Feasibility study and business plan for manufacturing a 3 kW-electrical solar Stirling engine and dish for stand-alone power supply units

by

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Thesis presented in fulfilment of the requirements for the degree of Master of Science in Engineering in the Faculty of Engineering at Stellenbosch University

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

December 2015

ABSTRACT

Africa has some of the richest solar resource regions in the world. These remain largely untapped. Meanwhile, numerous rural communities in Africa are without access to electricity. Rural communities are in most cases isolated and scattered, in addition they have low population densities. This makes it expensive to extend electricity grids to them. Therefore, the Stirling system is one of the promising off-grid technologies that Africa could explore in an effort to produce electricity in a sustainable and environmentally-friendly way.

The main objective of this study was to investigate whether there is a viable market in Africa for the use of the solar Stirling system. In addition, an economic evaluation was performed to determine whether it is economically viable to manufacture the solar Stirling system in Africa. Finally, the study prepared a summary of the economic evaluation for a residential 3 kW solar Stirling system.

Market research was included in the study to establish the market viability of the Stirling dish. In addition the market research was used to identify those needs of the customers that could be incorporated into the design of the Stirling engine and the concentrator. The market research was carried out in a rural community with households without access to electricity. Furthermore, a manufacturing plan was developed to determine whether it is economically attractive to manufacture the Stirling system.

Africa has the skills and resources to manufacture the Stirling dish. The market research revealed that most of the people in rural communities survive on a very low income. Furthermore, the research showed that while they are interested in acquiring the technology, it is unlikely that they will be able to afford it on a basis of a once-off purchase. The selling price of the Stirling system was found to be too high compared to other off-grid technologies. However, the study showed that the residential Stirling system is attractive with a levelised cost of electricity (LCOE) of R1,37 R/kWh and R0,82 R/kWh for a Stirling dish with storage. The standard Stirling system storage has a payback period of 16 years and the system with storage has a payback period of 7,9 years. The economic evaluation of the project from a manufacturer's point of view showed that the business will take about two years before it starts bringing in positive cash-flows.

OPSOMMING

Van die rykste sonhulpbronstreke ter wêreld is in Afrika geleë en is steeds grotendeels onontgin. Intussen het verskeie landelike gemeenskappe in Afrika geen toegang tot elektrisiteit nie. Landelike gemeenskappe is in die meeste gevalle geïsoleerd en wydverspreid, en het boonop lae bevolkingsdigthede. Dít maak dit duur om hulle by elektrisiteitsnetwerke in te sluit. Daarom is die Stirling-sonkragstelsel een van die belowende tegnologieë buite die kragnetwerk wat Afrika kan ondersoek ten einde elektrisiteit op ’n volhoubare en omgewingsvriendelike manier op te wek.

Die hoofdoelwit van hierdie studie was om vas te stel of Afrika oor ’n lewensvatbare mark vir die gebruik van die Stirling-sonkragstelsel beskik. Daarbenewens is ’n ekonomiese beoordeling onderneem om te bepaal of dit haalbaar sou wees om die Stirling-sonkragstelsel in Afrika te vervaardig. Laastens bied die studie ’n opsomming van die ekonomiese evaluering van ’n residensiële Stirling-sonkragstelsel met ’n leweringsvermoë van 3 kW.

Marknavorsing is as deel van die studie onderneem om die marklewensvatbaarheid van die Stirling-skottel te bepaal. Die marknavorsing is voorts gebruik om vas te stel watter kliëntebehoeftes by die ontwerp van die Stirling-enjin en die konsentreerder ingesluit kan word. Die marknavorsing is onderneem in ’n landelike gemeenskap waarin die huishoudings nie toegang tot elektrisiteit het nie. ’n Vervaardigingsplan is boonop opgestel om te bepaal of dit ’n ekonomies aantreklike opsie sou wees om die Stirling-stelsel in Afrika te vervaardig.

Afrika beskik wel oor die vaardighede en hulpbronne om die Stirling-skottel te vervaardig. Die marknavorsing bring aan die lig dat die meeste mense in landelike gemeenskappe met ’n uiters karige inkomste klaarkom. Daarbenewens toon die navorsing dat hoewel hierdie mense daarin belang stel om die tegnologie te bekom, hulle dit heel waarskynlik nie op die grondslag van ’n eenmalige aankoop sal kan bekostig nie. Die verkoopprys van die Stirling-stelsel blyk te hoog te wees in vergelyking met ander tegnologieë buite die kragnetwerk. Tog toon die studie dat die residensiële Stirling-stelsel ’n aantreklike opsie is teen ’n konstante eenheidskoste van elektrisiteit (LCOE) van R1,37 R/kWh vir ’n Stirling-skottel sonder bergingsvermoë, en R0,82 R/kWh vir een met bergingsvermoë. Met die Stirling-stelsel sonder bergingsvermoë duur dit 16 jaar voordat die voordele van die stelsel die koste daarvan gedek het; hierdie tydperk krimp tot 7,9 jaar met ’n stelsel met bergingsvermoë. Die ekonomiese beoordeling van die projek uit ’n vervaardigersoogpunt dui daarop dat so ’n onderneming sowat twee jaar sal benodig voordat dit ’n positiewe kontantvloei sal skep.

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"Behold, I am with you and will keep you wherever you go, and will bring you back to this land; for I will not leave you until I have done what I have spoken to you."

(Genesis 28:15 NKJV)

DEDICATIONS

I would like to dedicate this thesis to my loving parents, Ottilie and Isak Kayofa for encouraging me to study so discover the values of knowledge, investing in my costly education and only wishing the best for me.

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ABBREVIATIONS

CSP	Concentrated Solar Power
LHS	Latent Heat Storage
LPG	Liquefied Petroleum Gas
MENA	Middle East and North Africa
N$	Namibian dollar (Namibian currency)
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
O & M	Operation and maintenance
PCM	Phase Change Materials
PDC	Parabolic Dish Collector
PTC	Parabolic Trough Collector
PV	Photovoltaic
QFD	Quality Function Deployment
R	Rand (South African currency)
R&D	Research and development
SADC	Southern African Development Community
SMART	Smart, Measurable, Achievable, Realistic and Time framed
SWOT	Strengths, Weakness, Opportunities and Threats
TLCC	Total Life-Cycle Cost
TQC	Total Quality Control
UCRF	Uniform capital recovery factor

NOMENCLATURE

Δ I	Incremental investment costs
Δ S	Annual savings net of future annual costs
Δhm	heat of fusion per unit mass (J/kg)
AI_j	absolute importance
am	fraction melted
CA	Customer attributes
c_{ac}	accuracy index on 1-100 scale
$C_{casting}$	Casting cost
$C_{core\ sand}$	core sand cost
C_{energy}	energy cost
c_{index}	tooling cost index
C_{labour}	labour cost
C_{lp}	average specific heat between T_m and T_f (J/kg K)
$C_{material}$	material cost
$c_{miscellaneous}$	miscellaneous material cost
$C_{mould\ sand}$	mould sand cost
C_n	Cost acquired in period n
$C_{overheads}$	overheads cost
Cp	specific heat (J/kg K)
C_{pl}	specific heat of metal ay liquid phase
C_{ps}	specific heat of metal at solid phase
$C_{rel\text{-}tool\text{-}cost}$	relative tooling cost for casting-iron tooling

C_s	casting shape complexity
Csp	average specific heat between T_i and T_m (kJ/kg K)
$c_{tooling}$	amortized cost of tooling (cast-iron tooling)
$C_{tooling}$	tooling cost
$c_{unit\ core\ sand}$	unit core sand cost (kg)
$c_{unit\ labour}$	unit labour cost
$c_{unit\ mould\ sand}$	unit mould sand cost (kg)
$c_{unit\text{-}energy}$	Unit energy cost
$c_{unit\text{-}metal}$	Unit metal cost (per kg)
d	Density (kg/ m^3), discount rate
E	Energy
EC	Engineering characteristics
E_{kJ}	Energy in kilo joules
E_{Wh}	Energy in Watt hour
$f_{core\text{-}rej}$	Rejection factor for core making activity on 1.00-1.20 scale
f_f	Factor for metal loss in fettling
f_m	Factor for metal loss in melting
$f_{mould\text{-}rej}$	Rejection factor for mould-making activity on 1.00-1.10 scale
F_n	Cash-flows received at time n
f_n	Factor for furnace efficiency
f_p	Factor for metal loss in pouring
f_r	Factor for casting rejection on 1-1,12 scale
$f_{recycle}$	Factor for recycled sand on 0,1-1 scale

$f_{rey\text{-}act}$	Rejection factor for activity *i*
f_y	Factor for overall yield
I	Current (A)
kJ/kg	Kilo joule per kilogram
kW	Kilowatt
kWh	Kilowatt hour
L	Length
l_{act}	Number of workers involved in activity
m	Mass of heat storage medium (kg)
n	Analysis period, number of activity
nc	Number of cavities per mould
p_c	Casting metal density
$p_{core\text{-}sand}$	Core sand density
PF	Power factor
Q	Order quantity, quantity of heat stored (J)
Q_n	Energy output or saved in a year
R/hour	Rand per hour
R/hour	Rand per hour
R/joule	Rand per joule
R/kg	Rand per kilogram
R_{ij}	Relationship matrix
$r_{metal\text{-}sand}$	Metal: sand ratio
SA	Sub-assembly

t	Time (s)
$t*$	Time (hour)
t_{act}	Time for activity per component
T_f	Final temperature (^{0}C)
T_i	Initial temperature (^{0}C)
T_m	Melting temperature (^{0}C)
t_{melt}	Pouring temperature of metal
t_{room}	Room temperature
t_{tap}	Tapping temperature
v	Volume (m^3)
V	Voltage (V)
v_{cast}	Casting volume
v_{cast}	Casting volume
V_{core}	Core volume
v_{cost}	Casting volume m^3
V_f	Volume of all feeders per mould
V_m	Metal volume per mould
w_{cast}	Casting weight
W_i	Weighted average

Conversion

N$ 1,00 ≈ R 1,00

R1,00≈US0.09

CHAPTER 1

INTRODUCTION

1.1 Background and rationale

It remains a challenge for developed and developing countries to provide and distribute electricity within their countries equally in rural and urban areas. There are over 1,5 billion people in the world without electricity in their households. Of these, 589 million live in Africa alone. It is estimated that 80% of the people without access to electricity live in rural areas. In most instances, rural communities are isolated and distant from urban areas, increasing their chances of not having access to the main electrical grids. In some countries it will take a number of years before the main electricity grids are extended to rural areas. The government authorities in most of these countries concentrate mainly on providing electricity to urban areas because it is expensive to extend the electricity grid to rural areas. The other reason is that rural areas are inhabited by small and dispersed populations making their electricity demand small. It is therefore uneconomical to provide electricity immediately through the extension of the main grid to rural areas (Rolland *et al.*, 2013).

As a result, households in the rural areas are left to generate their own individual energy supplies, which are mainly obtained from traditional fuels such as wood, crop residues and/or conventional fuels such as paraffin and candles. Therefore, there is a need for African countries to supply off-grid electricity to areas without access to electricity, while also considering environmental sustainability. Over the years, there have been newly developed technologies around the world that make use of renewable resources such as solar energy, to produce off-grid electricity. One such technology that Africa can look into is the 3kW solar Stirling engine and dish. Henceforth, the 3kW solar Stirling engine and dish will be referred to as the Stirling system, unless otherwise stated.

1.2 Research problem

Africa has a high number of days with uninterrupted sunlight. Indeed, the African continent has some of the richest solar resource regions in the world, which remain largely untapped (Abbas *et al.*, 2011) . The solar Stirling system technology is one of the four types of concentrated solar power technologies (CSP) which have a high potential for producing affordable electricity in Africa. It is one of the favourable renewable energy technologies that Africa can explore.

Various literature sources are available on the technical aspects of the Stirling system but little is mentioned about its market potential in Africa. Even though there is potential in solar Stirling technology, stakeholders are still sceptical as to whether investing in such a business venture would be profitable. The risks involved in entering the rural off-grid markets in Africa remain unclear, if not completely known. The Stirling system is not yet accepted in the African market and the market size is unknown. At the moment, no Stirling system is being manufactured in Africa. Furthermore, little is known about the manufacturing costs of manufacturing Stirling systems in Africa.

1.3 Objectives of the study

The solar Stirling system can be used to generate electricity in off-grid areas. The deployment of such technology would eventually assist with diversification of Africa's electricity production, supplying rural electricity, creating employment for local people and increasing energy security. The main objective of the study was to conduct a mini-survey and use literature to investigate whether there is a viable market in Africa for the implementation of the solar Stirling system. In addition, an economic evaluation was done to determine whether it is economically viable to manufacture the solar Stirling system in Africa and a summary of the economical evaluation for a residential 3 kW solar Stirling system. Finally, an enterprise model and a business plan would be constructed.

1.4 Research design

One part of this study was a non-empirical research study whereby secondary data from various types of literature studies concerning solar Stirling systems were carefully studied and sourced. Subsequently, a literature study was developed that focused on general economic feasibility and technical viability matters in the manufacturing of a Stirling system in Africa. The second part consisted of empirical research which involved a market research.

1.5 Research methodology

A market study was the method applied to establish the perception of the community members on the Stirling system and market viability. The market research was carried out in a rural community on households without access to electricity.

The technical data such as designs and material usage were provided by the students from the mechanical department of Stellenbosch University, who were responsible for designing and manufacturing the free-piston Stirling engine and the concentrator.

1.6 Project information

This study forms part of a standing project that aims to develop a 3 kW-electrical solar Stirling engine at Stellenbosch University. This particular study involved collaboration with two other students from the mechanical engineering department. One of the students was responsible for designing the free-piston Stirling engine, the title of his thesis is 'Design, simulation, manufacture and testing of a free-piston Stirling engine'. The other student worked on developing the parabolic dish and his title for research study is 'Automatic positioner and control system for a motorized parabolic solar reflector'.

1.7 Thesis outline

The outline of the thesis is represented in Figure 1.1. The purpose of each chapter is explained below:

Chapter 1: Introduction

Chapter 1 introduces the research concept of the study. It provides the purpose of carrying out the study, research methodology and project background.

Chapter 2: Preliminary Literature Study

Chapter 2 provides an overview of the literature on current energy shortage in Africa, solar energy availability in Africa and the Stirling system components.

Chapter 3: Business Plan Components

Chapter 3 provides the business plan methodology for the production of a 3 kW Stirling system in Africa.

Chapter 4: Strategic Intent Architecture

Chapter 4 provides the foundation of the business and the purpose of establishing the business.

Chapter 5: Business Model Formulation

Chapter 5 describes the nine building blocks of the business model canvas. In the same chapter the business plan canvas was used to describe key aspects of the company and its environment in Africa.

Chapter 6: Market Research Design and Methodology

Chapter 6 describes the research design and methodologies that were implemented.

Chapter 7: Market Research Findings

Chapter 7 is a discussion of the results of the survey in Chapter 6.

Chapter 8: A Simplified House of Quality Framework

Chapter 8 contains the simplified house of quality framework based on the survey results, the ideas of the designers and the literature.

Chapter 9: Manufacturing Facilities Design

Chapter 9 presents the manufacturing plan for the Stirling system. This chapter also provides the cost structure of producing the Stirling system.

Chapter 10: Energy Storage Options of the Stirling System

Chapter 10 presents an evaluation of possible energy storage options available for the Stirling system.

Chapter 11: Estimating the End-user Cost of Use of a 3 kW Residential Stirling System

Chapter 11 investigates the economic feasibility of a residential Stirling system for a stand-alone system in a rural community.

Chapter 12: Environmental Life Cycle Assessment

Chapter 12 gives a brief summary of the environmental assessment of the Stirling system.

Chapter 13: SWOT Analysis of the Stirling Dish in Africa

Chapter 13 presents a summary of the strengths, weakness, opportunities and threats (SWOT) involved in the analysis for the production of a 3 kW Stirling system in South Africa and Africa. Furthermore, an additional SWOT analysis considers the business opportunity relating to the manufacturing of 3 kW Stirling system in Africa.

Chapter 14: Financial Analysis

Chapter 14 investigates the economic feasibility for manufacturing the Stirling systems in Africa. This chapter will also touch on the profitability and break-even analysis.

Chapter 15: Risk Analysis

Chapter 15 identifies risks that are associated with the establishment and implementing of manufacturing Stirling systems. Discussions of the risk mitigation strategies for the high level risks are included.

