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Case Studies on various approaches to using Technology as a driver for African Development

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Author: Matthew Dimmock
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Supervisor: prof. Ing. František Freiberg, CSc.

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own, except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification except as specified.

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Date *Name*

Acknowledgements

First and foremost, I want to express my gratitude to the Merciful and Compassionate God, for his grace in helping me in write this thesis, as well as throughout the course of my studies. Through his wisdom and imagination every nation and people group has been created, including the numerous African peoples whom I hope this thesis will serve.

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Finally, I dedicate this work to the African people, caring, sociable, and infinitely precious.

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Abstract

Sub-Saharan Africa (SSA) has been largely left behind in the last century's race for development. This thesis explores the connection between innovation and standard of living in the context of technology. We address the question: What can be learned from current efforts to use technology to resolve real-life issues encountered by Africans, and how can this be applied in new contexts?

Initially we conduct a broad overview of the situation in SSA, concentrating on the areas of health, clean water, power and transport infrastructure. By studying two specific companies, Zipline and Desert Rose working respectively in the fields of drone distribution and water filtration, we examine their approaches to the African market, the needs which they address and their chosen solutions to meet those needs. Finally, we propose our own project, to establish a solar panel factory using the principles which we have discovered, selecting the optimum country and conducting a brief study into feasibility.

The principles established in the paper relate to the need for innovation, a careful choice of country in which to locate, the use of robust designs and the importance of working closely with Africans. These are of value to investors in the continent, and those considering humanitarian work through the medium of business. Taking them into consideration can help challenge the way we approach sustainable development, prioritising the inclusion of Africans in the process.

Keywords: Sub-Saharan Africa, African development, Appropriate technology, Thin-film photovoltaics, Solar panel manufacturing, Unmanned aerial vehicles, Household water filter, Technological innovation.

1. A survey of challenges which can be addressed through Mechanical Engineering

1.1 Introduction

Despite numerous advances over the last few decades, Africa has struggled to develop. Whilst endowed with many natural resources, many Africans live below the poverty line and when ranked in order of GDP per capita, twenty-two of the thirty lowest nations are in Africa [Country Comparison, 2017]. Notable exceptions to this are South Africa and much of Northern Africa, the latter Arab states being culturally, politically and economically separate from their Southern neighbours. Hence, we will only be considering the nations of Sub-Saharan Africa (SSA) in this paper.

Technology is the story of human advancement, and throughout history mankind has developed increasingly sophisticated machines and tools, helping it to meet its own needs and improve its standard of living. The lack of initiative in the realm of technology by the African people over the last two centuries exposes an underlying failure of local people to resolve their own problems. And therefore, efforts to address this, particularly those which empower local communities, will act as a remedy to the social and economic problems faced by SSA.

The aim of this thesis to consider in broad terms, how innovative technology is currently being employed to tackle the underdevelopment in SSA. To achieve this, we will evaluate two businesses which offer solutions to issues within Africa, by using and developing appropriate technology, extracting lessons that can be learned in order to advise future efforts in the field. At the end, we will propose we our own business venture, building on the principles extracted from studying the two businesses.

The majority of SSA economies rely heavily on agriculture, with much of the population living by subsistence farming, using very basic tools to grow crops, whilst remaining dependant on unreliable rainfall. Even so, agricultural output for the continent is low, a challenge which needs addressing if the continent is to feed its rapidly growing population [Bachewe et al., 2018].

As far as industry goes, the manufacturing sector makes up only a small proportion of Africa's GDP, with most of its industrial output being produced by South Africa alone. Most African factories produce items that are basic in nature and simple to manufacture, mainly belonging to food processing, textile and cement production [Gardiner & Mabogunje, 2018].

The causes of this underdevelopment are various, and can't be explained purely by economics. Many of the current issues have roots that can be traced back to the colonial era, when the continent was divided up and exploited by European powers for their own benefit. However, unlike many other similar former colonies, it seems that for the majority of African nations, independence did not trigger an acceleration in economic development and progress. Wars, incompetent authoritarian governments and unsuitable infrastructure combined with famines and diseases have certainly played a significant role in stalling the economic development of the African people. Yet it is important to remember that local cultures, traditions and world-views also interact, creating a situation where favourable circumstances alone will not necessarily lead to a solution. Africans are their own people, and proposed solutions, even of a technical nature need to take that into account.

It's clear that in response to this, economic development needs to take place across the continent. The Cambridge Business dictionary defines economic development as "the process in which an economy grows or changes and becomes more advanced, especially when both economic and social conditions are improved" [Economic Development, c2018]. And while national and continental development is influenced by many factors, technology plays crucial role.

More fundamentally, technology is a tool used across the world, for humanity to meet its needs and solve its problems. And though Africans have proved very adept at modifying Western and Asian-made machinery to suit their own requirements, they have lagged behind when it comes to identifying local issues and coming up with original solutions.

Global business over the last few decades has been driven by advances in technology, and thanks to globalisation, markets across the world have opened up, allowing for products and services to be purchased from across the planet. This promises huge opportunities to Africa, offering its people the potential of entering these markets both as customers and suppliers. In many cases, African governments and businesses could be enabled to supply previously unmet needs relating to infrastructure and services (i.e.: the health sector, power production, etc...) by purchasing ever less expensive products available on the international market and also by accessing expertise and information previously reserved to western and developed countries. Africans in turn can make use of the disappearing barriers in order to sell their own products to a wealthier international customer base, allowing for an inflow of foreign currency and an increase in national output.

Hitherto, Africa has generally lagged behind other economies when it comes to technology; the flip-side of globalisation being that nations which fail to develop will be left behind, finding themselves in a worse state than before. Nevertheless, these new technologies present the opportunity for underdeveloped countries to leapfrog forward in various sectors of their economies. Yet despite a growing amount of entrepreneurship among the African people and an increase in the number of small-medium enterprises, government investment in developing technology remains limited. Due to an initial lack of funds, further diminished by corruption among government officials and an overwhelming number of calls for investment (even spending on maintaining current infrastructure is insufficient), most authorities don't see developing new technologies as a priority [Amankwah-Amoah et al., 2018].

It's clear that development requires financial investment, and this investment flows into Africa in four non-commercial forms:

- Firstly, there are **local governments**, responsible for the welfare of their people. Frequently hampered by corruption, ethnic bias and incompetence, these governments often fail to invest well even the small funds at their disposal. They are often blamed for many of SSA's short-comings. Nevertheless, there seems to be a recent improvement, with governments initiating projects across the continent, for example with the latest surge in investment into transport infrastructure by the Ethiopian government [Ahlerup et al., 2016; Lassou et al.,2016].
- Next are the **international aid agencies**, which come in various forms. Some, such as the World Health Organisation and the World Food Programme come under the umbrella of the United Nations, and work towards specific humanitarian or developmental goals by raising awareness, conducting research, striving for international coordination and in some cases by direct intervention. Others, named Multilateral Development Banks (MDB) such as the World Bank or the African Development Bank are key players in financing infrastructure development by providing governments with either loans or grants. Much of the funding for international development organisations comes from governments of developed nations [Nelson, 2015].
- Thirdly, there are **national aid agencies**, such as the Czech Development Agency or the UK's Department for International Development, who invest in development as part of their government's budget.
- Finally, there are **Non-Governmental Organisations (NGOs)**, motivated by altruism and sometimes religious reasons, who act independently of government control. Funded for the most part by donor generosity, they range in size from massive institutions such as The Red Cross and Médecins Sans Frontières (MSF) through to small organisations working in one particular location. All of these external aid providers, and particularly the larger ones, come under regular criticism for inefficiencies in their use of funds, whilst many have incredible success stories [Shah, 2005].

- Multinational companies are also a significant investor in the continent, though there are many accusations of them using their influence to plunder its resources rather than improve the local economies. Local SSA based businesses have been growing in size over the last few years, and are beginning to compete for their share of the market [Adusei, 2009; Tshabalala, 2015]

Before any talk of developing or importing technology into Africa occurs, it is crucial to consider the social situation into which the technology will be brought and applied. It does not suffice to merely create the ideal machine, tool or implement that will solve an identified problem, but the product must be accepted by society and integrated into their lifestyle [Farid, 2015]. Many African communities, particularly in rural settings are highly traditional and opposed to fast-paced change, mistrusting new inventions. Countless examples of failed attempts by foreign agencies with a "know-it-all" attitude, coming up with sophisticated, high-tech solutions, both in crisis response situations as well as in long-term development projects, offer us much to learn from.

According to NBC News, $22 million was invested by the Norwegian government in Kenya in 1971, in order to develop a fish-processing plant. The aim of the project was to provide jobs for the Turkana people through fishing and exporting the processed fish. However the Turkana people are nomadic, and fish is not a part of their diet. The factory was built, but then only operated for a matter of days; the running costs of required to power the freezers and provide fresh water in the desert outstripped productivity [Examples of failed projects, 2007]. Whilst such a project may have worked well in Norway, among a people used to salaried employment, the Norwegian government failed to appreciate both the cultural and environmental factors of northern Kenya.

The greatest flaw is usually a failure to consult properly with the local communities, before rolling out a high budget programme. Unfortunately, this issue still persists today, with many expensive machines (pumps, cooking stoves, etc...) being abandoned once they break down, since no-one in the local community is able to maintain or fix them. This has led to the popular use of the term "appropriate technology", referring to technology which beyond merely solving the given issue, will also be effective in the targeted society [Logan, 2016].

1.2 Key issues

The challenges to development currently faced in SSA can be broken down into various issues, of which many can be directly addressed by mechanical engineering solutions.

The Sustainable Development Goals (SDGs) set out by the United Nations in 2015 and agreed upon by one hundred and ninety-three different countries, outline key developmental issues for humanity to resolve by the year 2030. Among them are to commitments to: "Ensure healthy lives and promote well-being for all at all ages", to "Ensure availability and sustainable management of water and sanitation for all", to "Ensure access to affordable, reliable, sustainable and modern energy for all" and to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" [SDGs, 2017]. These issues are of particular concern in SSA, and we will discuss each of them individually, later introducing some of the technical solutions currently being adopted to resolve them.

1.2.1. Health

It comes as no surprise that health is a key factor to consider when it comes to the development of a region and population. Sickness leads to, among other factors, a reduction in population growth, life expectancy, levels of education, and the ability for the national workforce to maintain reliable jobs, without mentioning the untold suffering and grief it entails. Solving these issues leads to, on a nation level, increased economic performance as well as an all-round improvement in the lives of the population [Ashraf et al., 2008; Barofsky et al., 2015].

Whilst vast leaps forward have been made in the area of health and medical treatment over the last few decades, there is a long way yet to go. Numerous factors affect the general health of a population: access to medical care and treatments, sanitation and hygiene, the presence of serious diseases in the region as well as the outbreak of viruses which can develop in a very short space of time and decimate the lives of many people [The determinants of health, c2018].

Among the successes of fighting viruses in Africa, the most notable are the complete eradication of Smallpox, officially recognised by the World Health Organisation in 1980 [Fenner, 1988], and the extraordinary reduction in the number of cases of Poliomyelitis (Polio). The only SSA nations where Polio is suspected to still be present are Nigeria, and the Democratic Republic of Congo, the latter having only two cases identified in 2017, and the former none [Polio Now, 2018]. This is a massive improvement on figures from 2004, when, during an outbreak, one thousand and thirty-seven cases were identified across numerous countries [Polio in Africa, 2005]. Such achievements came about only after lengthy and costly immunisation campaigns, requiring coordination with local governments and international health organisations, since poorer nations often don't have the capacity to fund such projects by themselves.

Nevertheless, the recent outbreak of the Ebola virus in 2014 is a stark reminder that there is still a long way to go for the when it comes to fighting epidemics in Africa. The devastation caused by the virus, which killed over eight thousand people during the outbreak, was exacerbated by the weakness of the economies in the affected nations combined with poor health systems. Overburdened, they did not have the resources or equipment to respond quickly enough to the issue [Elmahdawy et al., 2017].

Another great tragedy is the ongoing battle against Malaria, a disease which affected an estimated two hundred and sixteen million people in 2016, with about ninety percent of the cases and ninety-one percent of deaths occurring in Africa. Despite a global funding of $2.7 billion into Malaria elimination and control, the number of cases in 2016 rose by 5 million on 2015 [WHO Malaria, 2017]. Solutions to tackle the disease involving the design and distribution of products, such as mosquito nets, are being implemented, yet despite a trend decrease in mortalities being observable over the last fifteen years, an estimated 360,000 Africans still die from Malaria every year [MSF Malaria, 2018].

According to Abayomi Ajayi, a Nigerian Obstetrician and Gynaecologist, the greatest need in Africa relating to healthcare is for access. Fewer than 50% of Africans have access to modern health facilities, with many countries spending less than 10% of their national income on healthcare [Clausen, 2015]. WHO figures show that many SSA countries have less than one hospital per 10,000 people. They also show that between 2007 and 2013 there was on average only one dental worker for 20,000 Africans, the shortage being most pronounced in West Africa and Madagascar. Equipment is also scarce, and in most nations MRI scanners are distributed at a rate of less than 0.54 per million inhabitants [Atlas of African Health Statistics, 2016].

