (calculated from Fa et al. 2006).
- And replaced the protein in **250T of sorghum**, which by itself is survival food for about 1,500 people per year, although Dorcas's protein has likely provided a better protein source in a diet of many thousands of people.

Secondary value is created by creating skilled manufacturing jobs in Dorcas's factory, paying taxes, potential exports, reduced zoonotic risks, and creating opportunities for the value chain. The costs which are borne to protein producers, are the displacement of jobs such as low-value fishing or farming, which seem like a small price to pay.

6.5 Assessment: How well does the system meet the goals and user needs?

My evaluation of system performance (Fig. 12) is that the system meets the high-level system goals (nutritional and environmental) better than today's existing protein systems. There are also better outcomes for the Government who have the potential to earn more taxes, as well as the Protein Consumers, who benefit from more affordable, high-quality protein. However, there are costs of the new system which accrue to the Protein Producers and Value Chain, many of whom will lose employment, may face a new consolidated buyer of protein, as well as the loss of opportunity to trade and add value as actors in the value chain.

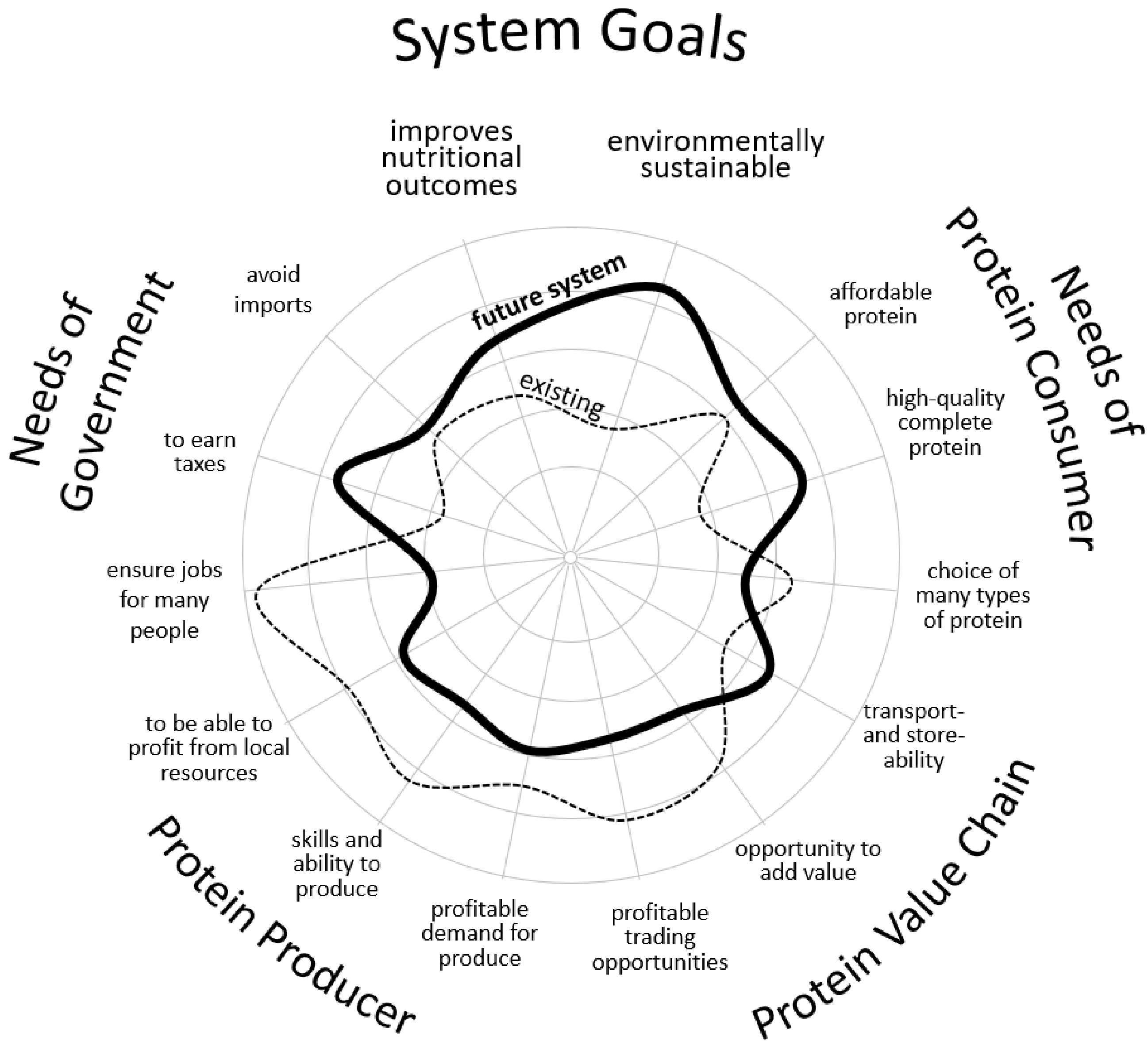

Figure 12 - Radial chart scoring the degree to which the system goals and user needs are met

Chapter 7

Conclusion

The thesis process has led to new system design which could meet the goals of improving nutrition at lower cost to the environment. However, there are societal impacts which accrue to the poorest of the population who rely on producing protein for their income.

The proposed system is based upon an interesting mix of well-known ideas, which when put together, deliver a product which can scale across different markets. The three core ideas are:

> Firstly, using a Product Platform Architecture which means adapting the product locally to each market using design elements which can be adapted, but keeping the core product the same. The design elements which could change are: the ingredients, finished form or positioning - all being adapted to whatever makes most sense locally.
>
> Secondly, using a system of Franchises to create modularity in operations and drive scale. The system could build a network of entrepreneurs who know local markets well to become franchisees. The could adapt the product and ways of working to ensure local success. Franchising is a mature model, and well understood and should be easily adaptable to Africa and this scenario.
>
> Finally, a Lean Organization in order to keep the product affordable. This comes from an idea in business called a Base of the Pyramid (BOP) strategy. It means keeping the organization light and efficient in order not to burden the product with high financial overheads.