Chapter 16: Conclusion and Recommendations

Chapter 16 highlights the contribution this study will make to the body of knowledge. Conclusions are drawn from the research findings, the limitations of the study are highlighted and some recommendations are presented.

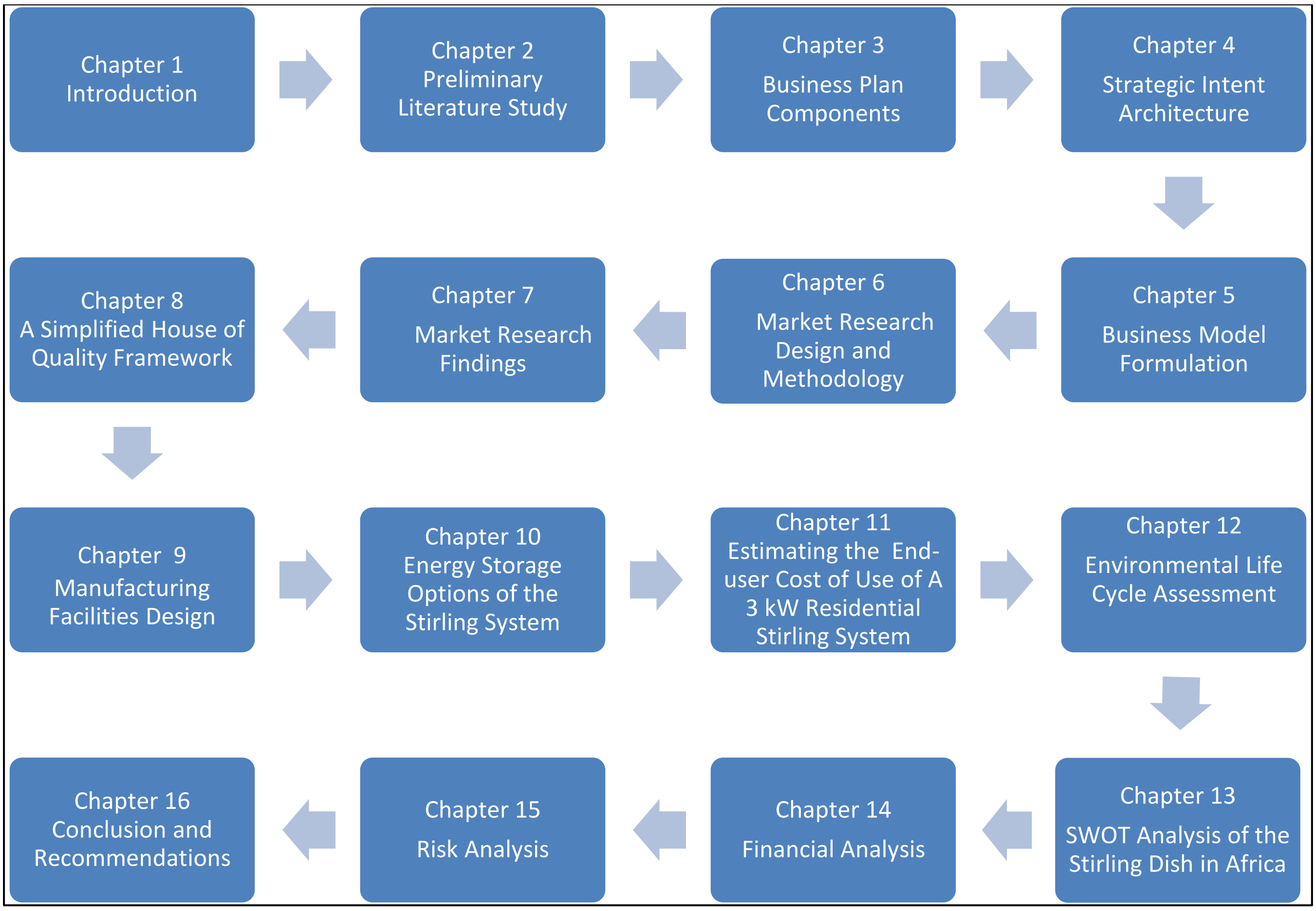


Figure 1.1: Thesis outline

CHAPTER 2

LITERATURE STUDY

2.1 Introduction

This chapter begins by giving an overview of the current electricity situation in Africa. It then gives a broad picture of the amount of solar insolation received by the whole continent. Finally the Stirling system is related to this context.

2.2 The electricity situation in Africa

The International Energy Agency (2013a) defines electricity access at a household level as:

> The number of people who have electricity in their homes. It comprises of electricity sold commercially, both on-grid and off-grid. It also includes self-generated electricity in those countries where access to electricity has been assessed through surveys by national administrations.
>
> (IEA, 2013a)

The electricity accessibility situation has worsened in Africa. Not even the intervention of international organisations has improved the situation. The number of people without electricity has escalated due to an increase in population. Only about 29 % of the population in Africa has access to electricity; however, this percentage is likely to drop in the future if nothing is done to improve the electricity accessibility (Alliance for Rural Electrification, 2013a).

The increase in the number of people without electricity can be attributed to an increase in energy prices, failure to implement policies and the poor economy. If Africa desires to prevent a decreasing electricity accessibility rate, it has to implement the right policies to combat inaccessibility to electricity and develop the economy (IEA, 2013b).

At present, 99, 6 % of the population without electricity in Africa live in sub-Saharan Africa. The following countries have the highest populations without access to electricity: Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Tanzania and Uganda. The following countries have a rural electrification rate of less than 5 %: Democratic Republic of Congo, Mozambique, Tanzania, Uganda and Zambia, see Appendix A (IEA, 2013b).

Sub-Saharan Africa has more potential to produce electricity from various renewable energy sources such as solar, wind, biomass and hydro-power than North Africa which has limited renewable energy sources. Compared to the rest of the world and other developing countries sub-Saharan Africa is lagging behind in terms of electrification. The rural electrification level of sub-Saharan Africa was 14, 2% in 2009. However, sub-Saharan Africa does not fully utilize the renewable resources available to produce electricity considering that the electricity level was 28, 5% in 2008 (Alliance for Rural Electrification, 2013a). Contrary to that, the rate at which North Africa and the rest of the world are providing electricity is much faster, see Table 2.1 and Appendix F. It is anticipated that North Africa will attain complete electricity accessibility by 2020. Tunisia has almost reached 100% electrification while the rest of the countries in North Africa have an impressive Urban electricity level of 99.6% of the population with electricity. North Africa's Rural electrification levels have advanced to a 98.4 % electricity level (IEA, 2013b) .

Table 2.1: Electricity access in 2009

	Population without electricity (million)	Electrification level (%)	Urban electrification level (%)	Rural electrification level (%)
Africa	587	41,8	66,8	25
-North Africa	2	99,0	99,6	98,4
Africa	585	30,5	59,9	14,2
Developing Asia	675	81,0	94,0	73,2
Developing countries	1,314	74,7	90,6	63,2
World	1,267	81,5	94,7	68

(IEA, 2013b)

2.3 Off-grid systems for electricity generation

The participation of the private sector in off-grid electrification via renewable energy technologies for distributed systems should be favoured when the electricity grid cannot be extended to rural communities. There are two types of off-grid systems available in the market today, the mini-grid (isolated grid) and the distributed (stand-alone) system.

Stand-alone systems are defined as:

> Power supply systems that only cover the needs of one single user such as a household, farm and so forth. Neighbours pooling resources or paying fees to a generator based on informal agreements are also considered to be stand-alone systems.
>
> (Newton, 2008)

Stand-alone systems are suitable for areas where people are dispersed and are under-provided with electricity (Norwegian Development Assistance to Rural Electrification, 2013). This is because distributed grid systems offer location flexibility and the electricity is generated where customers are based (Newton, 2008).

In contrast to electricity received from the grid, off-grid electricity provides cheaper electricity to rural areas. Recently, there has been a growing market for businesses that provide off-grid electricity, and possibly this market was triggered by a decrease in the cost of stand-alone technologies such as photovoltaic (PV) panels, and an increased demand for electricity. Off-grid systems can provide electricity for domestic use, public use, and village mini-grids (Reiche *et al.*, 2000). The Stirling system is an example of a stand-alone system that can generate electricity. The Stirling system can be installed to provide electricity to a household or community.

2.4 Challenges and solutions to grid extension

There are obstacles in the way of electricity provision in rural areas. In some cases it is impossible to extend the grid because of harsh climate conditions (IEA, 2013c). The various governments and donors in Africa are unable to meet the electricity demand of the entire continent by themselves. The main obstacle remains high capital expenses.

This is why the private sector plays a major role in assisting in the provision of electricity. The private electricity providers are seen as a "source of technology solutions and innovations" (Alliance for Rural Electrification, 2013b). The best option available to increase the rural electrification rate is the implementation of renewable energy systems. The private sector is able to provide equipment, expertise, specialised knowledge and better management.

Private companies in the past have installed electricity hybrid systems in Ghana, Tanzania and South Africa (Alliance for Rural Electrification, 2013b).

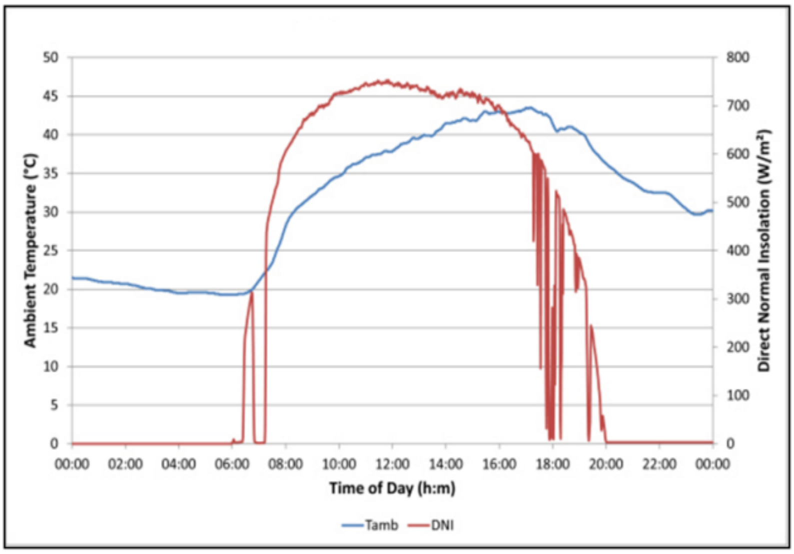
2.5 Benefits of electricity in rural areas

Rural electrification brings with it benefits to rural areas that are not possible without electricity. In the rural areas that were electrified through funds from the World Bank, the results showed that the electricity was used for lighting and watching television. Rural electricity increases time for studying and thus improves the education quality for school children. In addition, rural electrification improves the health of the people by improving the indoor air quality because of the absence of smoke (World Bank, 2008). Electrification also increases economic productivity by broadening the chances of income generation (Rolland, 2011).

2.6 The amount of solar insolation available

Solar energy is clean, free, renewable and readily available in abundance. Solar energy is becoming popular as a consequence of the depleting fossil fuel reserves, escalating fossil fuel prices and climate change issues. There are however, three concerns relating to the production of solar electricity. These are: solar energy availability, solar energy variability and high electricity costs involved in producing electricity from solar energy technologies especially CSP technologies when compared to conventional electricity.

Hereafter, the concerns of the solar energy critics are explained. Solar energy is only available during periods of sunshine, so how can it be an attractive energy solution since electricity is consumed 24 hours a day, 365 days a year ? On average the usable solar irradiance that the Stirling system can generate is only available for a maximum of eight hours a day, see Figure 2.1. Typically, the sun is available between 08:00 and 16:00 daily. In addition, the radiation from the sun varies: at times during the day the sun is unavailable like in instances when the sun is blocked by clouds or when it is raining. Currently, solar technologies can incorporate batteries to store excess electricity or phase change materials to store thermal energy.



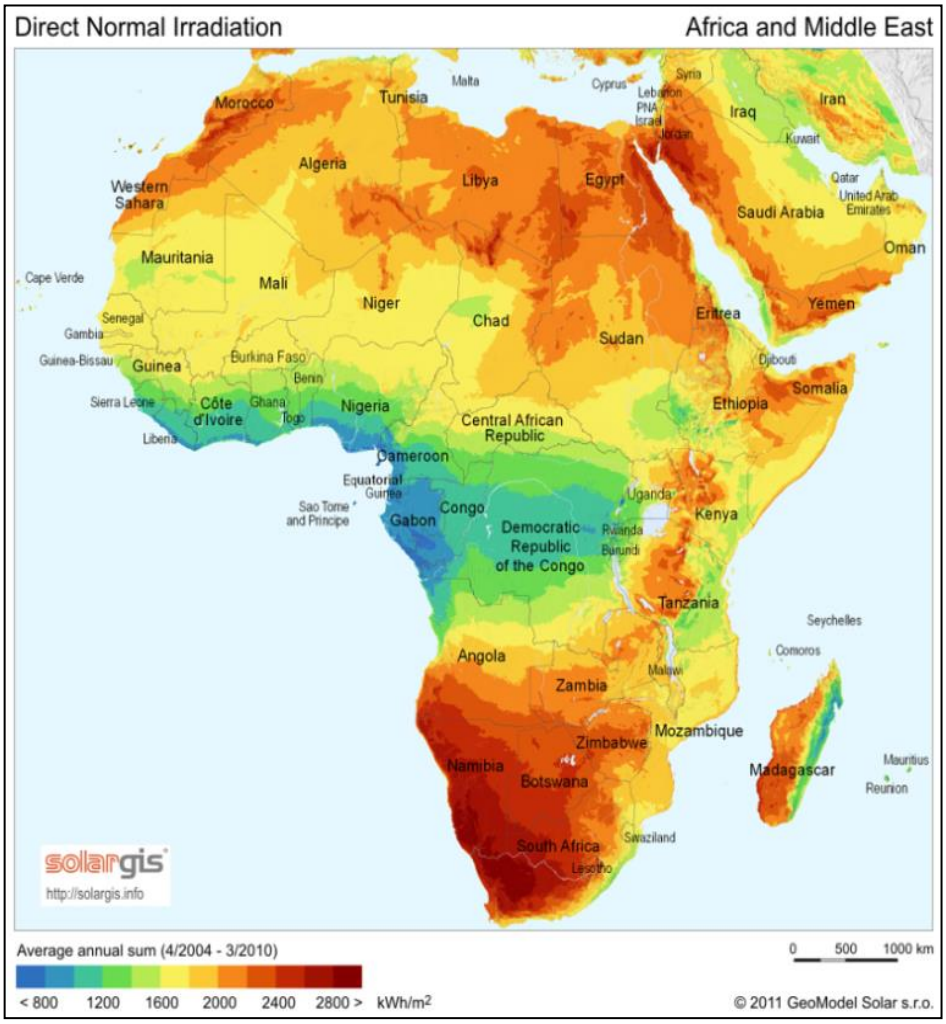
(Source: Solar at CSIRO, 2013)
Figure 2.1: The daily DNI variation

Over the years the costs of producing electricity from solar technologies has been decreasing. Additionally, the solar technologies provide environmental benefits and there is the possibility of making it cheaper through subsidies. With proper planning and designs in place, full exploitation of solar energy to provide for Africa's electricity needs is attainable (Chiras *et al.*, 2009).

2.7 The availability of solar insolation in Africa

The Stirling system and other CSP technologies make use of a special type of solar insolation called direct normal irradiance (DNI). According to Schillings and his co-researchers, DNI is defined as "the radiant flux density in the solar spectrum (from 0,3um to 3um) incident at the earth's surface perpendicular to the direction of the sun integrated over a small cone tracing the sun" (Schillings, Mannstein & Meyer, 2004). The minimum radiation required for any CSP technology to generate electricity is an annual DNI of 1,700 kWh/m² (Stine & Diver, 1994). The DNI is negatively affected by cloud cover and water vapour (Schillings *et al.*, 2004).

On the map in Figure 2.2, the areas in light yellow to dark maroon correspond to regions with a higher amount of annual DNI than the threshold, which is required to run CSP technologies. On the same map, it can be seen that the DNI is extremely high in the south and north of Africa where there are areas that receive sun radiation as high as 2800kWh/m^2/year. The map clearly depicts that Africa has rich solar resource regions. A high DNI indicates that a certain area has a high number of sunny days and vice versa. The areas in the central part of Africa are humid and often covered by clouds, which is why they are categorised as green and blue in Figure 2.2. The Stirling system can still operate in low DNI areas but with fewer operating days. Therefore, owing to a high DNI in southern and northern Africa the Stirling system is a viable solution to the energy problem in these areas.