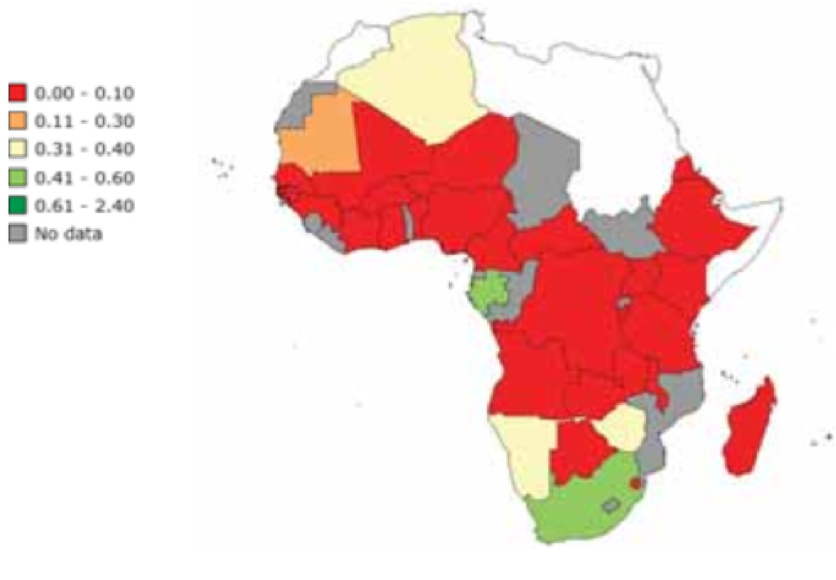

Illustration 1: Radiotherapy units (per million population) in the African Region in 2013, [Atlas of African Health Statistics, 2016]

Technological hindrances to medical care come in multiple forms. Many clinics, hospitals and health centres in SSA lack the basic instruments required for essential treatment. Frequent power-cuts leave centres without lighting and air-conditioning, often destroying reserves of vaccines and stalling electricity-reliant medical procedures [Franco et al., 2017].

Although much of the blame for poor healthcare can be placed on a lack of public funds and the high prices of medical machinery, this problem is seriously aggravated by rampant and systematic corruption which plagues many African nations [d'Agostino et al., 2016]. Empirical research shows that corruption has a negative impact on economic growth [Ugur, 2014], and it is clear that many SSA countries with high corruption also have an acutely low HDI rating. The size of many bureaucratic African governments, combined with a lack of transparency and accountability means that it is easy for officials to cream off money for themselves from public funds and international aid [d'Agostino et al., 2016]. Without addressing this issue, Africa will struggle to implement a successful healthcare system.

To illustrate: the transportation of expensive medical equipment through international customs can be hindered by numerous requests for bribes. Conversely, in the pharmaceutical realm, bribes can be used to allow unsafe or ineffective drugs to pass quality inspection tests [Clausen, 2015].

As regards energy, hospitals and health centres are one of the major consumers. Whilst the level of development in a nation is directly demonstrated by its energy supply, so its ability to deliver effective healthcare also depends on access to power. Hospitals require power both for the basic functioning of the facilities (lighting, temperature control, ventilation, etc.), and also for many medical processes and machines relating to diagnosis and treatment. Without these, the effectiveness, eventually even the usefulness of the facilities is affected. And poorly equipped hospitals can lead to a loss in staff, as dissatisfied doctors move away in search of a better work environment [Fanco et al., 2017].

Distribution of medical supplies are similarly affected by power-cuts, and it was estimated that 150 million vaccination doses were wasted across the developing world in 2007 due to issues relating to refrigeration [Hayford et al., 2011].

1.2.2. Water

The sixth SDG focuses on access to clean water, and SSA is one of the world's regions with the worst performance in providing it. With 66% of the population of Africa living in arid or semi-arid environments, it was estimated in 2014 that at least a quarter of the population spends more than half an hour collecting water, and that 115 people died every hour from diseases linked to poor sanitation, and water contamination. In that year, 40% of the total population of SSA had no access to improved source of drinking water. Even within SSA, the likelihood of a household having access to drinking water is significantly affected by its wealth, while an ever-growing population places strains on available water supplies in both rural and urban areas in different ways [Water for Life, 2014].

Improving access to drinking water creates many benefits for a community. On the one hand, there is a reduction in illnesses resulting from drinking unsafe water (e.g. cholera), an improvement in hygiene as people wash more often, and unsurprisingly, a decrease in the number of deaths caused directly by dehydration. On the other hand, the time and resources (often financial) saved by the members of the community tasked with collecting water can be invested in other ways. Since women are usually responsible for collecting water, sometimes spending hours every day on the task, they become able to use their time more effectively by generating income or studying [Lewis, c2018; What makes water important?, c2015].

Factors pertaining to the failure of distributing clean water in Africa include both the scarcity of clean water reserves as well as concerns of mismanagement, pollution and a political unwillingness to address the issue. Though access to clean water has been a long-standing problem in rural areas, it is becoming an increasing source of worry in large cities too, as the population growth severely outstrips current ability to provide for it. This raises socio-political concerns, as water becomes a scarce resource with strategic value, leading to the potential of futures conflicts [Dos Santos et al., 2017].

The urban population of SSA is set to triple to 1.1 billion by 2050 from the 346 million in 2014. Much of this growth is considered as being “spontaneous”, meaning unplanned, leaving many with an inadequate provision of essentials such as water. In fact, much of Africa’s urban water systems haven’t developed much since the colonial era, when they were used as a tool for social segregation. Nearly two-thirds of urban dwellers live in such underdeveloped areas, twice as many in other developing countries, with 24 million of them suffering perennial water shortages [Dos Santos et al., 2017; Hungerford & Smiley, 2016].

In rural areas, where the population is much more spread out, it is not financially feasible for African governments to expand their water distribution systems across vast stretches of land. Instead, rural Africans have typically relied on either wells, nearby streams or water-holes, none of which meet the WHO recognised criteria of improved water sources. Many attempts have been made to supply better drinking water to villages across Africa both by governments and by foreign and local NGOs, primarily by digging wells and attaching water-pumps. However, they have met with mixed results, and many constructed water points across the continent are abandoned shortly after their completion [What makes water important?, c2015].

Briefly considering agriculture, a 2013 report by NEPAD surprisingly commented that Africa’s water resources are under-exploited when it comes to farming, stating for example, that only one-third of the agricultural potential of Africa’s rivers is currently exploited. This is largely because the water resources are unevenly distributed and because inefficiencies in farming practices render an increased exploitation of the rivers uneconomical [Agriculture in Africa, 2013]. It's also worth remembering that water used in agriculture doesn't require the same standards of purity as water used for drinking and washing, and so farmers are able to use sources that would not be suitable for providing drinking water, such as rivers, lakes and seasonal pools. Indeed, most Africans practice subsistence farming, relying on seasonal rains. Unfortunately, this leaves them highly vulnerable to climate changes [What is Subsistence farming?, 2014].

One other serious factor threatening the water security of many African villages is the desertification of vast swathes of land cause by global warming. In the Sahel region, the semi-arid stretch of land contouring the southern side of the Sahara, the average temperatures have increased over the last thirty years, in some places by as much as 2°C. The total rainfall has declined, leading to a reduction in foliage density and placing strain on the food systems. Of the 60 million people living in the Sahel, about half face food insecurity in connection with climate change, and are left confronting the fact that the situation is likely only to worsen [Epule, 2017].

1.2.3. Energy

Due to the far-reaching consequences of energy access on development, it is worth looking into it more deeply. According to the World Economic Forum, 62.5% of Sub-Saharan Africans lived without access to electricity in 2017 [Energy Access Africa] and the poorest among them paid 80 times more for their energy than the typical Briton [Energy Africa Campaign, 2018]. Over the five-year period from 2008 to 2012, SSA's energy consumption equalled a mere 1.9% of the total global consumption [Kodongo & Ojah, 2016].

The significant failures in the national provision of electricity show up both in the rural areas where there are no sources of power whatsoever, and also in the urban centres where the unreliability of electricity also causes great problems. Villages and towns have developed entirely off-grid, with no provision of such basics as electric lighting to their houses and schools, while in cities businesses and services which rely on electricity are intermittently and unpredictably cut-off due to power outages. [Lighting a dark continent, 2014]

Although harnessing electricity is only a fairly modern invention, its benefits beginning to be appreciated in the 19^{th} century, the standard of living and comfort that is enjoyed in the Global North would not be possible without it. Indeed, electricity is a major factor in just about every aspect of Western society, from transport by electric-powered trams and trains through lamp-lit streets, to preserving foods and medicines, and to the vacuum-cleaning and ventilation of modern houses. Electricity is also a fundamental basis for the ICT world, modern computing and the internet, a platform on which so many businesses rely. For a country to run a modern, functioning economy, and to eradicate poverty, electricity is essential, as we will now see.

We will look separately at the issues facing rural and urban populations.

a) Rural

A report published by UNHESA in 2014 claimed that globally, electrifying schools naturally entails many social benefits, both in the educational sphere and also in other aspects of society. For example, providing electric lighting means that students can study beyond day-light hours, no-longer needing to gather in dangerous places such as street-lit car-parks to complete their homework; studying by candle-light often leads to house-fires. The UNHESA noted a trend improvement in the academic performance of students in electrified schools, from an increase in enrolment and attendance rates, through to higher completion rates too [Electricity and Education, 2014].

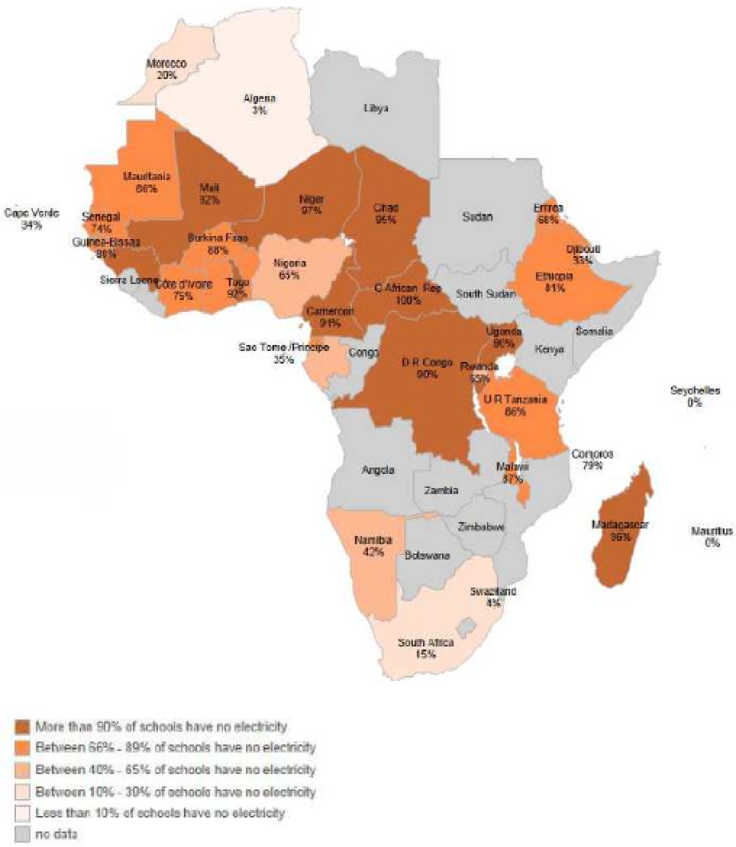

Illustration 2: Schools without electricity in Africa in 2014, [Electricity and Education, 2014]

Electricity in schools also means that they can install computer systems, opening up to their pupils and staff the world of ICT. The use of computers and photocopying machines helps teachers to deliver more effective lessons, and allows students to develop themselves along professional paths which the schools could not otherwise teach. For example welding, carpentry and engineering all make use of electrical power-tools. Nevertheless, the greatest benefit for students, without doubt, is access to the internet and the ability to interact with the wider world, and exposing them to the wide scope of information there available. Correlation between internet access and income levels, trade openness, and literacy levels have been measured. Staff retention is higher in better equipped facilities, and recruiters are able to find better teachers, improving the quality of lessons for the students. The internet can act as a bridge connecting ordinary African to the world, levelling the playing field with richer and more developed countries, and opening a world of opportunities to the youth [Electricity and Education, 2014].

Still, the study claims that though several countries did not publish such figures, the vast majority of SSA schools still have no access to electricity. This means that 90 million African students attend schools without electricity, including about 90% of primary school children. And migration is a serious issue whereby students move away from their home communities in order to find better employment opportunities in the large urban centres, or even abroad [Electricity and Education, 2014].

Along with the educational rewards, other easily measurable benefits of electricity are apparent. When it comes to the household environment, electricity is primarily used for two purposes: lighting and cooking. Besides the already mentioned benefits of students being able to study in the evenings, switching to electricity as an energy source offers various advantages. African households which cook their food and heat their houses by the traditional way of burning biomass (charcoal, straw, wood, dung, and sometimes kerosene) often suffer health-related consequences from the indoor pollution. Smoke from the fires can cause serious damage to the lungs of people who are regularly exposed, increasing their vulnerability to disease, infection and even death [Electricity and Education, 2014; Rahut, 2017; Spalding-Fecher, 2005].

Switching to electricity can reduce much of the strain on natural resources associated with burning charcoal, particularly around large urban centres such as Dakar, Addis Ababa, and Dar es Salaam [Zulu and Richardson, 2013].

b) Urban.

Whilst the lack of connectivity to the electric grid is a serious issue in the rural parts of SSA, equally damaging to the impoverished economies is its unreliability for those who depend on it. The World Bank estimated that blackouts were responsible for lowering the GDP of African countries by 2.1%, with many countries struggling to provide adequate power even for those who were connected [Onishi, 2015]. Despite energy production having begun in Nigeria in 1882, the ageing infrastructure is only able to provide consistent electric power to the connected 40% of its population, and that for only about 40% of the time. As a result, almost all businesses in Nigeria run petroleum powered generators, pushing the cost of electricity painfully high, rendering the economy dangerously dependent on oil, whilst hindering the development of other sources of energy [Aliyu et al., 2013].