These three ideas together create a system which can deliver a product. The product will be a new type of alternative protein which is based on plant ingredients, but looks, feels and tastes like meat. The design features which can be adapted based on local market characteristics are:

- Macronutrient: protein, fat, fiber and carbohydrates all depending on local availability
- Micronutrient: vitamins and minerals depending upon the established local diets (e.g. maize)
- Finished Forms: local customs will require different forms of ground meats
- Flavors and smells: adaptable so that they are familiar to customers based on local meat or fish
- Positioning: could mirror the values of local consumers (e.g. environment, health, low-cost etc.)

How good is the resulting solution? I think that it is feasible but would need a tenacious entrepreneur and patient capital to make it work, as well as a supporting government. It would be effective only when reaching scale, but this scale means disruption to small producers who make their living from protein today. This is the trade-off faced by alternative proteins in every geography, in that they are disruptive to traditional livestock farming communities.

How did the System Design methodology work? The methodology is more typically used in highly engineered applications like aerospace and defense systems. However, this thesis demonstrates that it can be used for messy socio-technical systems like protein in Africa. The method works but, in my personal view, can seem convoluted and be clumsy to communicate (and monotonous to read).

The method however forced me to think about protein production as an end-to-end series of parts and their inter-connectiveness. It led to design consideration of both the product (the technicalities of how to make a food) as well as the wider system needed to sustain it over time (the means of production, processing, and distribution to consumers in Africa). Performance in relation to the system goals, is measured in terms of the whole, not the parts.

The result is a detailed and connected system design. The method has advantages over more simplistic approaches – for example, just focusing on the product but not the means of delivering over time it may be more likely to lead to unexpected or poor system performance.

<u>What next</u>? The immediate unknown is the question of whether a convincing plant-based meat product can be developed which is both desirable for local cultures, cheap enough to compete with existing protein, whilst being shelf-stable for non-refrigerated distribution channels. A food development project would be well worth investment, but only if done in conjunction with better understanding the societal and cultural acceptance of PBMs.