(SolarGIS solar map DNI africa)
Figure 2.2: A DNI map of Africa

2.8 Concentrated solar power technologies

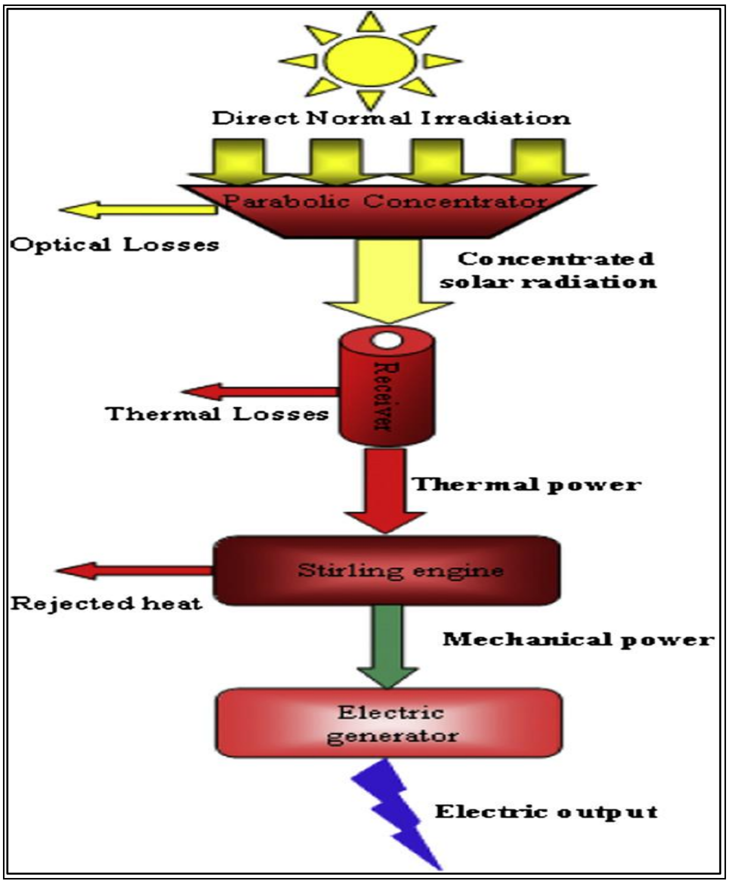
There are four types of CSP technologies, namely the Stirling system, parabolic trough, linear Fresnel and solar tower (Viebahn, *et al.*, 2011). At times CSP is referred to as solar thermal power. Furthermore, CSP technologies have the capability to generate electricity at night or during peak hours. However, CSP technologies nevertheless have the potential to supply low-cost and high-value electricity on a large scale. In comparison with solar photovoltaic (PV) panel systems, CSP technologies are more economical and efficient because they do not require PV cells and alternating current inverters (Patel, 2006). Studies done in Algeria have proved that the Stirling system can be used to produce electricity that can be cost competitive with PV and conventional technology systems (et Thermodynamique, 2009) .

CSP technologies can provide electricity to two types of markets. The first market is the large scale market that consists of on-grid and base load power. The CSP technologies are more suitable for commercial purposes. The second market is the small scale market that comprises of on-grid and off-grid applications. All the CSP technologies except the Stirling system can provide grid-connected power on a large scale basis. The Stirling system is more appropriate for small scale applications. One of the advantages of CSP technologies is the ability to cater for both grid-connected and distributed markets.

2.9 Background of the Stirling system

Typical large-scaled Stirling systems convert close to 31 % of direct-normal incident solar radiation into electricity. A 3kW Stirling system has an efficiency of about 24 %. With the exception of experimental multi-junction photovoltaic cells, the Stirling system is the most efficient of all the solar energy technologies (McConnell & Symko-Davies, 2006); (et Thermodynamique, 2009) .

The Stirling system tracks the radiation from the sun, and the solar radiation is focused onto and absorbed by a receiver. The thermal energy is then converted into mechanical energy and finally into electric energy. The Stirling system is integrated with a sun-tracking system that rotates the solar concentrator on two axes depending on the direction of the sun (Newton, 2008). The Stirling system is divided into four components namely the parabolic dish, the thermal receiver, the free-piston Stirling engine and the electrical generator. Figure 2.3 illustrates the pathway of generating electricity using a solar Stirling system.



(Abbas et al., 2011)

Figure 2.3: Solar Stirling System energy path

The minimum DNI required for a solar thermal utility to work efficiently is above 5 kWh/m^2/day. Some regions in Africa receive DNI above the minimal threshold to effectively and economically operate a Stirling system (Deichmann *et al.*, 2011) . Therefore, the African countries should look into utilising this resource. South Africa has the potential of generating 547, 6 GW of electricity from CPS (Fluri, 2009).

The Stirling systems that are currently being manufactured are relatively small in size compared to other CPS technologies. There are two reasons for this. Firstly, the engines sizes are small and, secondly, the small parabolic dish reduces wind load, which makes them suitable for windy areas. The Stirling system, being more modular than other CPS technologies, can also be assembled to any power size. The word ‘modular’ is defined as the degree to which a system is easily assembled and is flexible to arrange because it is made up of separate components. Modularity is one of the features making this technology appropriate for stand-alone applications (Patel, 2006).

A typical Stirling system generates energy between 3 and 25 kW. The typical household without any appliances the energy consumption is 0,2 kWh/day. However, a household that uses electricity for lighting and for appliances such as video players, refrigerators and televisions requires about 3 kWh/day (Nfah *et al.*, 2007). This study forms part of a research team that has already decided to build a 3kW Stirling system. Hence, a 3 kW Stirling engine/dish unit generates electricity that is more than adequate for households or groups of households in rural areas. Figure 2.4 depicts a typical Stirling engine and dish.

(Source: Infinia)
Figure 2.4: The Stirling system

The manufacturing company of Stirling systems can only go in operation if the following criteria are met (Tsoutsos *et al.*, 2003):

1. Large scale production of units
2. Long life span

There are several retired solar systems that have been developed in the past, some as early as 1982. Presently, there are two large-scaled Stirling system plants in operation and one under construction, see Table 2.2. Spain, USA, Australia and France are planning to construct Stirling system plants that will have a total capacity of 3254 MW (Ramaswamy *et al.*, 2012) .

Looking at Table 2.2 these countries still have a long way to go to achieve 3254 MW of CSP electricity because they currently generating 1, 51 MW using CSP. As previous stated, South Africa has a potential to produce 550 GW electricity from CSP technologies. This is more than the Spain, USA, Australia and France combined. In 2002, ESKOM, a power supply company in South Africa, installed and operated a 25 kW Dish Stirling at the Development Bank of Southern Africa, which is situated in Johannesburg. However, the Stirling system has been transferred to Stellenbosch University to be used for research purposes.

Table 2.2: Large scale Stirling system plants

Plant	Location	Capacity (MW)	Use
Enviro Dish	Spain	0, 01	Operational
Maricopa Solar Project	USA	1, 5	Operational
Renovalia	Spain	1, 0	Under construction

(Ramaswamy et al., 2012)

2.10 Components of the Stirling System

2.10.1 Parabolic dish

The function of the parabolic dish is to capture the solar energy and convert it into a useable form of energy. The incoming energy from the sun is reflected onto an aperture area to accomplish high temperatures. According to Newton (2008), the receiver is a significant element of the Stirling system. The concentrator has a parabolic shape with a reflective surface. However, the curved surface can only be covered by aluminium or silver reflectors. The two possible solar tracking methods are azimuth elevation tracking and polar tracking (Newton, 2008).

1. **Azimuth elevation tracking**: tracking is through an orientation sensor or determined by the sun’s coordinates.

2. **Polar tracking**: the solar collector rotates about an axis that is parallel to that of the earth.

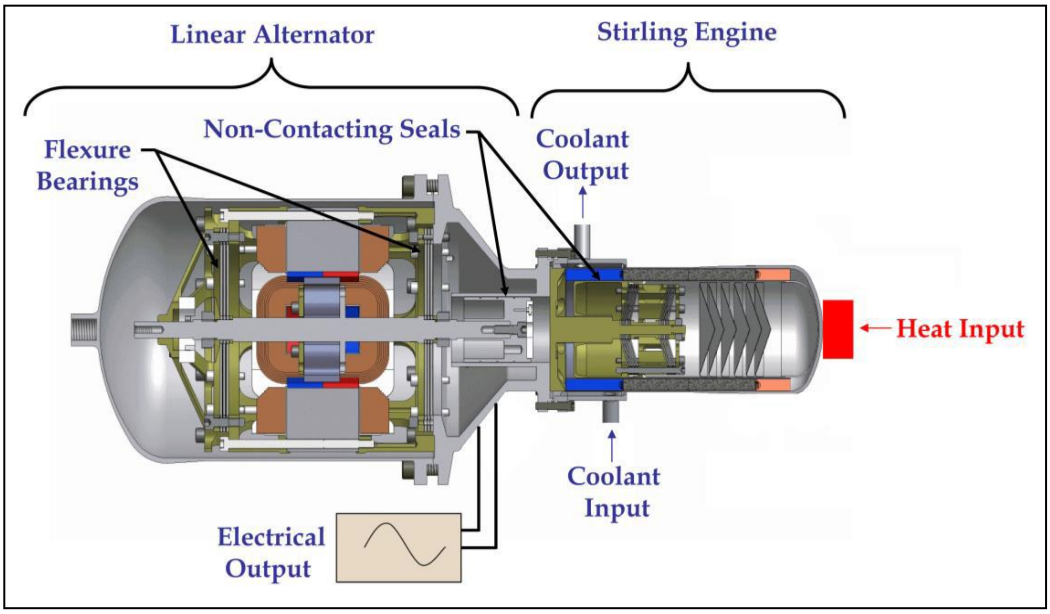
2.10.2 Thermal receiver

The thermal receiver absorbs the light energy and converts it into thermal energy that is responsible for moving the working fluid that is found in the Stirling engine. The working fluid generally consists of either helium or hydrogen. The temperature of the working fluid is between 650 and 750 ^{0}C. The high temperature can have a negative impact on the efficiency of the engine. The receivers are produced with a cavity design to accommodate the high temperature (Newton, 2008).

2.10.3 Stirling engine

The Stirling engine is a reciprocating, external heat source engine which requires heat outside the engine's cylinder. The Stirling engine technology is used in a wide range of technologies such as vehicle propulsion, gas-fired heat pump drives, aircraft propulsion, sub-marine and electricity generation. The advantages of the Stirling engine are: low gas emissions, silent operation, high efficiency, commercial availability and the ability to be powered by a variety of fuels and solar energy (Majeski, 2002).

There are two types of Stirling engine designs available, namely the kinematic Stirling engine and free-piston Stirling engine. This study focuses on the free-piston Stirling engine, similar to the one depicted in Figure 2.5.



(Source: Infinia)
Figure 2.5: The free-piston Stirling engine

The free-piston engine is mechanically simple compared to the kinematic engine. The free-piston engine generates power from a linear alternator. This type of engine has a high torque due to low piston frequency. These engines do not require lubrication and have no rotating parts and therefore they require less maintenance. Free-piston engines consume fuel more efficiently than kinematic engines. Free-piston engines are more suitable for off-grid application since the power they generate is able to stabilize the operating frequency of the engine (Majeski, 2002).

The Stirling engine has a theoretical efficiency of 40% in converting heat energy into mechanical energy. The Stirling engine is flexible since it runs any type of heat i.e. heat produced from either fossil fuel or renewable sources. Some engines are cogenerated, which means the engine produces heat and electricity simultaneously. Therefore, since the continuous expansion and contraction process occurs inside the Stirling engine, these engines emit fewer emissions than other engines. The sizes of the Stirling engines range from 1 to 25 kW. The Stirling engine uses gas as an operating fluid that allows the engine's temperature to become very high. The temperature can only affect the materials used in manufacturing the engine but not the operating fluid. Due to these reasons Stirling engines are suitable for solar thermal power systems (Newton, 2008) .

2.11 The market barriers of the Stirling System technology

Three typical market barriers have been identified for the Stirling system namely: lack of starting capital, lack of necessary skills and lack of familiarity. Only when these market barriers are overcome should the investors proceed in investing in such a project (Vivid economics, 2010). This is similar to what (Trieb, 2000) suggested; that electricity markets must have a recognized technology, an understood financial risk and acceptable earnings.

The World Bank Group has not only seen the importance of financing and designing rural electrification projects but it has come up with an approach that would allow these projects to be self-sustaining. Their aim is to develop self-sustaining local markets that continue functioning on their own without external financing. Since rural off-grid markets are still unknown, these markets can only be profitable if private firms are allowed to run them (Reiche *et al.,* 2000). It is important that a certain technology is accepted before it is introduced into the market. (Wang, 2009) stressed that the market of the Stirling system can only target specific markets in off-grid power systems and in remote areas. This is due to limited sizes of the Stirling systems.

2.12 Benefits of the solar Stirling System

The Stirling system has technically and economically proved to be one of the potential future electricity producers for both off-grids and mini grid power systems (Corria *et al.*, 2006).

The advantages of a Stirling system:

The Stirling system has a higher conversion efficiency when compared to other CSP technologies (Müller-Steinhagen & Trieb, 2004). The electricity cost produced from CSP has decreased in terms of cents/kWh. CSP technologies are cost-effective and able to compete with the conventional power plants if they store energy or if they are hybridized (Trieb, 2000; Tsoutsos *et al.*, 2003). Stirling systems become cheaper when mass produced. Stirling systems are easy to operate and require little maintenance. They are applicable for both distributed and centralised systems. The Stirling system is a stand-alone system. It is modular and thus able to adapt to changing or increasing demands. There is a long-term knowledge on the application of the Stirling system on a small scale basis (Trieb *et al.*, 1997).

CSP technologies are more effective in areas that receive more sunlight because there are more working hours. One challenge for areas with high solar radiation is that they often have a limited water supply. To run a CSP technology in such areas that requires extra costs in piping water from a long distance away or in cleaning the available low quality water might have limited feasibility. However, the Stirling system unlike the other CSP technologies does not require water for cooling or other operations, except for cleaning the mirrors. The engine does not require water for cooling since it is air-cooled (U.S. Department of Energy, 2001). The Stirling system runs merely on solar energy therefore it emits very low quantities of greenhouse gases and other emissions as compared to conventional systems that consume fossil-fuels. Consequently, the Stirling system technology can help mitigate climate change (Stoddard *et al.*, 2006; Timilsina *et al.*, 2012; Viebahn *et al.*, 2011).

2.13 The disadvantages of the Stirling System

The Stirling system requires a strong supporting system and accurate tracking systems (Trieb *et al.*,, 1997). Various laws and fiscals such as incentives, loans, tax incentives and so forth, have been established to encourage the deployment of solar energy. Some of the fiscals have not yet materialised. Despite numerous policies and incentives for solar energy, the technology has not been adequately utilised (Timilsina *et al.*, 2012).

2.14 Maintenance and safety precautions in handling Stirling System technology

The parabolic dishes can cause temporary blindness or severe burns when one looks directly into the focal point. Thus, the best time to clean the mirrors of the Stirling system is when it is cloudy or at night. A company named Infinia has produced a 3 kW Stirling system called PowerDish that, after sunset, reorients itself to face the ground in order to reduce dust accumulation and hence requires less washing (O'Connor, 2010) . Strong winds tend to affect the parabolic dish negatively, by decreasing the electricity produced. However, the PowerDish can resist strong wind loads by changing its orientation.

Safety precautions regarding the operation of dish optical devices:

Exposure of the eyes and skin to concentrated sunlight can be immediately harmful. It can cause blindness and severe burning, respectively. All necessary precautions are to be followed to avoid exposure to any level of solar concentration.

Fixed length focal points as encountered in parabolic dishes and parabolic troughs typically have short focal lengths and are only harmful in the immediate vicinity of the concentrator. Operation of these devices:

1. Keep covered or out of direct sun when not used or during setup.

2. Note that a poor parabolic dish can have a focal point temperature exceeding 1,000 °C.

3. Provided that these concentrators don't have the ability to become flat, they pose no risk at a long distance much like a curved motor vehicle window does not reflect much light to people in other cars. Thus concentrators pose no risk to people in adjacent buildings.