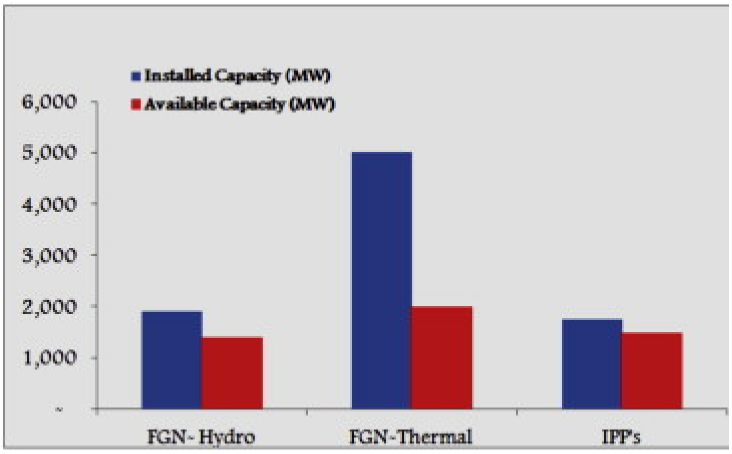

Illustration 3: Nigerian electricity production, installed and available capacity, [Aliyu et al., 2013]

Aliyu documents that even though demand for grid energy drastically outstrips supply, Nigeria's power-plants are not producing at full capacity. This shocking reality is caused, he explains, by poor training of the workforce, the scarcity of spare parts, weak distribution infrastructure, theft of equipment, corruption and by the shear age of the badly maintained machinery. During the 1990s, government funding to the power sector was cut almost completely, and despite a recent renewal of interest in the sector, has resulted in today's electricity crisis. Along with the recent change in policy, 20 independent power producers (IPPs) were licensed in 2011, in the hope that the private sector can make up for the short-comings of the national producer controlled by the federal government of Nigerian. Nevertheless, constructing new infrastructure takes time, and its benefits will only begin to show with time [Aliyu et al., 2013].

However, beyond financial trade-offs and demands for government investment, Africa is also beginning to come to terms with the need for renewable energy. Whilst most of the continent's power is generated from burning fossil fuels, expanding production to meet the 2030 SDGs is not feasible without embracing renewable energy sources. The use of fossil fuels leads directly to an increase in pollution, contrary to the targets laid out in the SDGs and the Paris climate agreement. Nor does it meet the criteria of sustainability, as global oil reserves are continually being depleted. Although in the short-run, in order to mitigate energy poverty, countries such as Nigeria may consider investing in traditional thermal power-plants [Aliyu et al., 2013], many SSA governments are rising to the challenge of producing sustainable energy. Numerous renewable sources are available in Africa, particularly wind, hydro, solar and biofuels, which we will look into more closely later [Davis, c2018; Bah & Azam, 2017].

1.2.4. Transport infrastructure

One underlying factor exacerbating all of the previously mentioned issues and frustrating attempts to resolve them, is the inadequacy of Africa's transport infrastructure. We consider infrastructure in general as being physical installations such as roads, bridges, telecommunication facilities, water distribution networks, power-grids, etc. relating to transport, communication or providing other services forming residents' consumption bundles, necessary for them to maintain a modern and acceptable standard of living. Having already looked into energy and water provision, we will now focus only on transport. Despite access to infrastructure being proved to be linked to economic and human development, Africa is seriously lacking when it comes to its provision. [Kodongo & Ojah, 2016].

In the field of transport, Africa's road networks comprise strategic trading corridors, in total not more than 10,000 km, which merely link larger population centres. As a result, road access is 34%, far lower than the 50% found in other developing countries around the world. In 2011, a meagre 15% of SSA's roads were paved, and many of those often in poor repair; thus the average road density lies significantly below that of the rest of the world [Kodongo & Ojah, 2016]. With the large continent being made up of 48 mainly small states, the result is that 15 of them are land-locked, roughly a third of the region. This means that the cost of accessing global markets is higher for them, since all goods have to be shipped by road and through international customs' barriers, and the resulting trade volume is lower. The fact that Africa is a fairly fragmented continent, with only limited regional cooperation, does nothing to improve this [Ndulu et al., 2005].

Constructed during the colonial era as an efficient way of extracting the continent's natural resources and transporting them to the coastal ports, Africa's railways are also in dire need of overhauling. Following the post-independence break-up of SSA into smaller nation states, many of the rail lines were left straddling borders, and with reduced markets for transport. Combined with poor management, the railways failed to compete with the increasing use of road transport. Developing or running an effective railway line requires a large amount of coordination and investment which many African governments were unable to provide, and, with the exception of South Africa, rail transport across the continent stagnated and declined. Despite concessions by the World Bank and other donors during the 1990s, the Africa's railways never properly recovered [Rail Infrastructure in Africa, c2015].

For all Africa exports large quantities of raw-materials to developed nations each year, its sea-port capacity remains small. With changing global shipping trends, and an emphasis on using ever larger vessels, the size-constraints of many ports mean that they miss out on much potential trade [Trujillo et al., 2013].

Infrastructure is a significant influence in the creation of wealth by firms and households alike. It reduces the operating costs of companies, by allowing them to move products and resources quicker and cheaper. It demonstrates a government's commitment to improving the conditions of doing business, and desire to support economic growth. On the household level, improving transport allows for higher economic mobility, meaning people are able to travel in search of work. It enables better circulation of goods and services, resulting in a higher standard of living, better nutrition, and access to healthcare, etc. On the macroscopic level, transport infrastructure impacts directly upon trade, and the current situation puts Africa at a serious competitive disadvantage [Ndulu et al., 2005].

1.3 Solutions

"Improving the welfare of people in Africa requires sustainable development supported with peace and stability, and with human, institutional and organizational capacities to address immediate challenges, such as poverty, diseases and cultural diversity" [Omwoma et al., 2017].

In this section we will look at solutions currently being employed to address the issues in Africa, in the context of technology and mechanical engineering. The recent explosion in the use of mobile phones and ICT across the continent is topic all of its own, and so won't be address here, being already amply covered by recent literature [see for example: Njoh, 2018; Asongu & Nwachukwu, 2018; Kabbiri, 2017].

1.3.1. Health

In the literature, the vast majority of discussed solutions to the medical crisis in Africa relate to governmental issues, international communications, data collection and research, medical staff training, and in the case of epidemics, improved preparedness [see for example: Kollmann et al., 2015, Rojek et al., 2017, Viboud et al.,2017]. Nevertheless, in looking for a crossover into the realm of engineering, there are also calls for work to be done on infrastructure [Macdonald et al., 2014; Sam-Agudu et al., 2016].

It makes sense that an improvement in, for example, the road networks would allow for a wider distribution of modern healthcare, as well as reducing the transport time of supplies. Due to short shelf-life and the unreliability of refrigeration, many medicines are not widely stocked and have to be collected by rural medical clinics from more central locations and towns. This becomes particularly difficult in situations where patients need to be treated immediately, considering that the procurement of life-saving supplies in remote areas can take longer than four hours [Walcut & Leif, 2017]

Nevertheless, the outstanding urgency of issue can't wait until new infrastructure is produced, and some SSA governments are turning to even more creative solutions to deal with the pressing need for an improved supply chain. Certainly, mobile communication plays an ever-increasing role [The health of the people, 2014], but there is also a growing interest in the potential of drone technology to overhaul the distribution of medicines, as we will see in the second part of the paper.

Whilst research is still underway to develop an effective vaccine for Malaria, other measures to prevent infection by the mosquito-borne parasites exist. The use of chemically treated bed-nets, indoor residual spraying, increasing the availability of medication and the speed of diagnosis, as well as the large scale targeting of mosquito populations are methods that have been used with great success [World Malaria Report, 2017]. Campaigns to distribute nets as widely as possible can in many ways be visualised as a typical example of product promotion, with the first step being to convince the public of their benefits. Next comes the question of whether the nets should be supplied for free by the government or other outside sources, or whether the local people should be made to purchase them. The advantage of the second option, provided that the public can be persuaded to purchase them, lies in the fact that people will take much better care of something they have spent money on, whilst freeing up government funds to be used to address other issues. And finally, the nets can be produced locally, providing a stimulant to the local textile industry.

This works primarily due to the simplicity of the products, but other cases, such as the supply of sophisticated medical machinery (MRI scanners, radiotherapy units, life-support systems, etc.), governments will need to consider facilitating imports, until such a time as Africa's manufacturing and health industries develop to a sufficient level in order to build their own machines.

1.3.2. Energy

Whilst Africa may have sadly inadequate energy infrastructure, paradoxically, this remains a huge source of promise for the continent looking forward. With the recent global change in focus towards renewable and sustainable sources, many developed nations remain powered by older expensive and polluting power-plants, and are highly dependent on fuel imports to operate them. Africa now has the opportunity to leap-frog the progressive development that the global north has undergone, and by taking advantage of more recent technology, can become a forerunner in the world of renewable energy [Africa Energy, 2015]

Several nations have seen the benefit of investing in renewable energy sources. In Ethiopia, the government has invested over €3 billion in developing what it calls the "Grand Ethiopian Renaissance Dam", which, once completed will generate 15,000 GWh/year, helping to power the rapid growth of the country's manufacturing sector.

The country benefits from high rainfall in its mountainous regions and there remains much untapped hydroelectric potential [GERD Project, c2014]. Ethiopia has similarly invested in a large geothermal plant. Increasing the potential output goes a long way to forwarding the industrialisation of the country. Once businesses can depend on a consistent source of electricity, they are much more willing to invest in electricity consuming machinery and technology. This creates an environment where local production and servicing are no longer at a serious capital disadvantage compared to imports, allowing the local markets to grow.

Nevertheless, the success of such large projects will certainly be hampered by the limited spread of the electric grid. Perhaps, increasing the available electricity to match the current demand will allow large electric corporations to begin looking at expanding their grids in search of new markets, but this will still take a relatively long time before power comes to the more remote and hard to access corners of the continent. If the SDGs are to be met by the year 2030, another solution has to be found to electrify rural Africa.

One option, which is gradually gaining traction is the idea of microgrids: autonomous power networks supplying a village or small community with electricity. The energy sources usually come from utilising solar or wind power, though are sometimes supplemented by a diesel generator for improved reliability. Although top-down funding is commonly provided to set-up larger grids, smaller sized networks are frequently private enterprises in and of themselves. After an initial investment to provide and set-up the network, the business can run at a fairly low cost using renewable energy sources, and charging for power use, just as any normal electricity supplier would. With the ever-growing demand for electricity in rural areas, often in order to charge mobile phones, and gradually decreasing cost of solar panels, microgrids look set to become a major factor in providing energy to SSA [Nordman, 2018].

1.3.3. Water

Despite being the stereotypical aid project, many attempts undertaken by governmental and non-governmental organisations to provide better water sources (pumps, wells, etc.) in rural villages have resulted in failure. Some estimates suggest that a lack of community involvement causes 50% of these projects to be abandoned, either because the solution doesn’t meet the specific needs of the community, or else because the pump is hard to repair. When a pump is provided for free by an external organisation, many African communities feel no sense of ownership and therefore don’t take good care of the device [What makes water important?, c2015]. Engineering ever more sophisticated pumps doesn’t seem to be the solution, rather, the issue should be approached from the point of view of economics, encouraging local businesses to produce their own solutions specifically adapted to the needs of the people, and selling them at a price which is both affordable and at the same time makes business sense. In several sad situations, foreign intervention and aid has had a negative effect on African communities by distorting fundamental market laws, and stifling local ingenuity [Gerhardt, 2010].

Another facet to the issue of providing water to the continent is the idea of water purification. Purifying water allows unclean water sources to be exploited as well as making better use of water in situations of scarcity by allowing it to be reused. Filtration is seen as one of the most efficient forms of water purification, due to its low energy requirements, and is often more effective, and requires less maintenance and part replacement than other existing methods (such as distillation, photodegradation or electrolysis) [Ying et al., 2017]. We will later look at a business trying to encourage local production of water filters in Ethiopia by using only locally available resources.

1.3.4. Transport

In the field of transport infrastructure, much investment has taken place recently to open up development corridors. Development corridors are defined as networks of transport infrastructure such as roads, railways, sea-ports and so on, allowing for the movement and transport of commodities between land-locked production regions and cities, or the coast for local and international markets. There are currently plans to expand SSA's corridors up to a total of 53,000 km. These corridors have the potential to open up large areas which were previously difficult to access, and allow Africa's rich deposits of raw-materials to be exploited more effectively. And these corridors also hold the potential to unlock development for the communities who inhabit these regions, as well as the areas flanking the corridors and the nations as a whole, provided that they are carefully planned and executed in order to benefit the maximum number of people [Enns, 2017].

The anticipated improvement in infrastructure holds much promise for development in the continent, as ideas and products will be able to circulate with greater ease. Nevertheless, these are long-term projects, requiring consistent funding during construction and then adequate maintenance once completed.