Appendix A

Edited Excerpts from Interview: Alt Protein Technical Expert

The following are edited excerpts from an interview with an Alternative Protein Technical Expert who works for an NGO whose purpose is to support entrepreneurs, researchers and scientists in the field.

I believe that system metrics are protein quality, environmental impact and cost. Do you agree?
Yes, Protein Nutritional Quality and Environmental Impact are important. However, Cost is not really a well-used metric because it simply doesn't matter in high value markets like the US where alternative proteins sell today. Most alt protein products cost more than meat today and consumers accept this.

What do you think is the most effective way to measure protein nutritional quality?
It's hard to measure. Nutritional science is not as advanced as you would imagine. PDCAAS is not perfect, but its commonly used data is available, so that's the best to use until there is something better.

What do you think is the most effective way to measure environmental impact?
It is measured by (1) CO2 and (2) a composite of greenhouse gasses, depending on the situation.

What are the main costs involved in producing plant based alternative proteins?
Costs are a function of: costs of inputs, costs of electricity and the capital costs of the equipment.

Please tell me more about the process of turning plants into plant-based meats.
The food production for plant-based meats consists of two processes: Fractionalization – this means breaking down plants into 'isolates. Then, extrusion – this is by far the most successful method for plant-based meats. The sequence and parameters of the extruder process is the key to getting plant-based meats right. This is effectively what Beyond Meat have done to get their product so good. The key steps which Beyond Meat have got right are firstly, knowing exactly which isolate to take from each plant and secondly the parameters of fractionalization.

Is Cell Base Meat close to being commercially viable?
The first problem is the cost of FBS (which I think will be solved quickly) but also the scaffold issue (which I think may take longer – 10 years). Most CEOs of say "*5 years to market and 10 years to cost parity*". The cost savings only come with scale, so this is unlikely to be soon. The FBS growth factor is the focus of most research now - its function is to tells the stem cells which cells to turn into (i.e. fat, muscle, etc.), but, it's not even a good growth factor, it's just used as it's cheaper than synthetics.

Are insects promising for alternative proteins?
The most exciting thing is the use of insect cells as co-components of an animal cell multiplication. This is because they are less fussy than animal cells, and so if you have an un-noticeable amount then you can get more biomass from less cells. Normally, the stem cells are doubled (say) 40 times to get far more biomass, but when doubling, some cells die. Insect cells are more stable, you they so die less.

What about marketing of these products? Why have they been successful now in the last few years?
That values-based arguments have consistently failed ('you should not eat beef because it's bad for the environment'). Recent product success though (Beyond Meat etc.) is due to the focus on product (this product is taste great and looks like meat, regardless of the environment). The successful companies create products which work for consumers. Lecturing on values doesn't work, especially in Africa.

Appendix B

Edited Excerpts from Interview: Food Scientists

The following are edited excerpts from an interview with a group of Food Scientists who do research at a Plant Protein Innovation Lab at a top university at the United States.

How big of a technical investment would it be to use local sources of protein in Africa?
Soybean protein took 50 years to develop, but we learnt a lot by developing that which can be used in other crops, for example pea then took 10 years. Still developing something new like cowpea will still take a long time. Our ability to use new plants depends on their structure - firstly, you have to extract the protein out of the source to make it useable. Then you have to first make it into a flour, and then from that develop the concentrates or isolates. One researcher is looking at Moringa in Africa because it is high in iron, but because it comes from a plant, but the iron is not especially bioavailable. One company 'Believe in Bambara' is looking at Bambara as a local protein source. Some big companies like Land O' Lakes and Cargill have teams which goes into these countries and tries to build up crops there.

What about soy, it seems like an amazing choice of protein. Why is it not used more?
We have moved away from soy because of consumer fears of health challenges and alleged concerns, even though we as food scientists will tell you are unfounded. Therefore, even though it sounds like a great option to use cheap soy protein isolate, there could be major publicity issues with it.

Can you make a PBM product which doesn't need refrigeration?
Plant protein meat analogs go through a dry state after extrusion in which they are shelf stable. They need to be re-hydrated before they can be used. This may be useful for the product design in this use case. There are a lot of research going into using a dry, low-moisture extruder which would create a de-hydrated steak which you could re-hydrate and cook - there is some research happening now, but I don't know of any on market yet. I'm unsure people would buy de-hydrated steak.