(Gauché, 2011)

The Stirling system is safe for household use when the necessary precautions are taken. As the technology develops these risks must be addressed.

CHAPTER 3

BUSINESS PLAN COMPONENTS

3.1 Introduction

This purpose of this chapter was to develop a business plan methodology. This chapter comprises of the business plan outline and an introduction to the enterprise engineering process. A business plan is prepared following the feasibility study. The business plan acts as a business tool for the business and the outside world. It contains all the information of the business such as the mission of business, product information, market and customers, manpower, financial profile and business growth plan. Hence, a business plan is seen as a roadmap for keeping a business focused, meeting its goals and minimising risks.

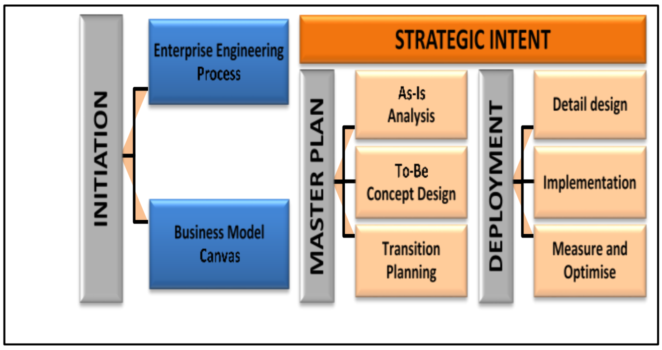
3.2 Business plan components

The sections of the business plan are organized as follow.

1. The enterprise model process
2. Strategic intent
3. Financial analysis
4. Risk analysis

3.3 Enterprise engineering process

This chapter follows the enterprise engineering process. Enterprise Engineering is defined as the body of knowledge, principles, and practices having to do with the analysis, design, implementation and operation of an enterprise (Liles *et al.*, 1995). The enterprise engineering process consist of three phases namely, the initiation phase, master planning phase and deployment phase, refer to Figure 3.1.



(Booysen, et al., 2014)
Figure 3.1 Enterprise engineering process

3.4 Enterprise design life cycle

In order to apply the enterprise engineering process the enterprise design life cycle should be developed. The enterprise design life cycle is made up of iterative phases that change over time, see Figure 3.2. The enterprise design life cycle is the foundation of the development stage of the product.

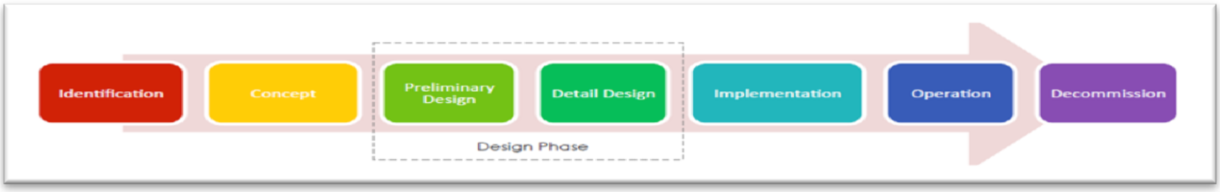


Figure 3.2 Enterprise life cycle

3.5 Enterprise engineering process roadmap followed

The aim of the roadmap is to move from the initiation phase to the deployment phase. The enterprise roadmap followed in this study is the one depicted in Figure 3.1:

3.5.1 Initiation phase

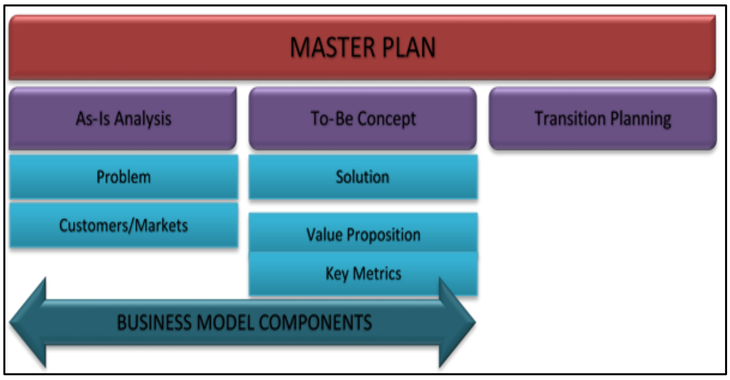
The initiation phase consists of the enterprise engineering phase and Osterwalder's business model canvas that compromise the roadmap to where the project is headed.

3.5.2 Strategic intent

The master phase and deployment phase falls under the strategic intent. The strategic intent is the section that discusses the purpose of the management to embark on this project. It consists of the vision, mission and values of the enterprise.

3.5.3 Master phase

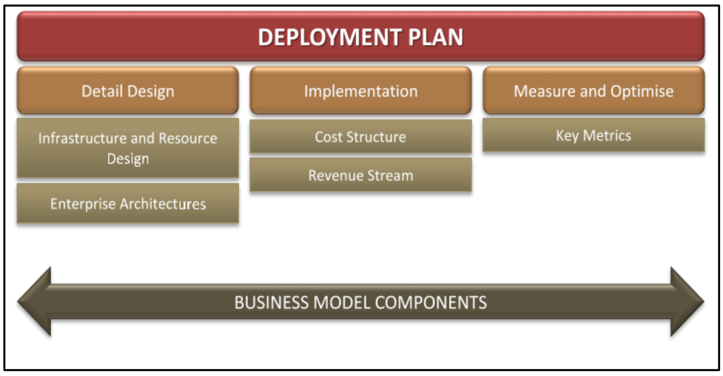
The master phase is the guide for the process of planning the enterprise, see Figure 3.3. *As-Is Analysis* investigates the problem, market gap and customers segmentations. *To-Be Concept* is a section where the solution to the problem is addressed and the value proposition is discussed. The transition planning is the launch of the business.



(Booysen, et al., 2014)
Figure 3.3 Master phase

3.5.4 Deployment phase

At this point the concept is ready to be used, see Figure 3.4.



(Booysen, et al., 2014)
Figure 3.4 Deployment phase

3.6 Chapter summary

This chapter will therefore serve as a guide during the further exploration and development of a business model canvas for a Stirling system manufacturing business in the succeeding chapter.

CHAPTER 4

STRATEGIC INTENT ARCHITECTURE

4.1 Introduction

As mentioned in the previous chapter, the strategic intent is the first section of the business plan. Hence, chapter 4 will discuss the foundation of the business.

4.1.1 Executive Summary

This business plan assumed that a company called **African Power Supply cc** has already been formed in 2013 as a University of Stellenbosch spin-off company. Such a spin-off company will make extensive use of the university facilities, lecturers and students. The objective of the company will be to manufacture a 3 kW-electrical solar Stirling engine and dish for stand-alone power supply units. The company aims at empowering areas without access to electricity through the application of the solar Stirling technology. It will produce and supply a Stirling system on behalf its customers; that is the rural African communities. It aims at increasing the customers' satisfaction and maintaining a client relationship by providing custom support services by providing a return policy for damaged products. In the next 10 years the company wants to be a world leading provider of Stirling technology systems with factories throughout Africa.

4.1.2 Vision

To become a world leader in R&D in the Stirling system field, deployment of technology and world-class manufacturer. Further, the company wants to establish economically viable and stable rural communities in Africa, thereby alleviating the increasing rate of urbanisation and the negative consequences thereof.

4.1.3 Mission

The mission of the company is to become a profitable, self-sustainable, reliable company that provides a technology that generates electricity. The company will maintain the highest level of quality, and ensure prompt delivery and efficient client services at all times.

4.1.4 Values

The core values of African Power Supply cc are very important in order to ensure product quality and reliable products:

Commitment: The staff is committed to their job and getting the work done.

Providing quality products: The products produced are expected to out-perform competitor products and last 30 years on average.

Continuous improvement: The Company will strive to improve products in terms of price, size and performance.

4.1.5 Short term objectives

The short-term objectives of the company are to manufacture the most cost-effective Stirling system, to promote the product effectively by applying aggressive marketing, so that it reaches the target market, and thence to conduct the business in an efficient and profitable way.

4.1.6 Long term objectives

The long-term objectives are to expand our business globally. This will be achieved by opening up new factories in areas where there are high demand, and where conditions are conducive, such as political stability, access to raw material, cheap labour, availability of infrastructure, and so forth. The goal is to create a flexible product that will be altered over time with new technology advancements.

4.1.7 Proprietary rights

The legal form of our business is listed as a close corporation (cc).

4.1.8 Key successes

Some of the key successes for which our company wishes to be known are the following: a proudly African product, excellent product quality, technology that is simple to operate and maintain high efficiency, long product lifespan, and availability of customer support.

4.2 Chapter summary

At this point the investor has a clear picture of the foundation of the business. In conclusion this chapter discusses the management's intent for developing the business. The company's name, vision, mission and values were clearly summarised.

CHAPTER 5

BUSINESS MODEL FORMULATION

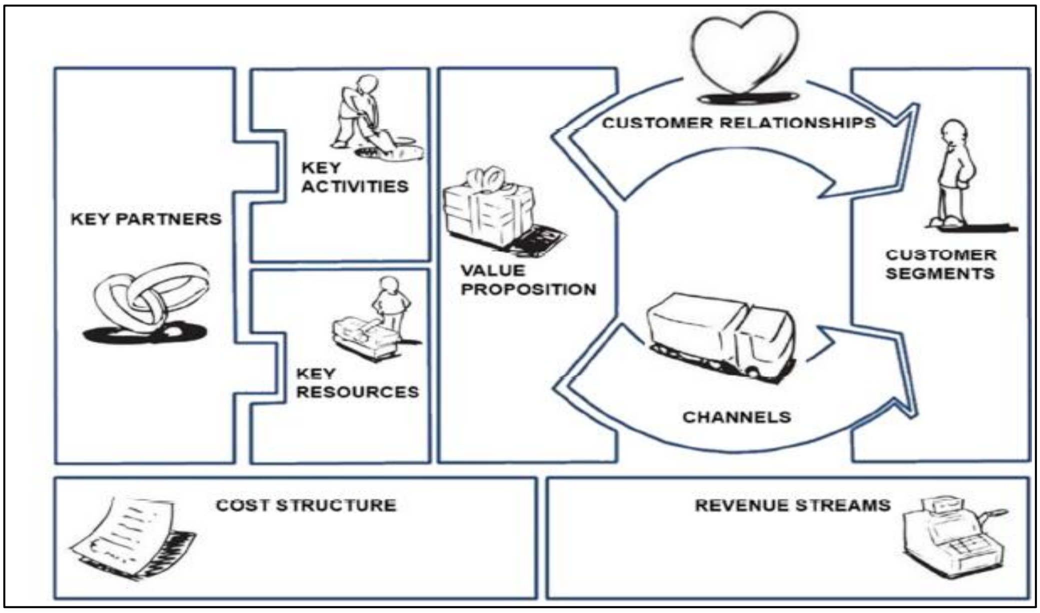
5.1 Introduction

The business model is defined as a rationale "of how an organization creates, delivers, and captures value" (Osterwalder & Pigneur, 2010) . The business model is like a blueprint for a strategy to be implemented through organizational structures, processes, and systems (Osterwalder & Pigneur, 2010) .The enterprise model is the crucial section of the business plan. The business model will be used to guide the development process for formulating the Stirling system manufacturing business. Unlike the traditional business plan, the business model is a much easier tool to communicate with investors.

The business model can best be described through nine basic building blocks that show the logic of how a company intends to make money. The building blocks of the business model are as follows (aligned with the chapters from the thesis were each building block was highlighted excluding the current chapter):

1. Customer Segmentations- the market study discussed in Chapter 5, 6 and 7
2. Value propositions - discussed in Chapter 5, 7, 8 and 10 (where the various energy options of the Stirling system were described) and in Chapter 11 (comparison of Stirling system versus other electricity supplies or grid).
3. Channels- partly addressed in Chapter 7 with the feed-back of the market survey
4. Customer relationships- the section was addressed in Chapters 5 and 7
5. Revenue streams- was covered in Chapter 14
6. Key resources- was covered in Chapters 5, 9 and 10
7. Key activities- was covered in Chapters 5, 9 and 15
8. Key partners- was highlighted Chapter 4 plus some reference to government and Stellenbosch University
9. Cost structure- was highlighted in Chapter 14 and partly Chapter 11

Figure 5.1 depicts the relationship between the nine building blocks of the business model canvas.



(Osterwalder & Pigneur, 2010)

Figure 5.1 The relationship between the nine building blocks of a business model canvas

The nine blocks cover the four main areas of a business (Osterwalder & Pigneur, 2010) :

1. Customers
2. Offer
3. Infrastructure
4. Financial viability

5.2 Customer segmentations

The customer segments building block describes different groups of people or organizations and enterprise aims to reach and serve those. Sometimes the customers segments are divided into distinct segments with common needs, common behaviours, or other attributes. This allows the company to serve the customers better (Osterwalder & Pigneur, 2010). Customer segmentations were discussed in detail in Chapter 6 and 7. In Table 5.1 two customer segmentations were identified.

Table 5.1 Customer segmentation for the Stirling system in Africa

	Segment A	Segment B
Areas of likely deployment	Rural areas without access to electricity, remote areas	Commercial farms, remote areas, urban areas
Description of customer	Low income, unlikely to afford the technology.	High income, likely to afford the technology, government, non-governmental organisation, renewable energy enthusiast.
Estimated percentage of customer base	95	5

Segmentation A includes, but is not limited to people living in rural areas and isolated (remote) areas without access to electricity in Africa. The target market is the whole African continent but gradually this product could also be sold globally. This idea was motivated by the high number of people without access to electricity outside Africa.

Segmentation B includes townships, small farms, and any other interested stakeholders. People in this segment can be with or without access to electricity.

5.2.1.1 Geographic profiles

In 2009 the statistics of Africans without access to electricity stood at 29%, which was 590 million people; while in other parts the numbers lacking electricity stand at 675 million in developing Asia, 1,341 million in developing countries. The overall rural electrification rate of Africa was worse in sub-Saharan Africa. In contrast, the situation is greatly improved in North Africa where the same statistic stood at 99% (IEA, 2013c). However, the main energy sources in North Africa are from non-renewable fuels, fossil fuel and natural gas (Mohamed *et al.*, 2013). Refer to Appendix A for the total number of people in Africa without access to electricity. The number of people without access to electricity in Africa is too high considering that “access to a reliable, adequate, and affordable electricity supply of sufficient quality for personal and household (domestic) use” is a human right for all human beings (Tully, 2006).

5.2.1.2 Demographic and psychographic profile

People living in the same community tend to have similar demographic and psychographic characteristics. They are likely to exhibit the same characteristics with regard to income, needs and buying patterns. These are explored in Chapters 6 and 7.

5.3 Value propositions

The value propositions building block describes the products and services that create value for a specific customer segment. The value propositions are created to eliminate the customer's problem or satisfy a customer need. Values propositions may be quantitative for example price, speed of service or qualitative such as design, customer experience (Osterwalder & Pigneur, 2010).