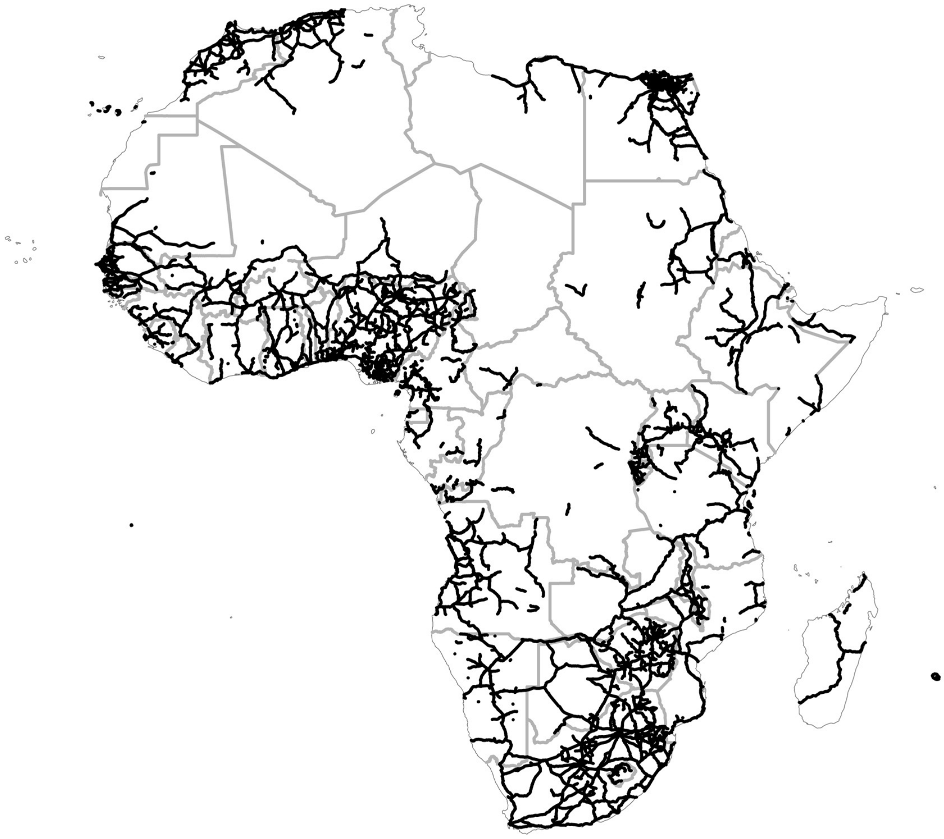

Illustration 4: Main and Asphalt roads in Africa in 2002, [Bonfatti, 2017]

1.4 Analysis of current situation

African governments who want to see their countries develop need to address several issues, and need to do so with careful thought, planning and evaluation. As the biblical proverb goes: *“Plans fail for lack of counsel, but with many advisers they succeed.” Proverbs 15:22 [NIV]*

Firstly, they need to provide an environment where the private sector can thrive, to nurture growth of business and industry. This requires reducing bureaucratic obstacles to new businesses and innovation, and cutting back on corruption. It is important that Africans cease to see politics as the easiest way to get rich, but are encouraged instead to embrace business and are allowed a fair reward for their risk-taking. As long as hurdles are thrown in their way by a corrupt hierarchy of officials using their power to block advances until they receive their cut, new technology companies will continue to be frustrated. Creating a political environment where innovation is facilitated rather than hindered is crucial.

Another necessary requirement is the development of infrastructure. We’ve already looked at the reasons why reliable transport, power networks and water distribution systems are necessary for the population in general, but in the specific situation of the companies developing and producing technology the same holds true. They require the provision of electricity in order to operate machinery, of water, and transport. Without roads, the company will not be able to source raw materials, nor distribute its products. Nevertheless, Africa's lack thereof can also be seen as an opportunity, as the continent has the possibility to recreate itself directly for the 21st century and isn't constrained by existing infrastructure.

Next, governments need to see the opportunities tied up with their young and increasingly urban populations. They need to provide education and train up a new generation of engineers, which requires investment into technical colleges and universities. This however is paired with the challenge to retain their skilled workforce in the country, as so much of Africa's skilled workforce moves abroad to find well-paid employment in the First-World. In order to do this, they will need to guarantee employment for their graduates, either by attracting foreign companies, or by encouraging them to start their own.

On order to do this, many SSA governments are already establishing centres for innovation and entrepreneurship, such as Pretoria's Innovation Hub [The Innovation Hub, 2018]. The leading countries for such centres are South Africa, Ghana, Nigeria, and Kenya. Whilst many of these design hubs focus specifically on software and app development, some of them also try to incubate businesses working in the realm of Mechanical Engineering.

On an individual level, the opportunities for business owners and entrepreneurs who want to develop technology in Africa is huge. Essentially, they are functioning in an untapped market, as so little technology is created with SSA in mind. However, it requires a mindset shift for innovators to spot issues which can be met, and to develop creative solutions to them. Yet in Africa there is plenty of space for trialling and adapting ideas, as initially they are faced with little competition. Ideally, once innovation proves its worth in a community, more people will be encouraged to follow suit, empowering that community to meet its own needs.

A tool recently placed in the hands of African innovators is the internet, and to small start-ups it offers many benefits. Firstly, designers can draw inspiration from seeing how similar problems are solved elsewhere in the developing world, for example in South-East Asia or South America. Then, there is a wealth of information and explanations available online from which much can be learned about developing particular areas of technology. And the internet opens Africans up to global market. Through this they can find suppliers for equipment and materials, as well as advertise and find customers both at home and abroad.

2. Case studies of technology innovators

In this section we will be examining two different companies working in SSA to address the previously highlighted issues with the help of technology. The first step will be to look at the company's specific approach and the solution offered in the context where they work, followed by a discussion relating to their effectiveness, highlighting issues and successes in order to finally evaluate the potential for company expansion, and how the technology can be adopted more widely by the African people.

The reason that we are only considering businesses rather than other institutions, is that viable private-sector businesses offer a way of generating income, and therefore can operate over a prolonged period of time without large inflows of foreign aid money. If developed correctly, they become platforms where communities can meet their own needs.

2.1 Health and transport: Zipline

As far as ambitious solutions to health-care and transportation issues go, the concept of drone-based delivery might at first seem too sophisticated for SSA's current capabilities. Nevertheless, the US based company Zipline has been supplying African hospitals with blood packages and medicines since October 2016. Founded in 2011, and working hand-in-hand with the Rwandan and Tanzanian ministries of health, Zipline has been quietly installing the largest drone distribution network in the world [Domanska, 2017].

2.1.1. Background: Rwanda and Zipline

A relatively small country in terms of size, yet with 12 million inhabitants, Rwanda has a population density of 494.9 people per square kilometre, nearly four times higher than that of the Czech Republic [UN Data, 2018]. Known for its mountainous terrain, Rwanda faces a similar lack of infrastructure as the rest of SSA. A deficiency of paved roads mean that quick transportation can only take place between major cities, and otherwise travel must be undertaken on winding dirt-roads, often impassable during the biannual rainy seasons [Rosen, June 2017]

Though one of the world's poorest countries, Rwanda has been making vast leaps forward in the field of health-care since the genocide in 1994 devastated its health system. Though plagued by AIDS, Malaria and other illnesses, the Rwandan government has been making good use of international aid resources, working towards achieving an internally funded health-care system which provides treatment for the entire population [Wen & Char, 2011; Farmer et al., 2013]. In conjunction with this recent progress, the Rwandan government is willing to consider innovative approaches.

Before 2016, some of the major causes of preventable death in Rwanda came from simply solved issues such as haemorrhaging during child-birth leading to a loss of blood, or snake-bites requiring a specific antivenom [Walcutt, 2017]. Despite having a comparatively well distributed health-care system, a lack of available medication -particularly blood- hampered the efforts of Rwandan doctors to rescue lives [Abbott et al., 2017]. Blood has a very short shelf-life meaning that it needs frequently replacing. This is a serious issue for many rural hospitals in Rwanda, forcing them to make regular trips to the cities along the difficult roads. It also needs to be kept in cold conditions even during transportation, so a power outage can ruin a whole batch of blood. While there are eight main blood types, some are more prevalent than others. Hospitals usually stock larger amounts of the more common types such as O positive, but they often won't store as much of the rarer ones due to a lack of demand. This can cause problems if a patient with a rare blood type suddenly needs a transfusion of a large amount of blood. Restocking blood used to take upwards of several hours, sometime even days, eventually leading to patient deaths [Rosen, June 2017; Walcutt, 2017, Ackerman & Strickland, 2018].

Seeing the opportunity to put cutting-edge technology to humanitarian use, Zipline founders William Hetzler and Keenan Wyrobek along with CEO Keller Rinaudo came to an agreement with the Rwandan Ministry for Health to deliver blood packages on demand by Unmanned Aerial Vehicle (UAV) to hospitals across the nation [Rosen, June 2017].

Zipline uses well-stocked distribution centres, linked with specific hospitals which it supplies with blood when an order is placed via WhatsApp messenger. Should the hospital run out of a particular blood-type, they can contact Zipline, and a drone is dispatched from the distribution centre along a pre-determined flight path to the hospital. It navigates using GPS, and once it arrives over the required location, circles down, reducing speed and altitude before dropping its precious cargo attached to a parachute onto a designated collection point [Rosen, June 2017].

2.1.2. Technology overview

By designing its own drones, the company is able to tailor-fit them to their own needs, whilst guaranteeing their reliability. One of the key decisions in the design process was to use fixed-wing drones (called Zips) which operate much like small aeroplanes, over the traditional multicopter models. The benefits of using a fixed-wing craft are numerous. For one, they have far-greater ranges since their batteries are not directly required to keep them airborne, and can fly at much higher speeds than their counterparts, improving both Zipline's coverage of the country, as well as delivery times. They are also more resilient, being able to fly in rain and strong wind, weather that would ground a typical multicopter drone. This is crucial, since it allows the supply network to function continuously, regardless of the weather [Rosen, June 2017].

Nevertheless, using fixed-wing UAVs also comes with some drawbacks, mainly related to take-off, delivery and landing. In order to fly, a fixed wing aircraft needs a certain velocity relative to the surrounding air to generate enough lift to counter the force of gravity acting on the aircraft. They are therefore not able to take-off and land vertically in the way multicopters do (generating vertical lift by their spinning propellers). Zipline uses a high-speed catapult mechanism to launch its drones into the air, and they land on a crash-mat having been slowed down by the help of an arresting hook [Ackerman & Strickland, 2018]. However these issues are far less significant than the question of how to safely deliver their parcels from the air. Zipline's solution is to use a disposable and biodegradable cardboard box with an attached paper parachute which is discharged from the aircraft during flight. The Zips circle in on a predesignated drop-off site, usually an open space, and calculating for wind direction and speed, release their parcel at a low altitude. Its current precision is about five metres [Rosen, June 2017].

Comparing Zipline's drones to a similar concept developed in 2014 for medical deliveries in Germany, the Zip outperforms DHL's Parcelcopter 2.0 multicopter in three areas. It has more than double the speed and six times the range, also with a slight advantage in payload capacity and the important benefit of flying in all weathers [Zipline, 2018, DHL, 2016].

DHL have since upgraded their UAVs to a hybrid model with the release of the Parcelcopter 3.0, a similar development path to the drones designed by internet retailer Amazon. This shows the superiority of the fixed-wing model's transport capability, whilst permitting vertical take-off and landing. In Zipline's situation, developing such a sophisticated hybrid model is not cost-effective, and their current take-off and landing solutions are perfectly adequate.

Table 1: Drone comparison

	Maximum Range [km]	**Maximum Speed [km/h]**	**Pay-load [kg]**	**Weather Conditions**
Fixed-Wing Zip	75	110	1.5	All
Parcelcopter 2.0	12	43	1.2	Not rain

Source [Zipline, 2018], [DHL, 2016]

Considering the African environment, with a widely distributed and largely rural population, the fixed-wing drones show numerous advantages. These are particularly pronounced when considering applicability in areas that receive large amounts of rain. In Equatorial Guinea for example, some parts of the country have an average annual rainfall as high as 2400mm or more [Equatorial Guinea: Climate, c2018]. Nevertheless, Africa continues to urbanise, and although drones aren't needed for medical deliveries in cites, where vehicular transport is a better solution, developers of UAV technology for other uses may want to consider the effectiveness of multicopters, since large distances don't need to be overcome and yet space for take-off and landing is limited.

The largest disadvantage is most likely the limited size of the pay-load. Only being able to carry 1.5kg at a time, the Zips remain unsuitable for transporting larger objects or people. This removes any potential in the near future of them being used as an aerial ambulance, transporting seriously ill people swiftly to a well-equipped hospital in the capital.

Despite its humanitarian focus, Zipline runs as a business, charging the Rwandan government per delivery. Whilst neither Zipline nor the Rwandan government will reveal the cost of each flight, they have confessed that it is not cheaper than an ordinary supply trip by road [Rosen, June 2017]. Given that the Zips can carry only a limited quantity of products, they are unlikely to be used for restocking supplies in higher demand, such as more common blood types. Their effectiveness in emergencies however is incomparable, and in August 2017 they were delivering 20% of the nation's blood-supply outside of the capital [Walcutt, 2017].

In addition to the current distribution centre Muhanga in Rwanda, the Zipline intends to build another centre in the East. Equipped with the next generation of increased-range Zips, Zipline will then have the capacity to supply all of Rwanda's hospitals [Rosen, June 2017].

The requirements of setting up a distribution centre are numerous, and since operating them leads to an increase in running costs and overheads, Zipline will want to have as few as possible for their service. Firstly, the centre must be in an easily accessible location, with no risk of being cut-off during the rainy seasons. Since the regular deliveries to the centres are done by truck, the most logical location is along a main road, or else near a major and well-stocked city. Next, the centre must have a reliable source of electricity, and therefore will need its own generator. It can connect to the local network as well, for cheaper power during "up-times" when the network is functioning, though this is not imperative. The distribution centre requires electricity for refrigerating the blood stocks, charging the drones' batteries and for powering necessary technology, such as tablets and phones for tracking the drones' flights and receiving delivery orders via WhatsApp. And finally, it's important to consider the placement of the distribution centre in relation to the range of the operated UAVs. As the current Zips have a range of 75km before needing to return for a recharge, the distribution area of the centre can be considered as a circle of diameter 150km, with some adjustment for wind-direction. The drones will be able to supply any hospital within this radius. It's also important to consider the delivery time. Zipline intends to reduce the wait between ordering and collection to 15 minutes, and one of the key factors involved is the distance of the hospital from the distribution centre. Naturally, the further the distance, the longer the flight time. A drone flying the full range of 75km at the maximum speed of 110km/h will take 41 minutes to complete the delivery. The location must be chosen in order to be able to service as many hospitals as possible in the shortest time possible. This evaluation is reflected in the choice of location for Zipline's first centre in Muhanga, 30km along the main-road leading west out from Kigali, the capital. Sitting in a very central location, the distribution base is able to reach most of the western half of Rwanda, with 21 hospitals lying within the 75km operating radius [Ackerman & Strickland, 2018].