To what extent can locally-available starches (sorghum, maize, rice) play a role as say fillers?
It's not straight forward - yes, they can be used as a filler but proteins interact with other foods, so needs to be studied

Can products be nutritionally fortified without affecting sensory characteristics?
Yes, generally vitamins and minerals generally don't affect sensory characteristics. There are some which are fat-soluble and need to be introduced with the fat.

How easy is it to profile and recreate local flavors, such as bushmeat flavors, and sensory aspects?
It's easy to do the flavor profiling - we do it all the time. You can extract, and then a flavor company can recreate them. But the main problem is hiding the off-flavors. It's a big topic of research. Sometimes you can add a flavor to hide, but sometimes it doesn't work as proteins bind with these flavor compounds, which can cause off-flavors in itself. Sometimes you can modify a protein itself to stop it binding.

It may be possible to use animal-derived ingredients. Does this preset technical freedoms?
Yes, whey is a highly functional protein, and a byproduct of dairy production – it would be a great ingredient.

Appendix C

Edited Excerpts from Interview: Expert on Proteins effects on Wildlife

The following are edited excerpts from an interview with an expert on protein in Africa, who works with a global wildlife-focused NGO, with a particular interest in the forest areas of Africa.

What do you know about the supposed growth in protein consumption in Africa?
Most of it is poultry, rather than beef. Almost all countries show a correlation between GDP and meat consumption, but it's all poultry rather than beef. Poultry isn't as bed for the environment of course.

Do you agree with the idea that there is a major drift from rural to urban?
Yes, although the urban poor is growing fast and there are large areas of poor urban housing. Some of these areas have distinct characteristics and it's important to clearly define segmentation in urban areas as they are not all the same. There are some very poor conditions in the new urban areas in the cities.

Do you think that there is a place for alternative proteins in Africa?
Yes, however its vital that new protein systems provide opportunities for local producers of protein. At the moment, supply chains are inefficient and so making things very expensive. In any new system, the money should flow back to rural communities.

How much bushmeat is consumed in West-Central Africa?
Nobody really knows but everyone uses the 4-5 million tons figure – it's an uncertainty, but its large and bushmeat has many issues. It happens in very rural areas, and is illegal so people don't want to talk about it much. There is much more confidence in the numbers coming from South America or Asia.

Who is buying bushmeat? Where is the market?
As well as the rural poor, there is huge movement of bushmeat from rural areas to sources of money, which could be urban areas or mining camps. Bushmeat is seen as an aspirational food and in urban areas it's sort of a luxury good. There is a cultural affinity to it, and a perception that bushmeat is very good for you – and it's true, it's an excellent protein quality.

Could you replace bushmeat with alternative protein which mimicked beef or chicken for example?
Aspirational foods can be more nuanced than simply saying beef is the most aspirational food – there can be local traditional foods which could be considered aspirational. Using alt proteins to mimic these local foods should be considered also, rather than just beef or chicken.

What other alternative proteins may make sense in Africa? Is it only plant-based meats?
No, there are some huge opportunities with insect protein like mopani worm, and I'm sure that insects have a strong future in Africa. There are some South African/Kenyan startups who are working on it. They may be able to get the cost down in time. There is evidence of a cultural affinity and that it's an aspirational food source. Perhaps even plant-based foods should consider recreating insect characteristics

What other work is being done on this? What else should I look at?
Not much, although the EAT Lancet paper is an excellent analysis of that diet and the kind of minimum cost for a minimum nutritional diet, using local price data.

Appendix D

Edited Excerpts from Interview: MIT Student from Nigeria

The following are edited excerpts from an interview with an MIT Student who grew up in Nigeria

Can you tell me about the diet in Nigeria?
Rice and Yam is common. Seafood is in the south west. Even where you have power, then refrigeration is hard – much depends upon the access to refrigeration. Typically, people make small portions of soup, on a weekly cycle. My parents, had a salary so we may buy things for a month or a few weeks. Things which you can't preserve, then we were able to buy on a weekly or daily basis.