In summary the company would provide the following value propositions to the customers purchasing the 3kW Stirling systems:

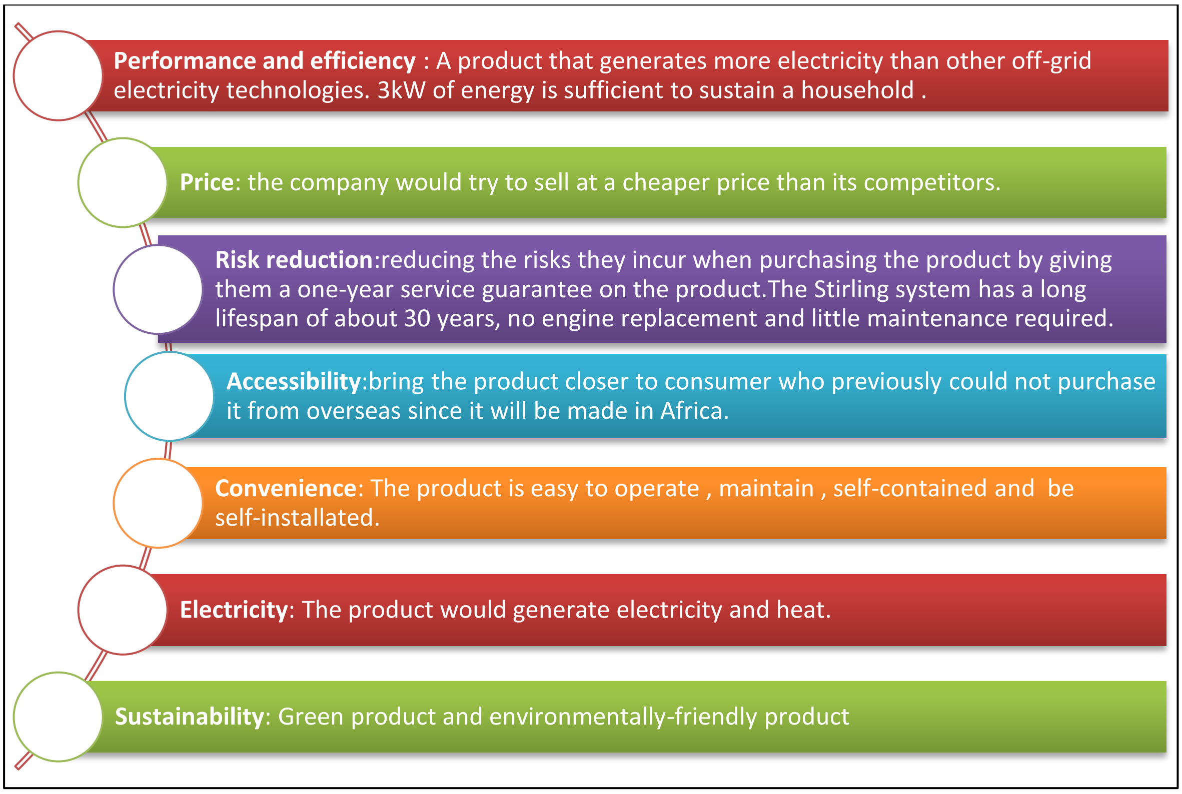


Figure 5.2 3 kW Stirling System value proposition

5.3.1 Comparative competitive analysis

To date, the Stirling system has certainly not been deployed in rural areas on a small scale basis before. Since the Stirling system is still in a developing stage, there are still opportunities for improvement and in the future this technology is likely to reach higher levels of refinement. Andraka *et al.*, (2012) discussed the on-going research activities and innovative projects aimed at improving the Stirling system, such as a higher operating temperature, higher heat transport, higher efficiency, a storage system installed behind the concentrator, and so forth.

The Stirling system will be manufactured as cost-effectively as possible so that it is affordable to the consumers. Unlike other stand-alone electricity generating technologies, this cutting-edge technology product will be produced **in Africa by Africans for Africans** and as many local materials as possible will be integrated into the design. The following features distinguish our product from other decentralised technologies:

- It can be hybridised to include phase change materials that charge during the day and power the Stirling system at night. Plus, during the night, the Stirling system can run on biogas or for that matter on any other fuel.
- It is technologically advanced, and requires and unites people from different disciplines into its value chain.

5.3.1.1 Indirect competitors

The stand-alone electricity generating technology competitors (indirect competitors) of the Stirling system are diesel generators and photovoltaic panels (PV panels); see Table 5.2 for a more complete competitive analysis.

1. **Diesel generators**

A diesel generator is able to produce electricity the whole day so long as it has fuel. But the price of the diesel is volatile, the household requires a continual fuel supply, and it is expensive for a household to own one for running the entire day.

Photovoltaic panels

Photovoltaic panels are popular in rural households for producing electricity. On the other hand, the PV panels are prone to theft and most of them are imported and not manufactured in Africa. Banoni *et al.,* (2012) made a comparative economic analysis between a Stirling system and PV panels, and the results proved that the Stirling system was more viable to own since it had better returns. A comparison analysis table for the Stirling system and its indirect competitors is available on Table 5.2.

Table 5.2 Comparison analysis table

	STIRLING DISH		PHOTOVOLTAIC PANEL		DIESEL GENERATOR	
	Benefits	**Disadvantage**	**Benefits**	**Disadvantage**	**Benefits**	**Disadvantage**
Prices	• More expensive than PV • Cheaper when produced in large scale	• Tracking systems add to costs	• PV panels prices are declining	• Not cost effective because of the high start-up capital	• Low purchasing costs	• "Most expensive technology for producing electricity" • Requires extra costs for fuel transportation
Energy	• Solar energy is available everywhere • Dual tracking system responsible for high energy output	• No operation during cloudy times and/or at night	• Solar energy is abundant fuel supply	• Does not operate during cloudy times and/or at night • Produces direct current (DC)	• Produces alternating current (AC)	• Fuel consumption
Performance	• High efficiency • Options to operate as decentralized or centralized system • Technology rapidly improving. In terms efficiency and heat storage aspects	• Requires water for cleaning	• Options to operate as decentralized or centralized	• Power output depends on the solar intensity • Experiences losses due to batteries and other parts therefore low efficiency	• Produce constant electricity	• Performance decreases the capacity • Low capacity factor
Life span	• 25-30 years		• 10 years for PV panels	• 3-5 years for the batteries	• 10 years	• Short
Installation and maintenance	• Requires little maintenance due to moving parts • Silent operation • Easy to operate		• Low maintenance costs • Easy installations • Little maintenance	• Requires regular cleaning • Batteries require replacements • PV panels are fragile	• Simple technology • No civil work required • Short installation time	• Maintenance and operating costs are high • Moving parts results in noisy operation • No electricity production during maintenance period
Relevant information	**Low impact on the environment**		**Popular technology in rural areas** **Noise free**	**Cadmium telluride contained in the panels is carcinogenic and toxic** **Most of the PV panels in Africa are imported**	**Applicable in emergency situation**	

(Lahimer *et al.*, 2013) ; (Tsoutsos *et al.*, 2003);(Trieb *et al.*, 1997);(Andraka *et al.*, 2012)

5.3.1.2 Direct competing service provider

There are two commercial companies that manufacture 3kW-sized Stirling systems. The first company is called Infinia Technology Solutions. It manufactures 3kW free-pistons Stirling engines called Powersystem. The second company is called Innova Solar Energy that produces a 3kW tri-generation system called Trinum, which simultaneously produces 1kW of electric energy and 3kW of thermal energy and cooling. The Trinum system is sold for €19 000, (R277 255,60) excluding installation costs of €3 000,00 (R43 777,20).

These three companies produce Stirling systems, however it is in larger seizes: United Sun Systems, Stirling Energy Systems Inc and The Powergroup.

5.4 Channels

The channels building block describes how a company communicates with and reaches its customer segments to deliver a value proposition. Channels have five distinct phases. Each channel can cover some or all of these phases (Osterwalder & Pigneur, 2010).

Channels serve several functions, including (Osterwalder & Pigneur, 2010) :

- Raising awareness among customers about a company's products and services
- Helping customers evaluate a company's value proposition (this was partially addressed in Chapter 7 with the feedback response of the survey)
- Allowing customers to purchase specific products and services
- Delivering a value proposition to customers
- Providing post-purchase customer support

5.4.1 Marketing strategy

The marketing and sales manager will approach energy ministries and energy departments in different African countries to promote the product. The same strategy will be applied to non-governmental organisations (NGOs) which fund rural development programmes such as rural electrification. The other strategies and plans that will be undertaken are:

- Embrace a theme for the business: "EMPOWER individuals in generating sustainable POWER and ENLIGHTEN rural communities on LIGHT creation".

- After a few years of aggressive marketing, the business should have created a customer base that would market the product with word of mouth.
- Educate the people from rural areas about the product and the benefits it brings through different exposures such as newspapers, television, radio and magazines. The message will be conveyed mostly through radio since it is likely to reach a higher number of people in rural communities than by means of other media platforms.

Refer to the channel phases diagram for African Power Supply in Table 5.3.

Table 5.3 African Power Supply channel phases

Channel types			**Channel Phases**				
Own	**Direct**	*Sales force*	**Awareness**	**Evaluation**	**Purchase**	**Delivery**	**After sale**
		Web sales	How do we raise awareness about our company's products?	How do we help customers evaluate our organization's value proposition?	How do we allow customers to purchase specific products?	How do we deliver a value proposition to customers?	How do we provide post-purchase customer support?
	Indirect	*Own stores*	The product will be made aware to the public through marketing. The company would be responsible for the marketing.	Reviews will be carried out by the company to investigate whether the product is selling and satisfactory.	The customers will purchase the product directly from the factory through making an order through telephone, email or physically visiting the factory physically.	The company will deliver the products to the clients in the most convenient way so the product is not destroyed. The product will be transported as loose items (pre-assembled items) to the client.	The company will provide customer support services for complaints, product exchange etc. Through the website a short questionnaire that clients can fill in perceptions about the product and services provided.
Partner		*Partner stores*					
		Wholesaler					

5.4.2 Marketing tactics and campaigns

In order to have an effective marketing strategy for the Stirling system, a SMART (Specific, Measurable, Achievable, Realistic and Time framed) objective was used as guide to reach the marketing goal, see Figure 5.3.

Specific	• Create an aggressive product marketing awareness campaign • Set up marketing goals and strategies • Create a brand image
Measurable	• The units sold should increase by 100 % per annum in the first 5 years. After 5 years it's possible that the product price might decrease.
Achievable	• Setting aside promotion budget for marketing for the first 5 years. The high growth rate and product awareness can only be reached with adequate finances available.
Realistic	• Create awareness campaigns in various African countries. Aim at selling the product in 20 % of rural households in SADC within 10 years, 5 % in the rest of Africa and 2 % in the rest of the world.
Time framed	• Marketing phase is scheduled to last about 5years. This duration is long enough for the product to be known.

Figure 5.3 SMART marketing framework

5.4.3 Marketing budget

The company expects to spend about R 225 000,00 on an effective marketing strategy in the first 5 years.

5.5 Customer relationships

The customer relationships building block describes the different types of relationships a company establishes with specific customer segments. Customer relationships may be driven by the following motivations (Osterwalder & Pigneur, 2010):

• Customer acquisition

• Customer retention

• Boosting sales (upselling)

The main aim of the customer relationship of the company is for sales recurring. This would be done through the following methods:

1. **Personal assistance:** Customer feed-back and support is a part of customer relationship. The customers will be free to community directly to the company through the established

communication channels such as email, phone call, website and personal visits of customers to company.

2. **Online customer communities:** This idea would work mainly with segmentation B customers who are more likely to have access to internet. The company will form an online community where clients can interact with other, give suggestions and relate experiences to one another.

5.6 Revenue streams

The revenue streams building block represents the cash a company generates from customers (Osterwalder & Pigneur, 2010).

The company would generate money from the product sales, see sections 14.2.1.1, 14.2.1.2 and 14.2.1.3. The current price of the Stirling system is about R 83 000,00. This price is lower than what the government would pay for installing a small power plant in a community.

5.7 Key resources

The key resources building block describes the most important assets required to make a business model work. Key resources can be physical, financial, intellectual, or human key resources (Osterwalder & Pigneur, 2010). Key resources are identified in Chapters 9 and 10.

5.7.1 Factory location

The first full-scale factory will be set up in Johannesburg, South Africa, rather than in Cape Town, because the manufacturing sector in Johannesburg is more advanced. Johannesburg has more metal companies and construction companies because of the mines in the area, compared to the Cape Town region. Though the pilot factory will be established in Cape Town, this factory will be fully operational only once the product demand goes up. The advantage of a factory in Cape Town is that it is located near the harbour. Johannesburg and Cape Town have good infrastructure such as rail, road and energy, and, in the case of Cape Town, a port. When demand for the product begins to increase across Africa, different factories will be set up outside the borders of South Africa.

5.7.2 Material handling in the factory

Material handling is defined by Stephens and Meyers (2013) as simply as the moving of materials. A tray trolley is the proposed material handling vehicle for transporting of the materials in the factory between processing and assembly operations, see Figure 5.4. The tray trolley can serve both as a material handling vehicle and as a temporary storage unit. The trolley is suitable because of the light mass of the raw materials and finished products. Tray trolleys are fast, cheap and manually controlled. The tray trolley applies ergonomic principles, since it is safe to use and eliminates the necessity for workers to carry materials. A facility that operates with a proper material handling set-up results in fewer production costs, smooth flow of materials, and obviates long queues (Stephens & Meyers, 2013).

Figure 5.4: An example of a suitable tray trolley that can be used for material handling

5.7.3 Space requirement and office area allocation

The standard office space required for any person is 18,581 m^2; however, this number can vary depending on the workers' hierarchy. With reference to the organisational chart, the workers on the top level of the workers' hierarchy are more likely to be allocated more office space than the ones on the lower levels of the hierarchy (Meyers, 1993). Ordinary factory workers will not require offices. A space allowance was added to the space allocation for spaces that are too small to be calculated and for aisles. Table 5.4 shows the different office space sizes for the workers.

The office dimensions were calculated using the formula from (Meyers, 1993):

$$\text{Office space on default} = 18{,}581 \text{ m}^2 \times \text{number of workers} \tag{5.1}$$

$$\text{Office space on default} = 18{,}581 \text{ m}^2 \times 4 \tag{5.2}$$

$$\text{Office space on default} = 74{,}322 \text{ m}^2 \tag{5.3}$$

The total office space was 111,482 m^2. According to Meyers (1993) the total office pace will need to expand in the future as more positions are required therefore 100 % allowance is considered.

Table 5.4: Total office space required for the workers in the factory using the organization technique

Employees	Number of employees	Standard office size per employee	Total office size
General manager	1	23,226 m^2	23,226 m^2
Marketing manager	1	13,935 m^2	13,935 m^2
Product engineers	2	9,290 m^2	18,58 m^2
Total	4		55,741 m^2
100% extra space allowance			55,741 m^2
Total office space needed			**111,482 m^2**

The office size dimension was calculated in this way:

$$\sqrt{\frac{74{,}322}{2}} = 6,10m^2 \; or \; \sqrt{\frac{111{,}482}{2}} = 7{,}74\, m^2 \tag{5.4}$$

Therefore the rounded office size dimensions are as follows:

For the dimensions: 6, 10 m^2 $\approx 7\, m^2$ and $7,74\, m^2$ $\approx 8\, m^2$. Which is the same as, width × length, 7m ×16m (two 8m × 8m) = 7m × 8m× 2= 112 m^2.

The space requirement was determined so that it was possible to estimate the size of the factory. The space determination used was based on the formula by Meyers (1993) , see Appendix C. The total plant space was calculated at 600 m^2. The size of the factory depends very much on the number of offices/rooms, workstations and machines. Space is an expensive commodity, thus the designer should allocate space effectively (Stephens & Meyers, 2013).

5.7.4 Workspace design

The workspace provides the equipment, tools and tables within the reach of an operator to increase productivity, to ensure comfort and to reduce fatigue. A workspace is depicted in Figure 5.5. Each bench has a specific function to prevent confusion among workers and to increase productivity.

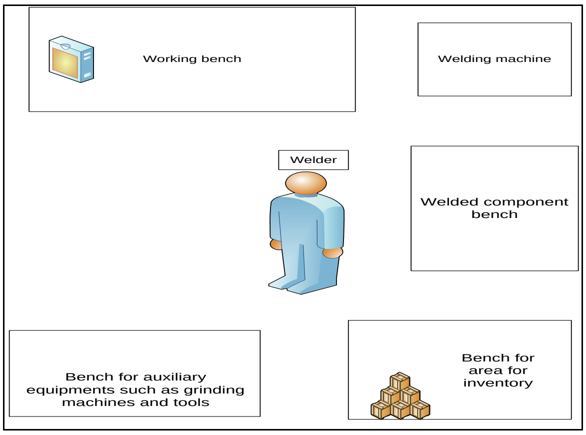


Figure 5.5: A sketch of workspace for a welder

5.8 Proposal of the plant layout and plant location

Layout refers to the physical arrangement of the production machines, equipment, workstations, people, location of materials at different stages and material handling equipment (Stephens & Meyers, 2013). Production line is a flow of products through a group of well-organised workstations and each workstation has a specific work function (Groover, 2007). Since the Stirling system consists of different components, the type of production line that was incorporated into the production process was the mixed model line.

The U-shaped production line is suitable for manufacturing the Stirling engine and the sub-components of the concentrator. It creates a good balance between manpower, machining and materials. The U-shaped production line also creates a good flow of materials: the raw materials enter from one point and leave at the end of the production line. This type of production line creates the shortest distance of material flow, see Figure 5.5.

The U-shaped production line allows operators to change places and perform other kinds of work, and in the process help each other. This can lead to improved line balancing. This type of production also requires fewer operators and workstations (Aase *et al.*, 2004). The factory is designed in such a way that the facilities (rooms, offices and production area) are close to one another to minimise material flow and people movement.