It may be that Zipline's greatest achievement is its successful cooperation with the government of Rwanda. Criticised for a poor human rights record and no tolerance of opposition, Rwanda's government doesn't appear much different from that of many other SSA countries. Yet the leaders of the small country have done an outstanding job in regard to economic development, leaving an uncomfortable quandary for Western development agencies with a strong emphasis on human rights [Rwandan critics targeted by government, 2017]. The government of Rwanda has come under criticism by its people for investing in seemingly far-fetched technology, when the country still suffers from acute poverty and is lacking essential infrastructure such as roads, and relies heavily on international aid [Rosen, June 2107]. Certainly, Zipline solves the problem of blood distribution, but for other reasons such as transport and trade, the roads will eventually still need to be built. Questions of conscience aside, Rwanda's willingness to take a risk on an unproven technology is a remarkable example of Africa's potential to leapfrog forward. While the lawmakers of developed countries debate the issue of regulating, sometimes even of permitting drone technology, Rwanda has actively partnered with Zipline, modifying legislation and allowing them to register with the civil aviation body [Rosen, June 2017]. Rwanda is something of a guinea-pig, a test-case for more hesitant nations, and the outcome of the experiment will impact on legislation across the world, even on the future development of UAV technology.

2.1.3. Expansion and wider impact

The wider impact of Zipline's work will become more visible over the next few years, both directly as the country expands, and also in other projects and initiatives which it inspires as it paves a way for others to follow. In this next section we will discuss this impact, evaluating areas that offer potential, and considering obstacles which will likely hinder any progress.

A logical place to start is the expansion of Zipline itself. Having impressed Rwanda's larger neighbour, during the course 2018 the company is rolling out a similar distribution network across Tanzania. A country of nearly five times the population of

Rwanda and similarly mountainous, Tanzania is a large step-up for the company [UN Data, 2018]. Indeed, Tanzania also has thirty-five times surface area of Rwanda, meaning the population is spread much more thinly. In order to supply such a population, Zipline is intending to open four distribution centres [Walcutt, 2018].

Seeing as four centres aren't sufficient to cover the land surface of the whole country, Zipline must be working with the fact that most of the population live in a band across the north of the country and in the far south. Targeting such areas means that Zipline can keep its distribution centres to a minimum number, whilst being able to supply a maximum proportion of the population and hospitals. Although this leaves several health centres without access to blood drops, as a business Zipline is constrained by the need to be profitable.

Otherwise, Zipline has shown in Rwanda that its drones are more than capable of handling the type of mountainous terrain encountered in East Africa.

The concern with regards to population density brings into question the applicability of a drone delivery system in countries with a particularly spread-out population. Rwanda has an exceptionally high population density, matched in SSA only by its neighbour Burundi. Most of the countries in the Sahara/Sahel area, as well as around the Namibian Desert have a population density of less than 26 inhabitants per square kilometre, sometimes even as low as 3 or 4 [Index Mundi, 2018]. Another issue with these countries which remains to be proven is whether the higher levels of dust in the air and the heat will cause damage to the drone motors and to their control systems.

Nevertheless, the expansion shows a new trust in the company's ability to deliver on its promise of revolutionising blood-distribution. Zipline's CEO Keller Renaudo comments that they are currently in discussion with several different governments about the possibility of setting up networks around the world [Ackerman & Strickland, 2018]. Their website has job listings for business development executives in West Africa, South-East Asia and Latin America, showing the ambition of the company to develop globally [Zipline, 2018].

As Zipline expands to Tanzania, they are also increasing the range of products they distribute. In Tanzania they will be supplying other items required in emergencies, such as antivenom. Because these products aren't often needed and are expensive to stock, many medical centres don't keep reserves. Zipline will be able provide them on a needs basis across the country. They are also considering providing more common medication as a "last line of defence" in the case of stock-outs or crises. This means that they won't be the primary distributors, but in the case of a shortage, their drones can be dispatched to quickly deliver them where needed [Rosen, August 2017]

Starting out in Rwanda was probably the safest option for Zipline, due to the country's population density, the willingness of the government to take radical steps to improve its healthcare service, as demonstrated over the last few years, and also due to its size. Having to only supply a smaller population means that Zipline had room to "practice", gaining experience implementing their services in the African context. Now that they have demonstrated their ability to deliver, they can expand quite rapidly.

The elephant in the room, which hasn't been addressed yet is Zipline's business model. It is indeed an American concept, the brain-child of Harvard graduates, brought to life by investment from the USA [Rosen, June 2017]. Every part of the design is generated at the company's California headquarters, by a team of aerospace engineers pilfered from giants such as SpaceX and Boeing. This is a spanner in the works of African development, since it means that all the engineering expertise is kept outside of the continent, and blocking Africans from having hands-on experience with the design process, and learning to independently develop solutions to their own problems. In many ways this reflects a kind of neo-colonialism, where power, resources, even responsibility for basic decision-making lie in the hands of the Westerner. By not training locals in the process, Africans remain only customers, unable to shape the technology in the direction that they see as most important to benefit their communities. While this presents a serious limitation to the concept of sustainable development, there are still a few reasons to be optimistic that Zipline will to some extent lead Africans in developing their own technology.

The primary one is the potential of Zipline to inspire. Children playing in the fields watching the drones flying overhead may be inspired to learn how to build their own, the technician who has spent several years repairing them will have a good understanding of their working, etc. Increasing access to the internet will allow people to research much for themselves about drone design.

Another reason is Zipline's cooperation with the African governments. Although other companies have managed to work with them on a large scale in the past, these are usually in the category of mining or oil firms, often securing contracts by promising large cuts to the officials who stamp the paperwork. Many of these companies come purely to export Africa's rich natural resources, not caring for the welfare of the nations in which they are working. For a government to be willing to make a large investment in health-care is a very promising sign of change in the continent. And considering Africa's weakness in maintaining infrastructure, it may be a good thing that there is a foreign company involved in the continual supply process, at least until such as time as the locals learn how to do it themselves. Note that a contract with Zipline is no one-off investment in expensive machinery, by rather a long-term payment for services.

The biggest source of risk that Zipline has to face comes from the -often unreliable- governments of the countries where they work. Since all their profit has been coming directly from one customer, defaults on payments would have dried-up the company's single source of revenue. Their options to minimise this risk are to expand as they currently are in order to spread themselves over several nations, or to find other customers, such as the private healthcare sector, or to enter the cargo delivery market. As a business with a humanitarian focus, Zipline has so far been unwilling to consider branching out into other sectors than the distribution of essential medical supplies, and they are already in the process of implementing the first option. However, a fall-out with a government would mean that they would have to leave an entire nation, which would be damaging to the company, and more significantly still, a matter of life and death to the many who rely on their services. If other companies enter the market, particularly ones run by Africans who understand the culture better and are thus more adept at communicating with local governments, in the case of a dispute between a firm and a government or else a potential bankruptcy by the firm, a competitor would be able to quickly replace the hole left behind.

Whilst numerous African drone companies have been springing up over the last few years, such as Aeroshutter and Rocketmine, these work more-or-less exclusively in the realm of image taking and processing. Their services are particularly aimed towards mining and telecommunication companies providing 3D volumetric image processing, and it seems that cargo-drone development is still a long-way beyond their reach. Taking advantage of the decreasing cost of commercially available and Asian-build drones allows Africans the opportunity to gain experience working with them and adapting them to profitable uses [Bright, 2016]. However, until Africa develops its own research and design centres and starts to build drones for itself, it looks set to continue in the familiar pattern of merely adapting technology build elsewhere, producing only limited solutions.

In conclusion, drone technology is set to continue improving over the next few years, and Africa has shown initiative in embracing it. By decisive action, African governments and organisations have the opportunity to direct the course of UAV development to meet their own needs, and to overcome many of the continent's challenges.

2.2 Potable water: Desert Rose

With the transition from the MDGs' focus on water accessibility to the SDGs' call for the provision of improved water sources of acceptable quality helps us to understand a previously little mentioned dynamic affecting the lives of many Africans. As has already been explained, access to clean water is a vital part of the developmental process, with a particularly significant role in the areas of health, gender equality, education and poverty. Providing households with a local source of potable water saves the time spent fetching and carrying it every day, reduces the water-borne diseases and medical-bills, allowing these resources of time and money to be better used for education or economic activities.

While many organisations and governments in the past have attempted to solve the issue by providing water filters and wells to rural communities, much effort has gone to waste as these often aren't accepted by the local community, or else they break-down and then aren't repaired. One Ethiopian development company, Desert Rose, has branched out from its consulting roots to begin the production of its own model of water filter, calling for human-centred design. We were able to contact the engineer behind the design of the filter, Andrew Smith, and much of the following information was obtained directly from him.

2.2.1. Background: Ethiopia and Desert Rose

Ethiopia, a country of ninety-nine million people, has a diverse range of climates. From mountains of over 4,000 metres high, down to the bottom of the Rift Valley well below sea-level, and from fertile high-lands through to parched deserts, Ethiopia represents not just a mixture of climates, but also of ethnicities. Suffering from serious droughts in the 80s, the country became a huge recipient of international aid. In the 90s, Ethiopia received a fifth of the total aid sent to SSA. Sadly, though the rains returned, many Ethiopians remain even today cripplingly dependant on food and support from outside [Broussard et al, 2014].

Although the government takes development very seriously, it has prioritised investment in expensive infrastructure projects, such as the Grand Ethiopian Renaissance Dam, and a new rail-way network across the country, as well as others in the capital, such as the light-rail. These investments may well bring rewards at some point in the future, however it leaves much of the population stranded in cruel poverty in the mean-time, even as relief-aid from abroad often does little towards improving communities' ability to develop themselves.

One of the biggest areas where this is visible, is the lack of access to improved water. Staggeringly, 61 million Ethiopians don't have access to safe drinking water, well over half the population. With many women and children walking more than three hours each day to collect the water from open wells and ponds shared by animals [Ethiopia's Water Crisis, c2018]. A 2016 survey shows that only 6% of rural Ethiopian households treat their water using suitable methods [Butterworth, 2018]. Another issue is elevated levels of fluoride the ground-water of the Rift Valley, causing Osteofluorosis and dental issues to those who drink it regularly [Rango et al., 2017].

Water can be purified either at the source or at the point of use. In urban situations with a mass-distribution network, it makes sense to clean the water before it enters the system, though concerns remain about contamination before its eventual consumption. In the rural context, where there is no distribution network, one approach for improving water is for households to purify their own using a filter. Filters are available either by import or as specifically designed models such as biosand and clay filters, which can be produced locally.

Imported filters usually have a high performance level when it comes to bacteria removal, however, their price can exclude many rural Ethiopians from being able to afford them. Tiva, a biosand filter model produced in the USA costs about $100 per unit, and as a charity, the TivaWater is limited by donations as to how many filters it can provide. Other highly effective Western-made water filters are also available on the Ethiopian market, such as various Sawyer models and BWN's Tulip filter, however the price is similarly an issue, particularly as there is a shortage of foreign currency in the country, and thus power to buy imported products.

As for locally made products, two basic options exist: biosand filters, and ceramic-pot filters, both of which can be manufactured at low cost and neither of which have been completely effective in removing bacteria during field tests [Mwabi et al., 2011; Sangol & Spuhler, 2018].

Ceramic-pot filters, made from porous terra-cotta and in some cases coated with colloidal silver, were developed and popularised by the organisation Potters for Peace during the 1980s. Colloidal silver has antibacterial properties, which attack the remaining bacteria which are able pass through the clay, increasing the filter's effectiveness. They can be produced in a fairly basic workshop and quite cheaply, though they are heavy to distribute and fragile. Potters for Peace does not actually manufacture the filters, but supports local initiatives to do so, creating a source of income [Potters for Peace, 2018].

Bio-sand filters, a system where water is drawn through layers of sand and gravel, while a naturally occurring and harmless schmutzdecke or biolayer develops on the surface, competing for food sources with the organisms in the water. The water is then filtered down through the sand, straining out contaminants as well as some of the remaining pathogens, significantly improving the quality of the water which collects at the bottom of the filter. This is then syphoned off into another container, to be stored and consumed. Biosand filters have been highly publicised by the Canadian Center for Affordable Water and Sanitation Technology (CAWST), due to their simple and easy production which doesn't even require workshop capabilities. Their key disadvantages however, are their sheer size and weight, which renders them hard to move, and also their low performance in contrast to other types of pumps [Sangol & Spuhler, 2018; Young-Rojanschi & Madramootoo, 2014]. Although able to perform well in laboratory settings, in the field most filters report an effectiveness of 91% when it comes to E. coli. bacteria removal [Smith, 2018].

As a small organisation of locally based consultants working in the realm of Household Water Treatment and Storage (HWTS), Desert Rose set themselves the challenge of designing a filter which met all of the following criteria: a light-weight filter which can be manufacture directly in numerous developing countries, and which has a sufficient flow rate for household use whilst removing a satisfactory quantity of bacteria. After a research phase, they concluded that a granular filter medium was the most viable option, and in September 2017 they opened a workshop to produce the "Minch" filters with an output capacity of 100 filters per month [Smith, 2018].

2.2.2. The technology

Desert Rose's Minch (meaning "Spring" in Amharic) filter is composed of a cylindrical aluminium container, with two 15 litre water storage chambers inside. The top one, into which contaminated water is poured, is separated from the bottom chamber by a layer of filter medium through which the water must pass. Clean water can be obtained from the bottom by turning a tap.