How do people view meat? Is it seen as essential? Is it a treat? Is it aspirational?
It depends. When I was growing up, meat was expensive, but we still had meat at every meal. Typically, a fist sized portion shared among children. It is seen as essential. I will finish up the rest of my food before meat, as this is how I grew up. But my friend would eat meat with her meal as she grew up differently – it just depends.

What are the luxury meats?
Beef is the luxury, as not many people have cows behind their house, but they would have goats/ chickens at home, so they are more commonly eaten. We raised chicken. Depending on where you are, people may not buy meat as it's expensive, or buy in on a once per week/ month basis.

What about bushmeat? Is it common?
Bushmeat is a delicacy. People will buy when they go home to their village – it's a tradition. Some places sell bushmeat every day even in cities.

What do people buy for protein and is there enough for all of the people?
Things like beans and rice you can get a lot - plant protein is not a problem. People eat a lot of beans. People in Lago's don't have the benefit of planting things as there is no space. Where some people live, the basic food is fish. Plant protein is more common in many areas. Things like meat maybe slightly expensive. Chunky meats like beefy parts would be more affordable - it wouldn't be uncommon to find even poor families that can still eat meat because they buy the less desirable parts of the animal.

What are the goals and aspirations of regular people in Nigeria?
This is a hard question - we all want different things. We want to be relevant, to be somebody, etc. Just show that you are comfortable. Have good things in our life - marry a nice family etc. Varies.

What about soybean?
Soy wasn't around, beans was not grown, soy seen as a type of beans but not eaten directly. You can make a type of milk from soybeans.

What about around the different areas of the country?
People by river they will eat fish every day. They love their fish. People are getting more health conscious. Everyone eats eggs, some people eat milk, which is also sold more in powdered form although this is slightly more expensive. In North, there are lots of cows, so milk is more common.

Appendix E

Edited Excerpts from Interview: Investor in Alt Proteins

The following are edited excerpts from an interview with an Investment Associate from an Alternative Protein Venture Capital Fund.

Do you think that alternative proteins can play a role in Africa?
Cell-based meats will take some time, and has a lot of investment needed and hurdles to overcome, and won't be suitable anytime soon for use in Africa. There are some fermented products, with high protein ingredients - they may be cheaper as they scale better and maybe more useful.

What are the trends in plant-based meats in the developed markets?
Developed markets are moving away from soybean protein because of the (unproven) issues with estrogen.

Where do you see the new technology going?
There is an interesting plant-based startup in Barcelona which is developing 3D printing of plant-based steak. Their approach can be used for pork, seafood etc. It's effectively a desk top 3D printer.

Then there is the Protein Brewery in Holland, who have a fermented product which is grown in tanks and can be sold to other manufacturing businesses who will use it as a base ingredient – I think that this is very exciting and you should look at it for Africa. This is something lie Quorn. Its on par with other offerings on the market.

Then there is 3F Bio who are based in Scotland and are developing a product which is based on mycoprotein, but with a better technology.

Another interesting approach is Emergy Labs have very interesting product which has a texture very much like whole-form meat – you should look at these also.

Have any of the alt protein companies gone to Africa?
Hampton creek / JUST sometime 2017/8 developed a plant-based product in bulk bags for sale in Liberia, but now appears to be discontinued. It seems that they didn't have the right product for the market. Now they will focus on their existing products, which is an egg type alternative.

Appendix F

Edited Excerpts from Interview: Alt Protein Entrepreneur in Africa

The following are edited excerpts from an interview with an entrepreneur in Africa who is working to bring new alternative proteins to Africa.