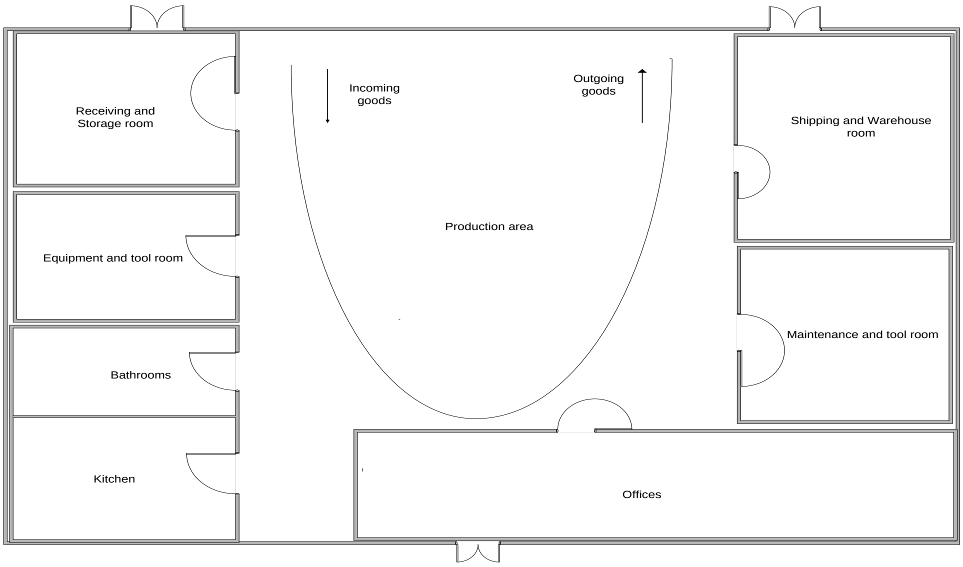


Figure 5.6: The plant layout

5.8.1 Total electricity usage in the factory

The amount of electricity from heavy electricity appliances was calculated as depicted in Table 5.5. It is relevant to have an estimate of the electricity demand and electricity costs of the factory. The quantities of the machines were based on Appendix C. The components and number of components were estimated on the factory size.

Table 5.5: The electricity consumption of the appliances in the factory

Component/Machine	**Quantity**	**Energy consumption**
Welding machine	6	11670 , 23 W × 6 = 93360 Watts
Hand grinding machine	1	2500 Watts
Computers	4	600 watts × 4 =2400 Watts
Lighting	12	200 watts × 12= 2400 Watts
Air con and heating	2	1000 watts for 10 % of time
Milling machine	4	2, 5 kW × 4 = 10 000 Watts
Lathe machine	5	4 kW × 5 = 20 000 Watts
Drilling machine	5	1 kW × 5 = 5 000 Watts
Total electricity requirement in the factory		107,42 kW

5.8.2 Quality assurance

The product will be sold with a homeowner's manual with basic instructions on how to install, operate and maintain the product, and safety precautions. The product will come with a three-year warranty and guarantee.

5.8.3 Waste produced during manufacturing

During this process a significant amount of scrap material was produced. About 80 % of the raw metal was turned into different parts of the Stirling engine. However, the different types of metal are recyclable for other purposes. Other machining process generated negligible amount of waste. The scrap metal was determined using the following formula:

$$Volume\ of\ raw\ metal = \frac{\pi}{4}\ d^2 L \tag{5.5}$$

Whereby d = density and L = length.

$$Mass\ of\ raw\ metal = volume\ of\ the\ metal(mm^3)\ \times density\ of\ the\ metal(kg) \tag{5.6}$$

The mass of the scrap metal was determined using software called Autodesk Inventor Programme. This software made it possible to view the volume of the newly designed product after the turning process.

$$Mass\ of\ new\ design = volume\ (mm^3)\ \times density\ (kg) \tag{5.7}$$

Therefore,

$$Mass\ of\ scrap\ metal = mass\ of\ raw\ metal - mass\ of\ new\ design \tag{5.8}$$

5.8.4 Management plan

The management team plays a huge role in any company and will oversee all the business transactions. The management team is the link between company and customers. They also identify the risks of the business and, most importantly, guide the business on the route to success. In the initial phase of the business, job positions will be limited, but, as the business starts to grow, new management positions will be made available. In the initial phase, the company will only employ the general manager (GM), marketing manager and two product engineers in the higher hierarchy. The organizational breakdown of the company is illustrated in Figure 5.7.

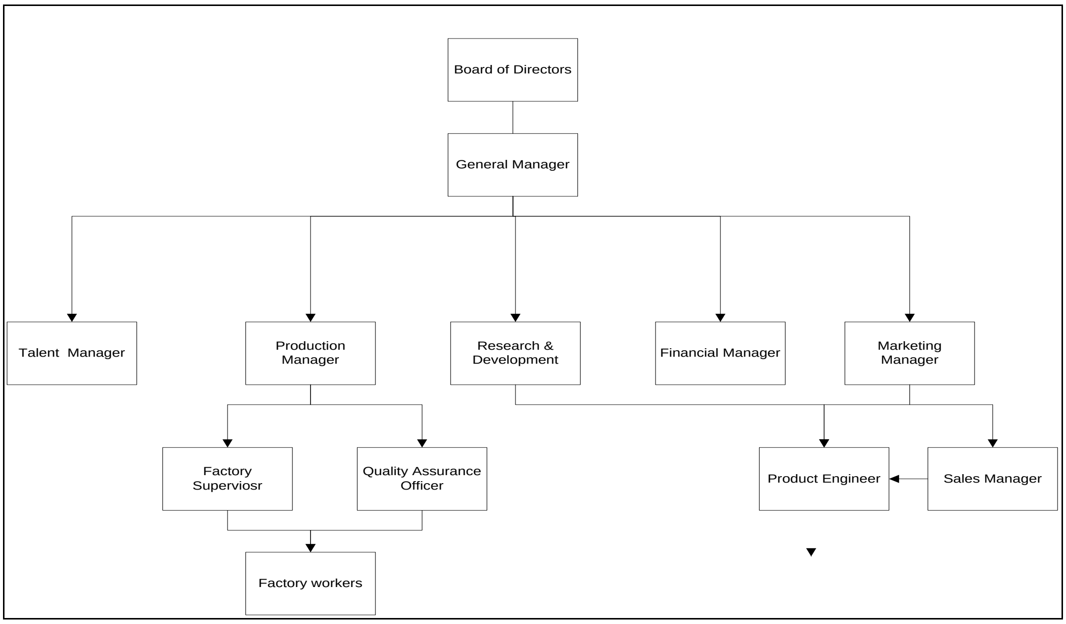


Figure 5.7 Organisational structure

5.8.4.1 General Manager

The GM will be the general overseer of the business. The responsibilities of the GM will be broad in the initial phase of the business until a point where the relevant employees are hired, and they include maintaining the image of the business, managing, training and employees, developing strategic plans for new opportunities that can create wealth for the business, improving the product and working conditions for employees.

5.8.4.2 Marketing manager

The marketing officer should have good communication skills and have outstanding marketing skills. The marketing officer will be responsible for identifying new markets and maintaining existing markets in the quest for market domination. The other responsibilities are to create an aggressive marketing strategy, increase market penetration, manage and control marketing matters, be responsible for distribution and logistics of products, and manage media relations.

5.8.4.3 Sales manager

Sales bring in profit for a company; therefore this is a crucial position in the company. A strong technical background in concentrated solar power and functionality of the Stirling system will be an advantageous ability for the sales manager in order to market and demonstrate the product better.

5.8.4.4 Product engineer

This engineer is responsible for designing and developing the parabolic system and the free-piston Stirling engine. The product engineer will be responsible for choosing the right raw materials and companies to which to outsource services, as well as for designing the manufacturing plan.

5.8.4.5 Research & development manager

The R&D manager will be responsible for research activities by using technical and scientific methods. He/she will be responsible for new ideas, innovation and product development. This department will be set up since Stirling system technology is still in its infancy in terms of development. There is a potential for new opportunities, thus the R&D manager must keep up with new technology. At some point an opportunity might avail itself for this product to be modified to suit certain regions, cultures and conditions – after all, Africa is a diverse continent.

5.8.4.6 Production manager

The production manager is responsible for producing the right quantity of the product and to oversee production, making sure that there is neither shortage nor overproduction. The production manager will be responsible for the senior factory staff, factory supervisors and quality assurance officer.

5.8.4.7 Quality assurance officer

The duty of the quality assurance manager is to make sure that all quality standards are followed in order to manufacture high-quality products. The replacement of faulty and low quality products will result in losses for the company. The quality assurance manager will set up quality-control mechanisms to minimise faulty products and to create a chain from consumer back to the factory, which allows faulty products to be brought back to factory to be repaired.

5.8.4.8 Talent manager

The talent manager is commonly known as the human resources manager. The talent manager will be responsible for recruiting and contracting suitable new staff, for employee development and training by providing continuous support programmes, for workforce planning, compensation and benefits, and for performance management.

5.8.4.9 Financial manager

The financial manager is a key player in the business, one requiring an excellent financial understanding. The financial manager will be responsible for budgeting, allocating funds, preparing financial projections, and collaborating with other employees in setting up plans on how to allocate and manage assets. Again, if the financial manager makes poor choices, these decisions may result in considerable losses for the company.

5.8.4.10 Board of Directors

The board of directors is a governing body appointed by the shareholders. The board of directors have the highest decision-making power in the company. The board of directors will bring with them valuable knowledge and experience, and consequently add new skills and industrial expertise to the business. They are responsible for managing the growth of the company, and approving the annual budget.

5.9 Key activities

The Key Activities Building Block describes the most important things a company must do to make its business model work. They are required to create and offer a value proposition, reach markets, maintain customer relationships, and earn revenues (Osterwalder & Pigneur, 2010).

- Marketing campaigns to make potential customers aware of the product. Initially, 10 prototype Stirling systems will be manufactured for demonstration purposes only, and some of the Stirling systems will be placed in communities without access to electricity across South Africa.
- Customer support services especially after sale support services are vital.
- Attending to product orders through online, telephone and personal visits.
- Production process.

The manufacturing plan in detail:

The solar Stirling system is this study was divided into two parts:

a. The free-piston Stirling engine (Appendix D)

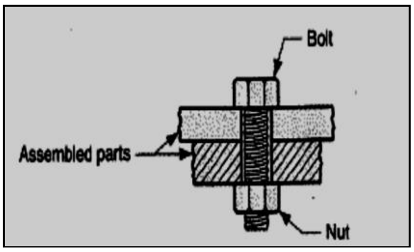
b. The concentrator (Appendix E)

5.10 Manufacturing processes

Manufacturing is defined as the transformation of raw materials into useful products through the use of the easiest and least expensive methods (El Wakil, 1998). Efficient manufacturing processes highly influence the competitiveness of the final product. Therefore manufacturing should be efficient, simple and fast (El Wakil, 1998).

5.11 Mechanical assembly

Mechanical assembly refers to the fastening methods that are used to affix together several components of the Stirling system. The advantage of mechanical assembly is that it depends on manual labour, meaning it is carried out by unskilled labour. The type used in the manufacturing of the Stirling system was threaded fasteners, i.e. bolts and nuts; the reason being that such fasteners allow the parts to be disassembled as often as needed without damaging the parts. This application is more popular than the other methods. This type of fastening procedure also makes it possible for the Stirling system to be assembled and disassembled in the field. The bolts are externally located, while the nuts are internally located (Groover, 2007). Different bolts and nut sizes were used, depending on the size of the assembled parts. Wrenches of various sizes were used in bolting the different parts together.



(Groover, 2007)

Figure 5.8: An illustration of two parts fastened using a bolt and a nut

5.12 The on-site assembly of a concentrator

The fastening of the bolts and nuts were intended to be performed on site and thus were to be performed manually. This allowed easy transportation of the loose components. The parts were fastened in the following sequence: Part from A–Part from B–Part from C–Part from D, see Table 5.6. The first part in list A is a single part, namely the Footplate, while the rest of list A are the sub-assemblies from the previous line.

Table 5.6: The fastening and joining of the different components that make up the concentrator

Part A	Part B	Part C	Part D	Fastening/joining
Footplate	Bottom half pipe	_	_	Bevel welding
Bottom half pipe	Flange	_	_	Bevel welding
Flange 1	1st slew drive	Transition box	_	Bolted
Transition box	2nd slew drive	Flange 2	Dish pipe	Bolted
Dish spoke main	Dish centrepiece	_	_	Bolted
Dish pipe	Stirling support flange	Stirling support flange 2	Stirling support arm	Bolted
Driver spoke main	Mirror mounting	_	_	Bolted
Dish pipe	Dish centrepiece			Fasten
Stirling support flange 2	Stirling support arm			Bevel welding
Stirling support arm	Stirling support arm 2			Bevel welding
Dish pipe	Dish spoke main			Bevel welding
Dish pipe	Driver spoke tertiary			Bevel welding
Dish pipe	Driver spoke secondary			Bevel welding
Dish pipe	Mirror mounting inner			
Dish pipe	Mirror mounting middle			
Dish pipe	Mirror mounting outer			

The sequence for fastening the bolts and nuts was done manually, using a wrench. The whole process takes about 5,25 hours in total to complete. Gradually, as this process is repeated, the time taken to complete the task will decrease. This speeding up phenomenon is due to the learning curve. In a manufacturing set-up, the learning curve is described as a period when a worker, who is requested to perform a repetitive task, begins by taking more time to complete the task, but with time the worker learns to perform the task in a short time.

Figure 5.9 depicts the proposed concentrator that was built by the mechanical engineering students of the University. The Stirling support system rests on a metal foundation; however in the future a concrete foundation will be used instead.

(Prinsloo, 2014)
Figure 5.9: The manufactured mirror mounting (right) and Stirling support system mounted on a rooftop at Stellenbosch University (left)

5.13 Manufacturing and assembly for the Stirling engine structure

Manufacturing a Stirling engine is a complex process. It involves machining and assembly of various components using different processes. The total time it will take for the Stirling engine to be completed is 77,25 hours (including the time taken by external companies and the workshop), of which 65,75 hours will be required by the workshop (Appendix F). The types of machining applied were: bending, broaching, drilling, grinding, laser cutting, milling, tapping, turning and welding.

(Deetlefs, 2014)
Figure 5.10: The left picture shows the alternator coils and the right picture shows the piston assembly

5.14 Key partners

The key partnerships building block describes the network of suppliers and partners that make the business model work.

- **Optimization and economy of scale:** The company would form buyer-supplier partnerships. The benefit of such partnership is to optimize the allocation of resources on time.
- **Reduction of risk and uncertainty:** When some services are outsourced the company reduces the occurrence of certain risks. Therefore with the manufacturing processes that the company is not performing the suppliers will be responsible for the risks.

5.14.1 Manufacturing process for the parabolic system structure

A 3 kW Stirling engine and system is a complex product made up of so many components that it will not be feasible for the company to manufacture all of them. When the company has no capability to manufacture a certain component or to perform a service, it is left with the option to outsource. This is also true when the standard cost of manufacturing is more than the cost of outsourcing. Furthermore, Tayles and Drury (2001) categorised the components into three groups:

Component A: This component can only be manufactured in-house. The technology used to design and manufacture the components is a trade secret and cannot be revealed to outsiders.

Component B: This is a component for which the design and technology that support it are not a secret and that is better off outsourced.

Component C: This is a component that is outsourced on a regular basis. The outsourcing of materials, components or services should lead to a profit for a company. Sourcing decisions depend on various factors: cost and profitability, strategic plans of the company, financial evaluation, efficiency, risk dimension with supplier, lead times and reliability (Tayles & Drury, 2001). The various components of the Stirling system that were outsourced fall under this section.

5.14.1.1 The Vendors

A vendor or supplier can influence the operating capacity of a factory; consequently in some situations it places the company in a vulnerable situation. The different parts of the concentrator and

Stirling engine that were unable to be manufactured at the University's workshop due to their manufacturing processes, were outsourced to carefully selected companies. Globalisation has made the business world a better place for trading goods in a faster and safer way. It is common practice especially in the manufacturing sector for a company to purchase components or obtain some of its components from overseas (Maurer & Degain, 2012). The local and off-shore outsourcing companies appear in Appendix K. Some of the qualities to consider when selecting outsourcing companies are: a good reputation for manufacturing the products; reliability and expertise; the machinery to produce high-standard products; experience in providing the services; cheap service; the ability to provide products in large quantities; and being a local company situated in a convenient location.