Whilst unwilling to disclose the exact sources of materials, Andrew Smith explained that the filter medium, produced from rocks by a milling and crushing process, is in no short supply, and is available in many countries. The total weight of the filter cartridge is about 6kg [2018].

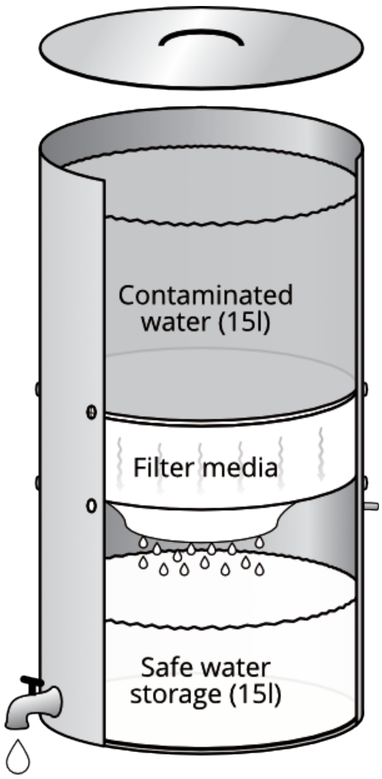

Illustration 5: Minch filter design, [The Minch Filter, 2018]

Many benefits are tied to the fact that the Minch filter is produced locally by consultants who understand the specific environment. Primarily, the support it provides for the local economy, by employing local labour and using local resources. Indeed, for their production, Desert Rose employs staff with hearing-impairments who might otherwise struggle to find work in the local labour market [Smith, 2018]. Another advantage is the reduced cost of producing the filters locally. They have a fairly basic design, the raw-materials are available, and the cost of labour in SSA is quite competitive. This advantage is of particular relevance to Ethiopia as a land-locked nation: all imported products have to be shipped to ports in Kenya, Tanzania, Djibouti, or Somaliland before being transported a minimum of 500km through a land-border and along questionable roads. In regard to this and also to Ethiopia's shortage of foreign currency, the Minch filter has a financial advantage over imported ones.

Now we can compare the performance of the Minch filter to that of its two local rivals, the Biosand and the Clay-pot models. Using independent data measured during a field test by the Ethiopian Kale Heywot Church Development Commission (EKHCDC) and supervised by CAWST, we are able to make the following comparisons. EKHCDC compared seven different filters, by distributing several of each type to families living in a rural village. After three months they collected the first round of results. Unfortunately, the published data doesn't include exact values for flow rate, so the following figures have been approximated from a bar-graph.

Table 2: Filter comparison

	Mean E. Coli Removal [%]	Approximate mean flow rate [ml/min]
Minch	99.99	30
Biosand	88.98	110
Clay-pot	95.14	60

Source: [The Minch Filter, 2018]

It's interesting to note that the Minch filter also outperformed imported filters such as the Sawyer in terms of bacteria removal.

Whilst the average flow rate from the Minch filter is lower than the Biosand and Clay-pot filters, it is still sufficient to adequately supply drinking water for a family.

As far as price is concerned, the Minch retails at about $20, and Desert Rose insists on the filter being sold and not given away. Minch's designer Andrew Smith argues that selling the filters allows customers to decide for themselves whether or not they want the product, exposing it to the natural refining process of a free market. Requiring customers to make an investment in the filter also means that they will understand its value. This is why Desert Rose functions as a business, and not an aid organisation. Nevertheless, they provide their product at the lowest possible commercially viable rate, in order for their filters to be bought even by the poorest families across the country, providing the cheapest filter cartridge available [The Minch Filter, 2018]

Initial tests also confirm the Minch's potential for removing fluoride from water, a feature which may particularly benefit communities living in the Rift Valley, though this is still under development [Smith, 2018; The Minch Filter, 2018].

Being housed in an aluminium container means the filter isn't affected by rust, and the end product is more robust and durable than those with plastic containers whilst retaining a lighter weight. Desert Rose hopes that the metal housing will give the filters an element of prestige and desirability, characteristics to not be underestimated when trying to influence community acceptance of the filter [The Minch Filter, 2018].

The clean storage compartment under the filter is also vital, as it stops contaminants from re-entering the water once it has been filtered. Instead of storing the filtered water in a bucket or other container, owners of a Minch filter are encouraged to drink water directly from the filter's tap. The tap also offers the advantage that separate cups or scoops aren't dipped into the clean water, possibly transferring pathogens back into the container.

In terms of maintenance, the filter must be cleaned about once a week. This is done by simply wiping the top container round with a cloth, and sponging out the remaining dirty water at the bottom of the filter. The user should not open the clean storage tank. The filter cartridge needs replacing every two years, and for this it is important the Desert Rose develops their distribution chain and of replacement cartridges. Because the whole filter does not need replacing, the cost for the new cartridge should be far less than the initial investment in the filter [The Minch Filter, 2018]. However, as the filters have only been in production for six months, it will still be a while before any real assessment of the long-term maintenance requirements and end-of-life of the product can be conducted.

In terms of the initial distribution of the filters, Desert Rose has secured contracts with Oxfam to produce 800 filters, which they will distribute in the eastern Somali region of Ethiopia. This provides a strong initial boost for the company, as they have a sure customer during the launching phase of production, and also allows their product to become more widely known. They also offer Ethiopians the possibility of selling their filters on commission, meaning that they can build up a network of local salesmen [Smith, 2018]. This is particularly advantageous as many of their customers live in rural settings, and allows Desert Rose to distribute their product across a broad area without having to significantly increase the number of staff.

2.2.3. Potential to expand and wider impact

As the filter is being produced, its designers continue to work on improvements. Their current research focusses on refining the media mix used in the cartridges in order to produce similar results whilst using less material, leading to both economies in weight and cost. Here it is worth noting that although various prototypes of the filter were initially produced, only one version has gone into production. Just as with Zipline, Desert Rose is in a phase of trial and experimenting, with lots of room to make adjustments, and lots of potential to improve.

As has already been mentioned, the decision to market the Minch filter as a commercial product is a very deliberate one. Humanitarian design agency Ideo.org explain that a successful product needs to be Feasible, Viable and also Desirable [The Field Guide to Human-Centered Design, 2015]. Andrew commented, that in the case of businesses, by default the design has to meet all three criteria. A product which isn't feasible can't be made, and therefore is not a solution, while a company producing products which aren't economically viable will quickly fail, their costs will be too high, and the company won't be profitable. Finally, a product which isn't desirable won't be purchased by the customers, and the business will by necessity stop producing it. Note that desirability doesn't just represent effectively meeting a particular need, but also shows the customer's attitude towards the product. This can be affected by factors such as local culture, the consumer's past experiences, appearance of the product and even the salesmanship of the seller. In the case of NGOs which largely distribute their products for free, viability and desirability are not usually considered, meaning that the products are often rejected by the local communities, because they do not see the product's value or are frustrated trying to use it. Desert Rose hopes that because they are required as a business to meet all three of the criteria, they will innovate sufficiently to develop a valuable product which customers want to purchase.

Working as a business also provides the natural constraint of sustainability. As NGOs are funded through donor grants, they are not sufficiently concerned with the long-term benefits of their product, contented to supply them as agreed before moving on to something else. Desert Rose on the other hand, will need to develop customers' interest in its product, slowly influencing and persuading potential markets of the value of the Minch filter. This is a long-term process and if successful, will reap benefits at some point in the future. The company's income depends directly on sales, and Desert Rose's humanitarian objective is thus altogether tied up with its success as a business. A successful product means growth for the company, which again provides them an opportunity to increase their influence in the market.

Similarly to Zipline, Desert Rose was founded by foreigners. Andrew Smith studied and worked in the UK, gaining experience which he has utilised in the Minch's design. Nevertheless, in contrast to the drone company, all the research and development of the filter has been carried out in Ethiopia. Possibly the greatest benefit the Minch will bring to Africa is the experience that will be transferred because they are manufactured locally. Although Ethiopians aren't currently involved in the design process, some have been instructed in doing laboratory work on E. coli. bacteria [Smith, 2018]. As DR's production grows, they will need to take on more staff to help oversee the various processes involved, and as long as these personnel are being employed locally, they will be trained in the different aspects of research, production and selling of the filters.

Andrew Smith has also trained three local students who then founded their own water testing company called Sparkle.

At some future date, once it has secured itself a strong position in the local market, DR would like to publish their recipe for the filter medium in hope that it will catalyse a wave of research into even more effective solutions [Smith, 2018].

Whilst the Minch filter has an excellent performance, it isn't by far the first model of filter to be designed for the African continent, yet the water crisis in Africa continues. For DR to successfully resolve the problem of providing clean drinking water, they first need to influence the culture they are working in. They won't meet their humanitarian goals by merely competing with other filter models for the same small pool of customers who understand the need to use filters, they have to make point-of-use water filters a standard household item for even the most remote families. Thus, their marketing strategy needs to be oriented towards developing new customers, targeting those who either don't see the need, or who don't have access to them.

Their current strategy for disseminating their product is through self-help groups, government health workers and through NGOs who can help spread the word [Smith, 2018]. However, it may be interesting for them to study the distribution model of the immensely successful Coca-Cola Company.

Coca-Cola is well known across SSA. Despite being an American product with essential elements of the recipe produced in the USA, the drink can be purchased in many of the most remote towns in the continent. The company has operations in every single nation in SSA, and although their product differs in some regards to water-filters, much can be learned. The Coca-Cola Company's business strategy in Africa works on a cascade of franchises. They supply the essential ingredients to independent producers who bottle the soft-drink and sell it on to Manual Distribution Centres (MDCs). These MDCs then further sell the product on to individuals who will transport it the "last mile" often by pushcart or bicycle. This gives locals a stake in the profits at every step of the distribution, and, although reducing the share of profits collected by The Coca-Cola Company, allows them to work through the local community to distribute their product to every corner of the continent. Thus, the business model benefits not just the company, but also the many Africans to whom it provides a source of income. By harnessing local creativity and entrepreneurship, The Coca-Cola Company has been incredibly successful in SSA [Maritz, c2018].

Taking a leaf out of their book could potentially benefit DR, as their goals are very similar: to offer a desirable product available to every household across the continent.

While DR isn't currently considering international expansion, they are not averse to the idea of doing so in the future. Developing the commission based distribution of the Minch into a fully-fledged franchise is not beyond imagining. For example, DR could produce and sell the granular cartridge medium to producers in various cities and countries, outsourcing the manufacturing to local enterprises who would then be responsible for distributing them further. This has various benefits, which include protecting the company's interests by collaborating with others, freeing up the DR from the responsibility of manufacturing, in order to focus on wider marketing, as well as increasingly empowering Africans in the task of filter-making. DR could even try to develop a strong brand associated with quality and performance in order to protect the Minch filter against rip-off versions.

All this would require building a network of partners across Africa who are willing to invest in the idea on faith that the Minch filter will sell. They would provide insight and cultural experience which is invaluable when doing business on the continent, and having combined interests means that success for DR is success for them too. Even so, this is potentially the Minch's biggest obstacle, convincing Africans of the value it brings and to help them promote the product.

2.3 Principles for Innovation in SSA

By looking at these two companies, we can see that they have successfully employed certain principles in their business model which allows them to improve their product and have a more significant impact on the communities in which they work. They also have some short-comings, which may limit the benefit of their work.

The first principle is the need for innovation. Innovation is the fundamental mechanism by which a society meets its needs and overcomes problems. SSA has a desperate need for people who beyond simply being aware of the issues in their communities, find practical and creative ways to meet them. Although perhaps not true for every country, Zipline has shown that some governments are open to new ideas and willing to support entrepreneurs developing fresh solutions.

This leads to the next principle, which is the need to start out in the right country. On the whole, the continent is a difficult place to establish companies, with issues ranging from power and infrastructure, through to finding qualified employees and government paperwork. Yet there are some countries who have actively sought to address this issue, one of them being Rwanda. The country chosen affects what kind of market the products will eventually be sold in. By no means is SSA lacking in diversity, and customer demands and needs vary from nation to nation and from ethnic group to ethnic group. This choice will also significantly impact any potential to export and import products. Ethiopia, for instance, being a land-locked country, doesn't have direct access to a sea-port for international commerce, yet it is surrounded by several other nations with whom it is developing impressive land transport links.

One important feature visible in the designs for both DR and Zipline, is that they are rudimentary and durable. Zipline's choice of fixed-wing drone allows it to endure the harsh African climate. The simple design means that even if the UAVs should be damaged or stolen, they aren't costly to replace. This is shown when contrasted to Amazon and DHL's hybrid designs for vertical take-off. It is a feature which is simply not necessary in Africa. Likewise, the Minch filter is built with an aluminium container and a metal tap in order to be robust, and to withstand the wear of daily use. Far from the world of planned obsolescence and quick-fix solutions, the frame should last for years. At the same time it's simple, not requiring expensive technology for manufacturing, being made almost completely by hand.

The products and services have to be aimed at a wide range of customers. As has already been mentioned, Zipline's main weakness is that it currently only has two customers: the Rwandan and Tanzanian governments. Should there be a significant dispute with either of them, then Zipline will lose a large share of its income. DR has sought to reach as broad a market as possible, working with government health workers, Aid organisations, and directly with Ethiopian distributors to distribute its product. If any of these channels folds, then it can still access its markets through other means.

Finally, and perhaps most importantly with regards to the aim of bringing sustainable development to the continent, is the need to work with locals. Any effort made by the companies to employ, train and empower local staff will have far-reaching consequences. Solutions can easily be contrived to meet African needs using only local resources, all it takes are individuals with the creativity and some technical know-how to be inspired to try.