What do you think the future of alternative protein in Africa is?
My theory is you need three products: Meat substitute, which must be 'on par' with chicken which is usually the cheapest (which is often imported frozen). Dairy substitute (this must be on par with cow's milk/dry milk powder). There isn't a good solution here in Africa yet. Finally, a protein fortified staple porridge - either cassava, sorghum or maize depending on local tastes, & traditions

What are some of the requirements of a perfect product in Africa?
It should be flexible across cultures and countries; note that culture can even be different within countries. It should not be associated with nutritional aid etc. It should be should be stable in a dry/bulk/hot supply chain (market trade). Also, consider that some markets (East Africa) people by food daily, so serving packages need to be 1-2 days to make them cheap. Meanwhile in other (mining/ salaried) markets, some people are on a monthly cycle, so they want to buy a month at a time – so packaging size is a huge consideration. Vegetable Textured Protein is taboo – has bad reputation. In general, in South Africa, Soy products are taboo because of the terrible taste

Is there a place for manufactured alt protein products?
Manufactured products must use and integrate with local farmers in the local supply chain. I feel that any product has to connect with local farmer supply chains in order to economically develop farmers. Because 60% of people are farmers and you need to make people productive at the lower levels. In Africa, there is an incentive to keep people farming because it keeps people out of poverty.

Can you tell me about some of the cultural and market aspects that you have learnt?
In southern Africa, cattle are core to society and have many uses besides meat. Generally, African's prefer red meat. At the moment 80% of the diet is carbs, because people can't afford meat. Vegetarian/Vegan is not a notable sector, nor an important trend. Environmental stability is not an issue that people think about. The fundamental problem in Africa is jobs - food and ag keep showing up as playing an important role in creating jobs. The 2050 population presents a major food security problem – I keep thinking there must be a way to 'leapfrog'. Pricing depends upon market – in pastoral countries, beef is cheap but chicken is expensive, but really in most markets chicken is far cheaper. In the US, 60% of the market is ground beef, and South Africa it looks more like Europe or the US where Ground Beef is a high%. But elsewhere in the continent, ground meat is just 10% of the market (although sausages are higher).

What about cereal based products? Is it an opportunity?
Yes, some countries do it well and others not so. There is a huge opportunity in some countries for a better branding – a 'cool' branding for a Protein Fortified Maize, Cereal Soy/Maize blend, including using a social media presence. Corn-Soy blend is a great food, to persuade people to use it, I believe that you have to (a) position it as consumer food (b) small packages (c) flavor it. Some products have been commercially successful, but one issue with a popular local brand too much moisture so only 6m shelf life. Just / Hampton Creek failed in Liberia with their porridge, probably because they hadn't done anything new with the product.

Appendix G

Edited Excerpts from Interview: Nigerian Food Entrepreneur

The following are edited excerpts from an interview with an entrepreneur / business owner who runs a food manufacturing business in Nigeria.

Do you have any plans to introduce a protein product?
Yes definitely. The big opportunity is soy-maize blend as a meal, porridge that needs to be boiled, and fortified with vitamins and minerals. The opportunity is marketing and making it trendy. An important requirement is to make something dried with a shelf-life. There is a lot of interest in snack-based products - school children want snack - nutrition etc. Governments may be also a customer for these.

How do you segment the consumer market in Nigeria? Which segment do you target?
Healthy is ok, but must be affordable. We had a hard time getting mainstream demand.

What is the best way to segment the market in Nigeria from a marketing perspective?
The best idea is to look at the WFP classifications: Ultra-poor, Poor, Lower middle, Middle, Upper middle, Wealthy etc. Each segment is going to have different needs and behaviors and characteristics.

What are the biggest constraints to selling to consumers?
The biggest constraint has been price point, we have found that the price has to be 50c or less for a single serve product.

Do you know other food manufacturing entrepreneurs who have been successful around Africa?
Yes, you should look at people in Nigeria, but also Zambia (pretty mainstream) and there is an interesting operation in Rwanda - Africa Improved Foods, a very successful business.

What do you think about my proposed requirement set for alt proteins?
I agree with all of your assumptions, but the important thing is that it should be packaged in a way that a customer can buy any amount - even 1-2 cents at a time. This is called making it affordable – more related to money in pocket at point of purchase, rather than the actual price per unit weight.

Would you want help to introduce an alt protein meat-like product which you can manufacture?
Yes of course, this would be an excellent idea. The problem is that I don’t have the time, resources and capacity to develop a product myself but there would be demand, and if there can be help to design, develop and build manufacturing capacity then it would be great.

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