5.14.1.2 The alternative vendors

Alternative vendors, see Appendix G and H were identified to help mitigate the risk of the main suppliers in case they were unable to deliver or when customer demand exceeded the vendor's production capacity. One of the reasons that some suppliers failed to be selected as main suppliers is that their prices were higher and they were located too far away, compared to the main suppliers.

5.15 Cost structure

The cost structure describes all costs incurred to operate a business model. Creating and delivering value, maintaining customer relationships, and generating revenue all incur costs. Such costs can be calculated relatively easily after defining key resources, key activities, and key partnerships (Osterwalder & Pigneur, 2010).

The primary cost of the company will be incurred from fixed assets and variable costs, see Chapters 9 and 14. The other expected are costs incurred from economies of scale, the cost advantages that a business enjoys as its outputs expand. The business would require about R 28 300 000 for expenses in the first year.

5.16 Business model canvas

Subsequently to the identification of the building blocks the business was designed, refer to Figure 5.11.

Key Partners
- ✓ Raw material suppliers
- ✓ Manufacturing process suppliers

Key Activities
- ✓ Marketing
- ✓ Customer support services
  - Reply back to customers
- ✓ Attending to product orders
- ✓ Production processes
  - Mechanical assembly
  - Welding
  - Turning
  - Milling
  - Drilling
  - Tapping

Key Resources
- ✓ Manufacturing plant
- ✓ Workers
- ✓ Raw materials
- ✓ Equipment/machines

Value Propositions
- ✓ Excellent performance
- ✓ Efficient
- ✓ Affordable price
- ✓ Risk reduced product
- ✓ Quality product
- ✓ Accessible product
- ✓ Convenient
  - Self-contained
  - Self-installation
  - Easy to operate
  - Easy to maintain
- ✓ Provides electricity and heat
- ✓ Sustainability
  - Green product
  - Environmental-friendly

Customer relationships
- ✓ Personal assistance, feed-back and support
  - Email
  - Phones calls
  - Personal visits to company
  - Website
- ✓ Online customer communities

Channels
- ✓ Marketing
  - Education through media
- ✓ Orders from email, telephone, website and personal visits
- ✓ Providing feed-back to customers

Customer Segments

Customers divided into two segments:
- ✓ Segment A people
  - Low income
  - Have no access
  - Rural or remote areas
- ✓ Segment B people
  - High income
  - Government or NGOs
  - Renewable energy enthusiast

Cost Structure
- ✓ Fixed costs
  - Worker's salaries
  - Rent
- ✓ Variable costs
  - Productions costs
  - Economies of scale
  - Overhead costs
  - Research &development
  - Marketing

Revenue Streams
- ✓ Product sales

Figure 5.11 The business model canvas for African Power Supply

5.17 Chapter summary

The purpose of this chapter was to develop a business model using the building blocks of the Business Model Canvas. Later the risks associated with the business model will be addressed.

CHAPTER 6

MARKET RESEARCH DESIGN AND METHODOLOGY

6.1 Introduction

This chapter describes the research design and methodology that was followed in conducting the market research. Market research is the application of scientific methods used to investigate the customers' needs and desires. The end result of market research is a clarification of customer's attitudes and buying habits. Market surveys are used to estimate the selling price of a product. Further, the results of the market surveys can be used to contribute to the design of a new product (Sule, 2009).

6.2 Research design

There are three types of surveys namely face-to-face interview, telephone interview and written questionnaire (by mail, email and web survey). Due to the lack of telephones and internet facilities in this particular village the face-to-face survey was more preferred. A mini-survey is appropriate when dealing with a small sample group. The questionnaire of a mini-survey comprises a few questions which can be completed quickly. Mini-surveys are practical for feasibility studies. Especially in cases where the researcher is aiming to collect information such as general patterns, trends, tendencies and non-specific information from a particular study group (Kumar, 1990). Therefore, a mini-survey was the favoured approach in this research. The survey was conducted in a rural area with no access to electricity. The objectives of the mini-survey were the following:

1. Formulating an overview of the energy situation in communities without access to electricity.
2. Determining market interest in the solar Stirling system among people without access to electricity.

3. Identifying the needs of the customers which may be incorporated in the design of the Stirling engine and concentrator.

4. Determining a realistic price for the solar Stirling system.

6.3 The research methodology

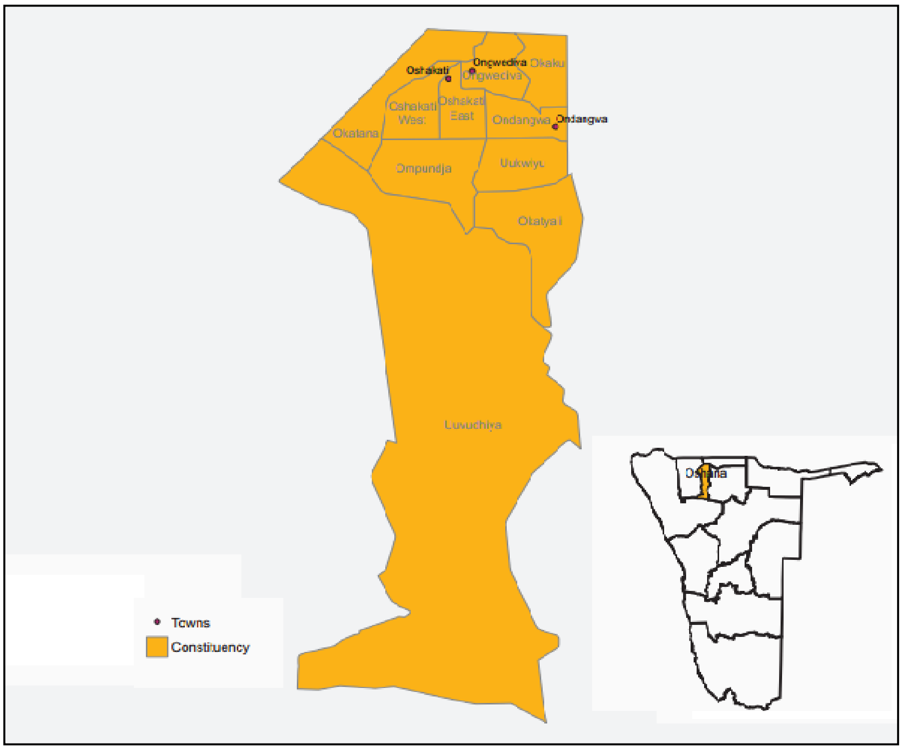
A confidential mini-survey was conducted using questionnaires, see Appendix I. The questionnaires were completed by means of personal interviews during which the researcher asked the respondents to answer questions and recorded the results anonymously. The researcher was responsible for filling in the questionnaires. The researcher translated the questions of the questionnaire from English into the vernacular language called Oshiwambo, the language that is spoken in the community. The reason for this was that not every community member was proficient in reading and writing in English. Consequently, this gave the researcher more control over the questionnaires and an opportunity to explain the questions and to minimise any respondent and bias errors. Owing to the small sample size and small number of questions the mini-surveys tends to have fewer interview and coding errors (Kumar, 1990).

The questionnaire was divided into two sections. Section 1 of the questionnaire was made up of fixed-alternative questions that enquire about information regarding socioeconomic impacts and the energy situation of the community. Section 2 of the questionnaire was a five-point Likert scale. The Likert scale measures the attitude of the respondents to a given statement. The statement is usually made up of five responses that range from a very positive attitude to a very negative attitude. The levels of agreement used were: strongly disagree, disagree, undecided/neutral, agree and strongly agree.

6.4 The study population and village set-up

The target population of this study resides in Efidilomulunga village which is situated near a residential town called Ongwediva. Ongwediva is situated in the Oshana region in the northern part of Namibia, see Figure 6.1. In 2011, Ongwediva had a population of 33700 people (National Planning Commission, 2012). The researcher estimates that the population of the village compromises approximately 5% of that of Ongwediva.

This particular community was chosen intentionally by the researcher to prevent any language barriers from interfering with the interview process. Furthermore, the researcher is familiar with that area. The area is a typical semi-village and the majority of the community members are agro-pastoralists, who depend on their fields for food and small livestock such as free-range poultry and intensively reared pigs. The villagers are prohibited from keeping large livestock since these animals tend to wander around, creating potential road hazards. Despite this prohibition, some community members continue to keep such livestock.



(Namibia Statistics Agency, 2011)
Figure 6.1: Map of the Oshana region

6.5 Sampling strategy

The survey started on 16 May 2013 and was completed on 24 May 2013. The households in a village set-up follow no particular arrangement order. They neither lie along streets nor have residential numbers. Therefore, for the survey, households were randomly selected. However, the researcher avoided interviewing neighbouring households because they tend to have similar situations. The researcher walked from one house to another. According to (Kumar, 1990) this type of sampling strategy approach used is called convenience sampling.

6.6 Sample size

The sample size of a mini-survey depends largely on the available time and funds. The sample size of a mini-survey ranges from 25 to 70 interviews. Even though the sample size of the mini survey is small it is possible to produce credible data. In total 30 households were interviewed for this study.

6.7 Ethical considerations

Since the survey involved human interactions ethical guidelines were followed. This research project is compliant with the University's research ethics policy. The study was approved by the Stellenbosch University Research Ethics Committee prior to data collection, see Appendix J.

The researcher explained the rights of the respondents before the interview. The respondents were also informed that the survey was confidential and that they had the right to withdraw from participating in the survey at any time. All these details appeared on the front page of the questionnaire, see Appendix E. The research protected the anonymity of the respondents; no names of the participants were required. The researcher was granted a secondary consent by the headman of the village: this is referred to as community consent. The community consent gave the researcher permission to interview the community members, see Appendix K.

6.8 Data quality

Zikmund and Babin (2007) define data quality as the degree to which data represent the true situation. They further explain that for data to be of a high quality it should be accurate, valid and reliable. The aim of the research design of this study was to make sure that the data collected from the survey was of high quality and to minimise the occurrence of various errors. The three criteria used to determine the measurement of data were reliability, validity and sensitivity (Zikmund & Babin, 2007) . These criteria are described below:

6.8.1 Data reliability

Reliability is described as an indicator of a measure's internal consistency. A measure is reliable when different attempts at measuring something converge on the same result. When a measuring process provides reproducible results, the measuring instrument is reliable (Zikmund & Babin, 2007).

6.8.2 Data validity

Unlike reliability that tests for precision validity tests for accuracy. Validity is the accuracy of a measure or the extent to which a score truthfully represents a concept. Validity addresses the problem of whether a measure indeed measures what it is supposed to measure (Zikmund & Babin, 2007) .

6.8.3 Data sensitivity

Sensitivity is considered when one is investigating changes in attitude. Sensitivity describes the ability to accurately measure variability in a concept. Adding 'strongly agree' and 'strongly disagree' to a question will increase the scale sensitivity (Zikmund & Babin, 2007) . This was applied in the design of the questionnaire (Likert scale section).

6.9 Data analysis

The first step of the data analysis was data editing. The editing process involved the researcher checking all the questionnaires for completeness. The data from section 1 of the questionnaire were divided into interval data and nominal data. In this section inductive and deductive methods were used for coding the data. For open-ended questions the inductive method was applied which involved "[recording data] in as much detail as possible" (Kumar, 1990). For questions with fixed answering options in section 1 and the Likert scale in section 2, a deductive method was applied which involved the "use of a predetermined classification scheme in coding data" (Kumar, 1990). The codes were entered into Microsoft Excel and they were analysed using statistical software called STATISTICA.

6.10 Chapter summary

This type of research design was applied so that the objectives of the survey could be met. The processed data from the survey are useful to the designers of the Stirling engine and the concentrator. The other information from the early stage of the study that is useful is the perception of the community members about the Stirling system technology.

CHAPTER 7

MARKET RESEARCH FINDINGS

7.1 Introduction

The research findings that are presented in this chapter depict the energy overview of the community, the socio-economic situation in the community, the perception of respondents about the Stirling system technology, and the expectations of the community members regarding the technology.

The energy overview of the community gives an insight into the energy situation in each household. It includes the energy consumption, energy demand, the availability of energy sources and the amount spent on the energy sources.

7.1.1 The energy source availability

Various energy sources are used in the households for lighting and generating heat. The various energy sources used in the community were: wood, candles, paraffin, cow dung, crop residue, liquefied petroleum gas (LPG), disposable batteries (also known as dry cell batteries), diesel generator and solar panels, see Figure 7.1. The sources diesel generators, biogas systems and solar panels were less commonly used or not used at all and therefore they were omitted in Figure 7.1. Wood was found to be the most commonly used source of energy in 93,3% households. The other two commonly used energy sources found were disposable batteries and cow dung in 80 % and 77 % of the household respectively.

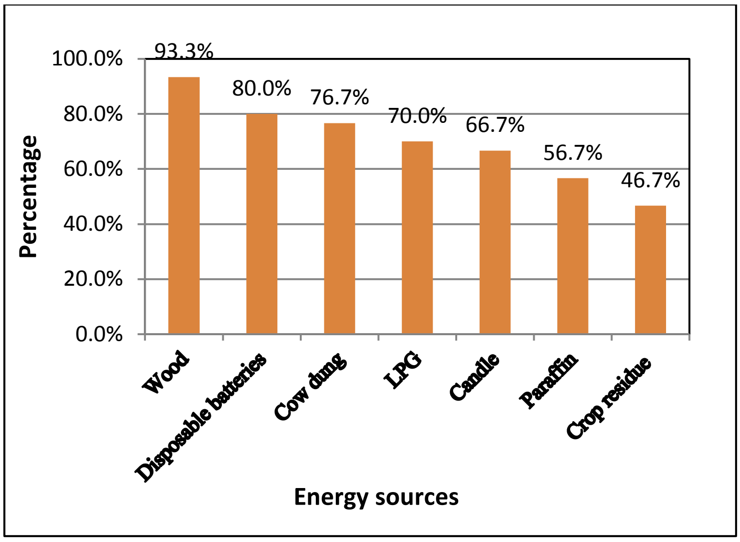


Figure 7.1: The frequency of the energy sources in the households

Candles, paraffin and solar panels are used in the community as a source for lighting, while the rest of the energy sources are used for generating heat. Sometimes some households used more than five different types of energy sources in a month to meet their energy demand. Table 7.1 is an example of a Kruskal-Wallis ANOVA test that was carried out to investigate whether there was a relationship between an energy source and housing structure. The result revealed that the p-value was more than 0,05. A Kruskal-Wallis test is a non-parametric test that is used to test whether two or more samples originate from the same population. It was found that the type of energy source was independent of the type of housing structure it was consumed in. The energy sources were more or less the same in each household.

Table 7.1: The relationship between the wood energy and a type of house

Kruskal-Wallis ANOVA by Ranks; Q.8 Energy source: wood Independent (grouping) variable: Q.3 Housing structure Kruskal-Wallis test: H (3, N= 30) =4.702952 p =.1949			
House type	**Valid - N**	**Sum of - Ranks**	**Mean - Rank**
Others	15	227,0000	15,13333
Traditional	11	143,0000	13,0000
Brick	3	74,5000	24,83333
Corrugated iron	1	20,5000	20,50000

Karekezi and Kithyoma (2002) stated that as the income of a rural household increases, the household tends to switch from utilising traditional fuel sources to modern energy sources such as LPG and solar panels. Further, the authors categorised rural households into three income groups, depending on the common types of energy sources used in the households, see Table 7.2. Rural households that consume predominately modern energy sources and less traditional fuel are considered high-income households (Karekezi & Kithyoma, 2002). The type of community that was surveyed for this study could be classified as a medium income rural community based on the information provided in Table 7.2. This is due a high number of the households utilizing traditional fuels and fewer households utilizing modern energy sources.