3. Solution proposal: solar panel manufacturing company

As our personal creative input into this paper, we will use this section to look into the feasibility of setting up a thin-film Photovoltaic (PV) panel manufacturing company. This will be done by discussing potential countries where the business could be located, evaluating factors that need to be taken into account by briefly considering feasibility, as well as expected issues and benefits that will arise from the production. The purpose of establishing such a business would be to assist SSA countries in developing technology in a sustainable way, in line with the aim of this thesis, and to demonstrate how the previously discussed entrepreneurship principles can be used in practice.

3.1 Background

With Africa's energy crisis already having been duly laid out in Part I, along with the promises held out by the rural provision of energy through Micro-grids, renewable energy sources look set to play an important role in the coming years in supplying Africa with electricity. Whilst the continent has potential for developing wind, solar and hydro-power, in this section we will narrow our focus to the realm of solar energy production. Indeed, there has been a notable recent effort by several SSA governments to promote the installation of solar panels both through microgrids, with Kenya paving the way, and through large government-led instillations and solar-farms, such as in South Africa and Ghana. Much of this new demand for photovoltaic (PV) panels has been met with imports, mainly from China, however there has also been an interest in developing local production of PV panels on the continent, and a small handful of producers have sprung up in the last decade.

3.2 Location

Choosing a country in which to locate a PV manufacturing start-up is an important decision, impacting almost every aspect of the business, and can account for the different between success or failure. A wise decision considers a range of factors such as the government, workforce, potential local partners, availability of materials, and product distribution. Here we will outline which countries in SSA should be considered by looking at several of these factors. We then apply a Weighted Sum Model (WSM) to select the best alternative. Although South Africa is a strong candidate, they are already making progress in this realm, and thus won't be considered for selection.

For the WSM, we award a certain number of percentage points (from 0 to 100), and a weight to each criterion (again as a percentage). This enables us to create a comparison table (Table 4) and to conclude which country is the optimal one in which to invest.

A prerequisite before establishing a large-scale business in any country is support from the government. It's advantageous to be located in a country where the state actively supports the development of its economy, particularly one that invests in expanding its use of renewable energy sources. In some countries the government will even offer incentives (for example tax breaks) to companies working in a particular area, which they deem strategically important for their economy. A politically stable economy is also necessary, and so countries undergoing war or civil unrest cannot be considered.

Using the World Bank's "Doing Business" (DB) index, which ranks 190 countries globally based on various factors pertaining to the ease of doing business in those countries, we compiled a short-list of five candidate countries where the production plant might be located. The factors considered in the index relate to the initial set-up stages of a business, access to finance, as well as the day-to-day running of the company and business security. The top five SSA countries on the list were Rwanda, Kenya, Botswana, Zambia and Namibia, once the other high-performing countries Mauritius, the Seychelles and Lesotho had been discounted due to their small population and thus limited local market size, as well as relative isolation from the larger SSA market [Doing Business, c2018].

Since ease of conducting business is by far the most important criterion, we give it a weighting of 40%. There are 190 countries in the index, and we recalculate each country's ranking as a percentage based on its position using the following formula, where *R* is the DB ranking:

$$X_{DB}[\%]=\frac{190-R}{190}\times 100 \qquad \textit{equ. 3.2.1}$$

The next criteria considered is the rate of Corporate Income Tax, which is a clear sign of whether a country is proactively trying to stimulate business. The lower the tax level, the more profit investors will be able to keep, and therefore their returns on their original investment are higher [Africa Incentives, 2016].

Although this is an important criterion from a business point-of-view, the motives for establishing this project are not purely financial, and thus we assign a weighting of 15%. We take a CIT rate of 30% as standard and compare the country's divergence from that value using the following formula, where *T* is the CIT rate:

$$X_{CIT}[\%]=\frac{(30-T)+30}{60} * 100 \qquad \textit{equ. 3.2.2}$$

A large amount of research and development is essential for any company operating in the field of PV technology. Being an industry with very fast-paced change, producers have to constantly update and refine their manufacturing processes in order to keep in step with competitors. To run a manufacturing company producing a viable product, it is necessary to invest heavily in research, and ideally cooperate with local research institutions. we compiled a rough list of the number of universities in each country with an engineering or science and technology department. Hopefully agreements could be made to cooperate with them in a mutually beneficial partnership. Technical universities are also an important source of qualified employees and engineers who will operate the project [WHED, c2018].

We assign this criterion a weight of 10%, and assume that 20 universities is an adequate number, assigning it a value of 100% and linearly calculating the difference from that value with zero universities being equivalent to 0%. The equation we used is the following, and *N* represents the number of technically oriented universities in the country:

$$X_{ac}[\%]=\frac{N}{20}\times 100 \qquad \textit{equ.3.2.3}$$

Considering the need to source input materials and equipment, and to distribute the final product, we look at transport. As regards accessing raw materials and domestic distribution, good road or rail networks are fundamental, and a large internal market is also desirable. Because exported products are charged with customs' tariffs and taxes, international trade is more expensive. Therefore, the company will want to sell a high quantity of the produced panels locally before expanding to foreign markets. In order to expand, they require international transport axes, with road access to neighbouring countries and sea-port access for international shipping.

To measure infrastructure development, we used the African Infrastructure Development Index compiled by the African Development Bank, which ranks 54 African countries on the following criteria: transport, electricity, ICT usage, and water and sanitation levels. This gives a good indication of the development levels of the countries, and the standards of living of potential staff. The level of development of transport axes reflects the ease with which solar panels can be distributed around the country [AIDI, 2016].

To convert to a percentage, we used the same method as for the DB ranking. Due to the importance of infrastructure, we assigned a weight of 30%, and the equation used is the following, with *I* representing the AIDI ranking:

$$X_{AIDI}[\%]=\frac{54-I}{54}*100 \qquad \textit{equ. 3.2.4}$$

As an additional factor, we consider whether the country has direct access to international markets through the means of a maritime port. While the aim of the company is primarily to produce PV panels for the African market, some materials and most of the machinery will need to be sourced internationally and having a sea-port can cause a reduction of cost and time involved in international shipping.

Here we allocate a small weighting of 5%, and the country obtains a binary score of either 100% if it has a sea-port, or 0% if there is none.

Table 3: Country comparison

	"Doing Business" Index Ranking	CIT Rate [%]	Universities with Engineering/ Science Department [-]	AIDI Index Ranking	Sea-Port
Rwanda	41	30	3	24	No
Kenya	80	30	20	18	Yes
Botswana	81	22	5	10	No
Zambia	85	35	7	22	No
Namibia	106	33	2	11	Yes

Source: [Doing Business, c2018; Africa Incentives, 2016; AIDI, 2016]

Table 4: WSM country comparison

	"Doing Business" Index Ranking [%]	CIT Rate [%]	Universities with Engineering/ Science Department [%]	AIDI Index Ranking [%]	Sea-Port [%]	Calculated Score [%]
Weighting [%]	40	15	10	30	5	/
Rwanda	78.4	50.0	15.0	55.6	0.0	**57.0**
Kenya	57.9	50.0	100.0	66.7	100.0	**65.7**
Botswana	57.4	63.3	25.0	81.5	0.0	**59.4**
Zambia	55.3	41.7	35.0	59.3	0.0	**49.6**
Namibia	44.2	45.0	10.0	79.6	100.0	**54.3**

From looking at the table above, one can see that the three most interesting countries in terms of investment are Rwanda, Kenya and Botswana.

While Rwanda stands out for its impressive rating in the "Doing Business" index, it doesn't have much to offer in the way of University partnerships. Also, its AIDI index is the lowest of all the considered countries. Indeed, we have already seen that distribution by road in Rwanda is often disrupted due to the climate and lack of infrastructure.

Next, we look at Botswana, which is a small country in southern Africa. Despite the fact that Botswana is heavily dependent on electricity imported from its neighbours, primarily South Africa, to provide sufficient power to its population, its size limits the potential domestic PV market.

Kenya, with the highest score from the WSM ranking, is the largest of the mentioned countries, and has already demonstrated a willingness to innovate with and implement PV technologies. Throughout Kenya, firms such as M-KOPA Solar equip rural, off-grid houses with solar-electricity, which they charge for on a "pay as you go" basis. Other innovators are setting up whole microgrid systems for villages, bringing power to remote parts of the country. Kenya also has the advantage of a coastline, and thus access to shipping through its port in Mombasa.

Considering these factors, we conclude that Kenya is the first choice of location for the company.

3.3 Considering feasibility

3.3.1. Overview of goals and implementation

The presented project aims to improve SSA's access to electricity by establishing a manufacturing plant for thin-film solar panels on the continent. This will provide cheaper, more versatile and better adapted solar panels than the ones that are currently imported, significantly increasing the number of locally-made models. As an important added benefit, this project will lead to the creation of a variety of jobs for locals, ranging from unqualified factory work through to cutting-edge research posts.

As much as possible the materials will be sourced locally, and local staff employed.

The stages for implementing the project of establishing the factory are as follows: firstly to conduct more detailed market research, then to negotiate with the government, patent holders, potential suppliers and wholesale customers, as well as raising necessary funds. Next, it is necessary to construct and equip the factory, hire staff, etc..., and finally begin output of products, firstly for local markets and eventually for export.

3.3.2. Kenyan market

Kenya currently produces a total of 2,336MW of energy each year, sourced mainly from a combination of hydroelectric, thermal and geothermal power plants. Of the population, 73% is currently connected to a source of power and Kenya has an ambitious target to connect the 3.2 million other households by the year 2020 [Kenya Power Africa, 2018].

The Kenyan government sees solar power as a key part of the solution, given the spread of the population in areas not yet reached by the national grid. To this end they have cut import taxes and VAT of renewable energy equipment and accessories to zero. This presents both an opportunity and a challenge to a solar panel manufacturer. The opportunity is that it would allow the company to purchase production machinery from abroad at a reduced cost, however it also means that competing imported products will also be cheaper.

One company, Ubbink, already produces solar panels in Kenya. Designed in Europe, these panels come in various sizes, so as to target both large scale installations and small off-grid home connections too. Ubbink's solar modules use polycrystalline cells.

3.3.3. Technical solution

For the proposed company, we suggest the use of thin-film solar technology over the traditional crystalline types.

PV panels come in broadly two different types: crystalline silicon and thin-film. Crystalline panels are usually thought of as typical solar panels. They are the elder of two technologies, and are composed of thinly cut wafers of silicon. Despite being more expensive, they have until recently had a significantly higher efficiency. Crystalline silicon panels themselves can again be sub-divided into monocrystalline and multicrystalline varieties, yet our main focus will not be on either of these. Thin-film PV panels are by contrast far less widely used, though can be seen in applications such as pocket calculators. The panels themselves are produced by printing silicon onto any of various types of substrates, determining the properties of the panel. Thus they can be flexible or rigid, with higher or lower efficiency and are incredibly versatile. They are currently being considered for applications in the automobile and building industries.

The reason that thin-film is being considered here, is that there are already a small number of crystalline solar panel producers on the continent, and more significantly, a large inflow of cheap panels imported from China, making the market fairly competitive. Thin-film panels in contrast are only produced in one country in SSA, while imports are also very low as international production is not currently on the scale of crystalline panels. Thin-film offers various interesting benefits, which may allow it to become widely adopted in Africa for unconventional and innovative applications, possibly also competing in certain domains with crystalline PV panels.

In South Africa, the firm PTiP has been working in collaboration with the University of Johannesburg and the South African government to first develop and then manufacture thin-film solar panels. With roots in research, they also license technology and production know-how to other companies. They remain Africa's only producer of thin-film solar panels [PTiP innovations, 2014].

Thin-film technology has a strong advantage in the fact that it uses considerably less silicon semiconductor material than the crystalline models. According to the website PVthin which represents global leaders in the thin-film industry, the semiconductor layer on thin-film solar panels can be as narrow as 3 μm, while the silicon wafer size for a typical monocrystalline panel is 180 μm. This is the most expensive component of the solar panels, so limiting its use leads to lower production costs. The website also claims that thin-film technology still has a large potential for future improvements, while efficiency gains for traditional solar technologies has not been as high in the last decade [PV thin, c2016]

The following table is assembled by comparing the data-sheets of various models of available solar panels.

Table 5: PV panel comparison

Type	Efficiency [%]	Warranty minimum performance after 25 years [%]	Approx. price of 200W panel [$]
Monocrystalline	16.5 - 18.5	80 - 86	~100
Polycrystalline	15 - 18.5	80	~80
Thin-film, glass substrate	12.4 - 20	80 – 86	~100

From this we can see that thin-film solar panels are comparable to the other types in terms of performance when printed on a glass-substrate, and can be used for similar applications such as large solar farms, as well as the off-grid powering of a household.

However, possibly even more interesting is the possibility to produce thin-film solar panels with a flexible substrate such as polyethylene. Such materials are readily available in Africa, aren’t expensive, and offer the potential of role-to-role manufacture which can lead to significant economies over the crystalline batch method where each cell has to be handled separately. Flexible panels produced on such a simple substrate don’t have as high efficiency, but the potential of reducing the cost and creating a product which can be used in far more diverse applications is attractive. This also fits with the principle of endurance, and creating a product which is robust enough for the applications it will be used for. For example, thin-film panels could be attached to the roofs of traditional African huts, which often need re-thatching, sometimes as much as once a year. In this situation, a traditional glass framed panel is impractical, heavy and fragile, while a flexible one can be easily manipulated. Another potential market could be among nomadic or semi-nomadic tribes, such as the Maasai, who spend large parts of the year moving around with their livestock. Having a small and light-weight solar panel could allow them, for example to charge mobile phones away from home. Whilst a first glance such a market may seem marginal, and these unconventional applications not worth considering, it’s important to remember that these are precisely the people who don't yet have access to power, and to whom the Kenyan government wants to provide electricity by 2020. For them to accept innovations such as electricity, it needs to be provided in a way which is relevant to their culture and needs.

To conclude, we recommend initially developing a range of both flexible and rigid options, and carefully evaluating the profitability and impact of both, once production and distribution have begun.

3.3.4. Break-even economic analysis

In order to decide whether the project is economically viable, it's necessary to conduct a break-even cost analysis. This indicates the number of products (in our case solar panels) that need to be sold each month for the company to reach its "break-even point", that is to obtain neither profit nor loss.

Owing to the difficulty of obtaining data without extensive market research the values used in the process, are only very rough estimates, and should be considered as preliminary calculations, not definite results.

I'll estimate the following values which we will use in our calculations, taking into consideration the lower salaries in SSA. We consider labour as a component of variable cost.

- Fixed cost of running the factory each month (FC): $100,000
- Number of workers (W): 200
- The variable cost of producing one PV panel (VC): $60
- The selling price (P): $80

We calculate the break-even point in terms of quantity of panels produced (Q*):

$$Q^* = \frac{FC}{P - VC} = \frac{200,00}{80 - 60} = 13,333 \text{ [units]} \qquad \textit{equ.3.3.4.1}$$

In order to appreciate productivity, we calculate the output per worker per day (O)

$$O = \frac{Q^*}{30 \times W} = \frac{13,333}{30 \times 200} = 2.22 \left[\frac{1}{\text{day}}\right] \qquad \textit{equ.3.3.4.2}$$

This value seems achievable, and Kenya's market for solar panels is easily large enough to absorb this quantity.

3.3.5. Set-up cost estimation

Estimating the cost of establishing the manufacturing plant is similarly difficult without a more in-depth break-down of all the different factors involved in the cost. But by comparing various other crystalline manufacturing plants which have been started over the last few years, we estimate the cost to be somewhere between $50 million and $100 million depending on the scale of production.

It is important to locate the production facility in a central and well connected area, near a population centre, ideally one with a university for recruitment and research purposes. Establishing the factory in or near Nairobi would be a logical choice, though much depends on where land can be procured.

3.3.6. Product distribution

Regarding distribution, Kenya has a relatively well-developed network of paved and unpaved roads, allowing products to be disseminated by lorry to major towns and cities across the country. Imported raw materials and equipment can be brought from the port in Mombasa to Nairobi by train if necessary.

In the event of saturating the local Kenyan market, PV panels can be exported to the surrounding countries. Uganda, Tanzania and Ethiopia are good candidates due to rising standards of living, and thus ability for households to pay for electricity and appliances. Somalia and South Sudan, Kenya's other two neighbours are currently undergoing political unrest, resulting in their populations not having much disposable income to spend, nor will their governments be considering establishing large solar projects requiring PV panels. Perhaps one benefit may be that failures from the electric corporations in these countries may push people to find alternative sources of power, but this is hard to gauge without a more in-depth market analysis. All these countries can be accessed by road

3.4 Challenges and risks

The establishment of any project will naturally face many issues which need to be considered and solutions proposed before any investment is made. If these challenges and risks are too great, then the project may be worth abandoning, however in moderation they can be worked around, and adjustments made to the initial plan. Investors need to be made aware of the risks involved, so that they can evaluate whether it they want to cooperate.

3.4.1. Challenges

We consider the following challenges:

- **Lack of industrial development:** despite Kenya's progress in relation to much of the rest of Africa when it comes to industrial development, the culture hasn't fully transformed into an "industrial society", meaning that the majority of people aren't used to factory work, and as a consequence, output per worker is low. Similarly, the education and training levels are low, so finding qualified staff who can undertake research and design, as well as be responsible for the management and running of the facility. The advantages of establishing the factory in an urban setting may offset this, as city dwellers tend to be more used to the discipline and demands of factory jobs. It may be necessary to recruit staff from countries such as South Africa where developments are being made in the field of PV technology, at least initially until Kenyans have been sufficient trained to do their own research. Nevertheless, this can also be seen as an opportunity to train and empower Africans to become world-leaders in the realm of solar energy research.

- **Limited number of complementary businesses and services:** The company won't necessarily be able to outsource production of components to other firms and therefore will have to be responsible for every aspect of the production process, from the initial raw-materials and semi-products through to completion.

  The lack of float-glass producers on the continent illustrates this well. While glass is not a historic building material in Africa, its use is gradually increasing, but there are few producers on the continent. In 2013, Kenya imported $17.3 million worth of float-glass [TanzaniaInvest, 2016]. Thin-film solar panels with glass substrates will need to be produced using imported glass until such a time as the nation begins its own manufacturing of flat glass panes.

- **Lack of distributors and distribution channels:** simply producing a viable product is not sufficient, but effort will need to be made to forge connections with retailers and electric companies across the country. Having the government's support in this matter is particularly advantageous. One important group of potential customers are Kenya's microgrid companies, since they have access to a large number of end users. Solar panels are only one component of a larger system required to have a functioning power network of any scale. Thus, cooperating with those involved in installing networks can help the solar panels to reach the market.

- **Competition:** Kenya doesn't currently tax imports of solar panels, meaning that Asian producers have relatively easy access to the African market. Perhaps the Kenyan government's stance would change once a locally produced variant became available, but if not, it is important that the locally produced PV panels have a competitive edge over imported ones. In this, the decision to use cheaper thin-film technology permits keeping the cost of the panels to a minimum, whilst simultaneously allowing them to be used in more diverse applications.

3.4.2. Risks

We also consider the following risks:

- **Delays in the project set-up phase:** fixed costs need to be paid even when there is no production underway, quickly sapping up the company's resources. We envision delays coming from the following areas: facility construction, shipping machinery, obtaining necessary paper-work and licenses.
- **Equipment failure:** PV panel production is a highly automated process, requiring large amounts of machinery. Equipment failure can lead to an interruption of the production process, and there is a scarcity of technicians and spare parts, which aggravates the issue.
- **Technological risk:** Since the project relies on constant research and improvements to the efficiency of the panels, failure to develop fast enough can lead to the solar panels falling behind competition, leading to a lack of demand.
- **Political instability and violence:** it is crucial to evaluate any risk of war or militant attacks in any SSA country, and Kenya is no exception. Although there have been only limited uprisings since the nation's independence in 1963, numerous attacks by the Somalia-based militant group Al-Shabab have taken place in Kenya in the last few years, including in the capital Nairobi. Also, an air of tension reigns in the political sphere, with discontent over the re-election of Uhuru Kenyatta as the country's president. According to some analysts, this may develop into a wide-scale conflict in the near future, if measures aren't taken to address the issue. Not much can be done to avoid this risk beyond employing security guards at the factory and offices, and following cautionary guidelines.
- **Corruption:** which is prevalent across the continent. Officials may try to block the establishment of a factory until they have been paid a sufficient bribe, or managers may try to embezzle funds needed for various aspects of running the company. Having clear accountability structures, and carefully checking where all the money is spent is of great importance, as well as being clear from the outset that bribes will not be paid.
- **Act of God:** Some factors are impossible to predict, despite diligent planning and foresight. Nevertheless, Kenya doesn't lie in an area prone to natural disasters, and thus the risk from such is minimal. Even with the Rift Valley running through the country, earthquakes in the country are infrequent and of only small magnitude.

While the risks involved in such a project are certainly higher than those which could be expected for a similar project in the developed world, the possible benefits that such a project could bring are similarly higher. The dangers call for a flexible and robust business model, which allows it to adapt to circumstances.

3.5 Potential benefits and impact

The merits of establishing a factory in SSA producing thin-film will help in achieving the SDGs of providing affordable and clean energy, ending poverty, developing industry, innovation and infrastructure, and acting to reduce climate change.

Many of the benefits of providing electricity to a society are covered in the first part of the thesis. The advantages of specifically using solar panels, is that they are simple to install, cost nothing to run, and can be located in remote villages, far away from any central grid. A widespread adoption of the solar technology can impact education, health, business, and much more.

If Kenya's rural population could become self-sufficient, providing themselves with decentralised solar energy, the development of the nation wouldn't necessarily drive an increase in greenhouse gases released into the atmosphere. With Africa wanting to develop and industrialise, modern technology can help them to do so without causing a large increase in emissions. But in order to do this, they need to produce their own technologies, and develop their own know-how.

Certainly, the factory will produce a certain quantity of pollution and waste, particularly if they are working with plastics. However this is negated by its role in enabling the widespread adoption of clean energy.

Other benefits are primarily economical.

Establishing a PV panel factory would provide jobs for local labourers and for graduates alike. Creating opportunities for highly-qualified work on the continent can help to stem the tide of new graduates emigrating in search of work, thus allowing the continent to make use of one of its greatest resources: its young population. The establishment of one factory creates the possibility for other enterprises to come into existence, as smaller companies fill niches in the industry and provide external services to the larger factory.

Providing jobs puts money back into the local economy, and improves the standard of living of the local population.

The success of such a project can give inspiration for others to try similar ventures, and improve investor confidence, making them more willing to back projects in the future.

Producing panels locally over importing them reduces the cash flow out of the Kenyan economy, and should the country begin to export, can even become a source of foreign currency.

3.6 Conclusion

We evaluated the effectiveness, risks and benefits of establishing a thin-film PV panel factory in SSA. By using WSM analysis on five countries, we selected Kenya as the place most worth-while investing in.

We discussed the purpose of establishing the solar panel plant, and the major steps involved in setting-up such a project. We followed that by a brief overview of the current market situation for solar panels in Kenya.

We then compared the different types of technology available, considering the characteristics and costs of monocrystalline, polycrystalline and thin-film solar panels, in order to explain our choice of thin-film as the most interesting option for SSA.

Following this, we conducted a rough break-even analysis for the project, despite a lack of concrete data, and concluded that the plant would need to create 13,333 units per month in order to make a profit of zero.

We also approximated the cost of establishing the plant by using data from similar projects in SSA, and considered how the product might be distributed.

Finally, we discuss the challenges and risks to the project, as well as benefits which it can bring to the local communities.

Conclusion

Despite the slow pace of development in Africa, new technology-oriented initiatives are coming into existence with the potential to lift the continent out of its current state of poverty. Getting to research some of these has enabled us to make important observations which are of great value to anyone innovating with technology in Africa. Beyond this, we have personally benefited from the knowledge we have acquired, and greatly appreciate the efforts that are already being made in this field.

In the Introduction, we outlined the current situation in SSA using primarily literature sources, focussing on challenges which the region faces with regards to meeting the targets set by the SDGs. The four fields of health, transport, water and power are explored in detail, as these can be directly addressed through mechanical engineering. For each we defined specific issues, commenting briefly on efforts to address them. While there is a lot of available information in the literature, we were hindered by the lack of research papers coming directly from the continent itself. Much of what has been written was not the work of African scholars, and thus we found it more difficult to locate knowledgeable sources.

For the research section, we chose to analyse two firms employing technology as solutions within the previously identified fields in SSA. Due to a lack of time and resources, we were unable to visit the firms personally. This limited our range of sources to internet articles in the case of Zipline, and to direct contact with Andrew Smith for Desert Rose. Despite our best efforts, we were unable to communicate with Zipline. As a result, the validity of our analysis is limited by the accuracy of the information we have been able to obtain. In both cases we able to elaborate on such elements as the technology involved, the environment in which the companies work, and their history, yet, constrained by time and distance, we were unable to evaluate the technology's direct impact on the local people. It was particularly insightful to consider the businesses' structure and approach to finding customers. Zipline, as an American company with vast resources, was able to negotiate directly with governments. Desert Rose, previously a small consulting firm, chooses to use its connection with the Ethiopian people, as well as taking advantage of their reputation in the business world.

A large amount of my work was to compare the technologies used by DR and Zipline against other available alternatives, in order to understand why they chose those specific solutions. It was clear that the employed approaches outperformed competing options, and thus there was no need for more in-depth analysis.

We looked at options for expansion of both businesses, offering a critical study of Zipline's current move into Tanzania, and suggesting for DR a form of franchise relying on local entrepreneurs in order to expand their business internationally, following the business model of the Coca Cola Company.

As a final step, we outlined several important principles for innovation in Africa, which can be learned from observing DR and Zipline. These are the fundamental need for creativity, careful choice of location, rudimentary and durable designs, developing a wide customer base, and the necessity of empowering Africans. These principles should be applied by everyone wanting to implement technology as a motor for sustainable African development.

In the third part, we unpacked the possibility of establishing a PV factory in SSA. This was done by examining a specific set of criteria agreed upon with our supervisor. The initial phase was to select the most beneficial country, thus we short-listed several candidates and compiled sufficient data for them, then we applied WSM analysis to select the optimal choice, which we concluded was Kenya. Next it was necessary to select the appropriate technology, in this case Thin-film offered the most potential, due to its diversity and versatility.

Much of the feasibility study was beyond the scope of this paper, particularly in areas such as finance and obtaining investment, and staffing the project. These however would have presented a digression from the original purpose of this thesis, and so were not addressed in detail.

As future work, we suggest conducting a study into the impact of various types of technology in the lives of the African people, in order to identify fields of innovation which will be most beneficial to the African people. It would also be interesting to track Zipline and DR over a longer period of time, to see how these relatively new companies expand in the continent, and whether they inspire Africans to undertake similar ventures.

For our personal development, we would like to further develop our understanding of businesses as a means to implement societal change, and to examine how combining business with technology and innovation can be used to improve standards of living in Africa.

To conclude, despite natural limitations due to the nature of the work, we consider that the research for this thesis has been a success, and the paper presents a useful guide to others wanting to innovate with technology in Africa, for the benefit of Africa.

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