Table 7.2: Categorisation of rural household by income depending on the energy consumption

End use household	Rural household income		
	Low	**Medium**	**High**
Cooking	Wood, residues, dung	Wood, residues, dung, kerosene, biogas	Wood, kerosene, biogas, LPG, coal
Light	Candles, kerosene (sometimes none)	Candles, kerosene, gasoline	Kerosene, electricity, gasoline
Space heating	Wood, residues, dung (often none)	Wood, residues, dung	Wood. residues, dung, coal
Other appliance	None	Electricity, storage cells	Electricity, storage cells

***(The World Bank, 1996*)**

7.1.2 Monthly expenditure on energy sources in a household

In the past, traditional energy sources were free and plentiful. Currently, some of the traditional energy sources are no longer free owing to their scarcity and inaccessibility. The number of trees and bushes in the villages and surrounding areas can no longer sustain households. The Mann-Whitney U test revealed that there was no relationship between the amounts spent on energy sources and the sex of the respondent. This is true in a rural situation: the households, regardless of whether they were headed by male or female occupants, consumed more or less the same energy sources and for the same purposes.

Table 7.3 shows only the number of households that indicated that they purchase energy sources and the amount they spent on the energy sources.

Table 7.3: The amount (N$) spent on energy sources in a month

Energy sources	**Number**	**Mean (N$)**	**Minimum (N$)**	**Maximum (N$)**
Wood	28	28,93	0,00	300,00
Candles	20	113,15	12,00	465,00
Paraffin	17	20,00	0,00	68,00
Cow dung	23	0,00	0,00	0,00
Crop residue	14	0,00	0,00	0,00
LPG	21	290,85	69,00	1 200,00
Disposable batteries	24	81,19	8,00	475,00

Out of 30 households that were interviewed only two indicated that they do not buy wood, even though they do use it. On average households spend about N$113,15 on candles. The highest amount of energy spent in a month on an energy source was N$465 on candles. The highest amount spent on wood by a household in a month was N$300. However on average the households spend N$30 on wood per month. Cow dung and crop residues are the only energy sources that are not purchased. On average the household spent about N$82 in a month on disposable batteries. The candles and disposable batteries frequently need to be replaced since they do not last long. This is one reason why the households spent a high amount on them.

The diesel, solar panel and solar panel energy sources were excluded from Table 7.3, the reason is that the LPG and solar panels are not purchased on a monthly basis. The LPG is only replaced once it has been completely consumed. According to the respondents they spend N$69 on a 19 kg cylinder of LPG and N$1 200, 00 on a 49 kg cylinder. Solar panels are purchased on a once-off basis. A 3 kW solar panel excluding battery storage unit costs around costs around R3 750. The respondents have no idea how much diesel costs, but a litre of diesel is about R12, 90 per litre in South Africa. The amount spent on energy from the different sources is quite high since the average income per household is N$3 800, 00 per month, see Table 7.4.

Table 7.4: The results of the household income

	Number	Mean	Median	Minimum	Maximum
Income	30	R3 800,07	R 2 000,00	R 2 000,00	R 11 001,00

A bundle of wood such as the one in Figure 7.2 costs about N$ 50. The price of wood increases the further away a household is from natural wood sources such as forests and the bush.

Figure 7.2 : The left picture is bundle of wood found in one of the interviewed household and the other picture shows crop residues

7.1.3 The energy consumption in the household

The energy sources were classified into two groups, namely: traditional and conventional energy sources. The four commonly used energy sources are wood, candles, LPG and disposable batteries.

Table 7.5: The quantity of conventional energy consumed per month

Energy Sources with measurement units	**Number**	**Mean**	**Median**	**Minimum**	**Maximum**
Energy wood (kg)	30	41,33	40,00	10,00	100,00
Energy candle (count)	20	32,95	24,00	2,00	155,00
Energy paraffin (litre)	11	4,46	2,00	1,00	31,00
Energy cow dung (kg)	15	3,57	1,00	0,50	30,00
Energy crop residue (kg)	15	3,07	2,00	1, 0	12,00
Energy diesel (litre)	1	19,00	19,00	19,00	19,00
Energy LPG (kg)	19	15,00	9,00	4, 0	49,00
Energy disposable batteries (count)	24	9, 50	8,00	1,00	24,00
Energy biogas system (kg)	0				
Energy solar panels (watts)	4	127,50	150,00	10,00	200,00

7.1.4 Traditional energy sources

The households use as much traditional energy as possible, but such resources are no longer enough to meet their demand. All the interviewed households use wood as a source of energy. Wood is used for cooking. On average a households uses about 41,33 kg of wood in a month. In some instances some households have used up to 100 kg per month of wood. The other traditional energy sources (cow dung and crop residue) are only consumed in 50 % of the households. The availability of cow dung and crop residue is low since it depends on the individual's resources (livestock and crop field). None of the houses interviewed used biogas. Therefore, wood is a basic traditional energy source in the community.

7.1.5 Conventional energy sources

Consequently, many households combine traditional energy sources with conventional energy sources, see Table 7.5. In contrast to traditional energy sources all the conventional energy sources are purchased. Candles and disposable batteries were found to be the most commonly used conventional energy sources in the communities. They are used for one purpose which is to produce light. Four households had solar panels with a size range of 20 to 200 watts as depicted in Table 7.5. The solar panels are used for lighting and for charging cell phones. Paraffin has a dual purpose: it can be used for lighting and cooking. The rest of the conventional energy sources are used for cooking. The amount of LPG consumed per month could not be clearly determined since the LPG cylinders are only replaced once the gas runs out. The sizes of the LPG cylinder were 9 kg, 19kg and 49 kg. LPG is seen as a luxury source, which is why it lasts longer and is usually used once in a while, especially when it is raining or during emergencies.

7.2 The socioeconomic set-up of the community

The survey results provided information regarding the demographic and psychographic characteristics of the study group.

7.2.1 Demographic profile

Based on Figure 7.3, 73 % of the respondents were female. One reason for this phenomenon is that several houses are headed by women households. The other reason is that it was usually women who were found at home during the survey.

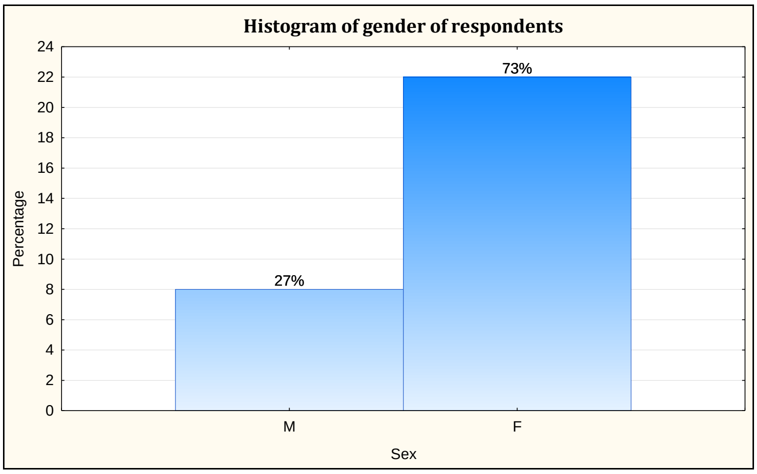


Figure 7.3 The sex of the respondents representating the population

About 59% of the respondents interviewed were in the age range of 40 to 70 years, as shown in Figure 7.4. Pensioners are classified as people aged 60 years and above. Pensioners made up 39% of the respondents.

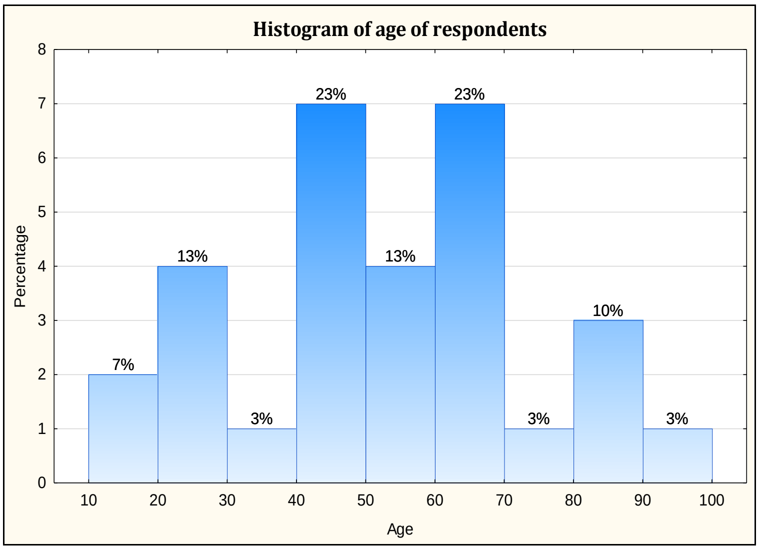


Figure 7.4: The age of the respondents

The market size in this study is defined as the number of people who can afford to purchase the product and this was determined by using the statistics from the survey. The type of statistical information used was the income of the households and the loan the community members were willing to take out to purchase the Stirling system. It was found that only 14% of the households surveyed had a total monthly income of N$10 000 or more, the 20% had a total monthly income of N$4 000-N$5 000, see Figure 7.5 . The remaining 67% of the households had an income of N$2 000 or less. There are a number of reasons why such a high percentage of households have a low income. Various households are headed by pensioners because many middle aged groups have migrated to urban areas in search of better opportunities.

As seen previously, 39% of the households are headed by a pensioner which explains why there are a high number of households with low monthly income. The Namibian government provides a monthly pension allowance of N$500 to each Namibian pensioner. Study data showed that the government pension allowance was sometimes the only income certain households were receiving. Only 14% of households receive a single or combined income of N$10 000 or more, see Figure 7.5.

It was also established that this community's energy consumption led it to be classified as a middle income community as discussed earlier in this chapter. In high income communities where people rely on conventional energy sources, you are more likely to find a higher number who can afford to purchase the Stirling system.

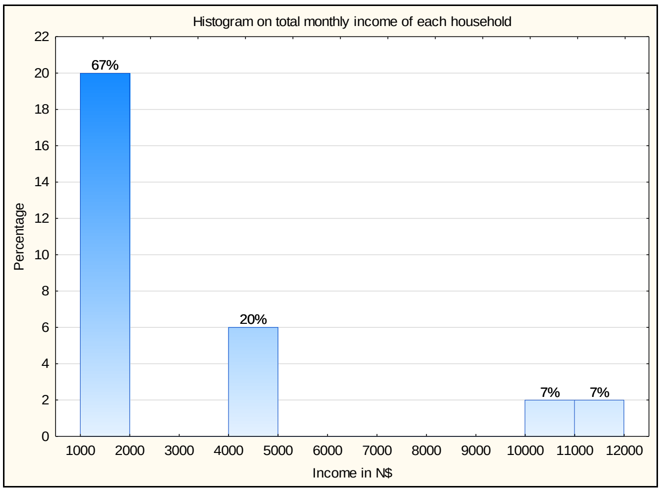


Figure 7.5 Total monthly income of the households

The respondents were required to state the how much they would borrow if they were to purchase the product. From the number of households interviewed, 10% were willing to take out a loan of N$10 000, 51% would take out a loan of between N$3 000 and N$8 000, while the rest would only be able to afford a loan worth N$2 000 or less, see Figure 7.6.

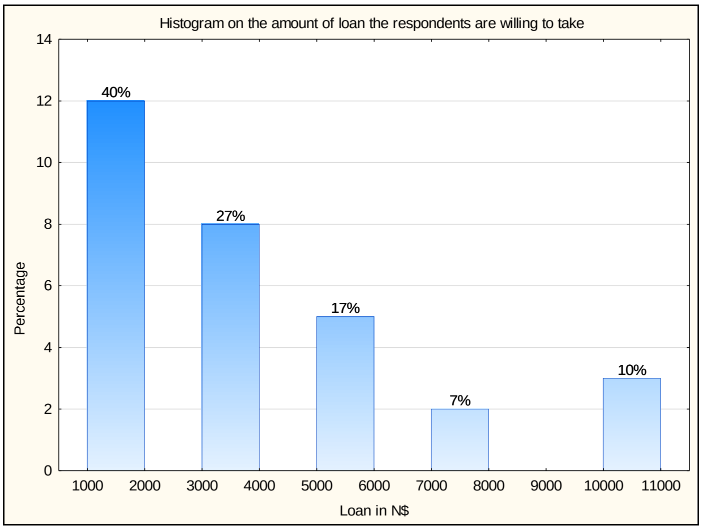


Figure 7.6 The size of loan that respondents are willing to take out

7.2.2 Psychographic profile

People in rural areas are heavily dependent on their fields and livestock for food and income for survival purposes. A high number of people in the communities do not have tertiary education, are low-income earners and are unemployed. Traditional houses in the rural areas consist of free-standing, traditional huts. Presently, however, a number of households consist of a combination of modern and traditional structures.

Traditional housing structures that are combined with traditional and modern structures such as brick fencing, brick-layered huts with thatched roofs and structures made with corrugated iron were classified as ‘other’ in the questionnaire. Of the households interviewed, 50% were referred to as ‘other’, see Figure 7.7. Housing structures can determine whether it is possible to support technology in terms of electrical wiring and where to install the Stirling system. For safety reasons, it is better to mount the Stirling system on top of a roof; however, because of its considerable weight this might not be possible in numerous cases in rural areas. Therefore, it will be better to install the Stirling system on the ground.

The rooms of a traditional house tend to be relative far from each other, which may lead to expensive outlay costs used for electrical wiring and installations for each hut or room. According to the data at least 60% of the households were classified as ‘other’ and ‘brick’, which have rooms that can support the Stirling system. It will be feasible if the Stirling system can provide electricity for at least two or three rooms in a household. A Krusskal-Wallis test was used to find out whether there was a relationship between the age of the respondents and the type of house structure they live in. Since the p-value on Figure 7.8 was more than 5% there was no relationship between the age of the respondent and the type of house he/she lived in.

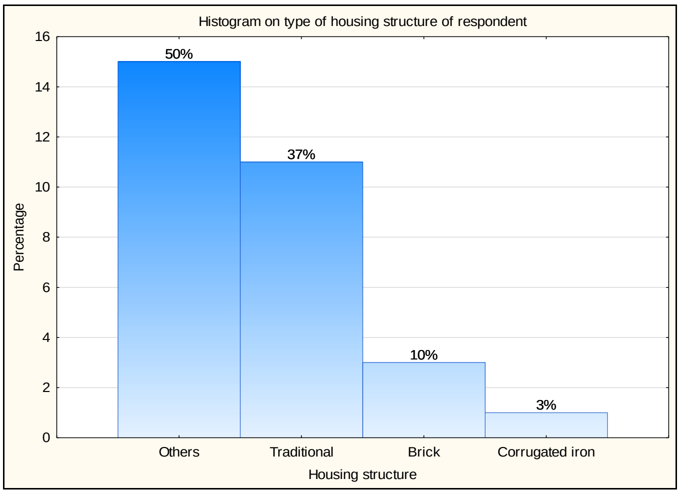


Figure 7.7: The housing structures of the households

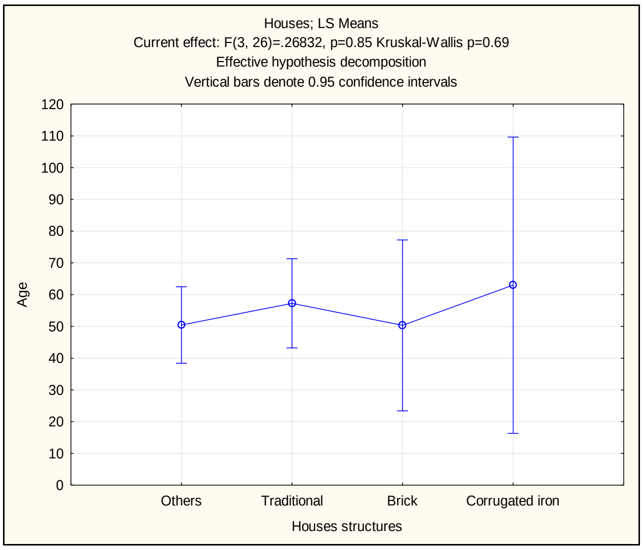


Figure 7.8: The confidence interval for house structure versus age

The different types of homesteads similar to the ones surveyed in northern Namibia may be seen in Figure 7.9.

(Dina and Mona in Namibia, 10 August 2013)
Figure 7.9: On the left is a complete traditional homestead (Serasphere,) and on the right is a traditional homestead with modern structures (corrugated iron), both in the northern part of Namibia

The rural households tend to have a high number of occupants; a typical household has seven or more people. About 76% of the households had six or more occupants, see Figure 7.10. This number of people would clearly demand a high amount of electricity. The number of people can increase during the festive season, when people migrate back to rural areas for holidays (Biermann, Grupp & Palmer, 1999). The energy supply of the Stirling system should be able to meet the energy demands of each and every household.

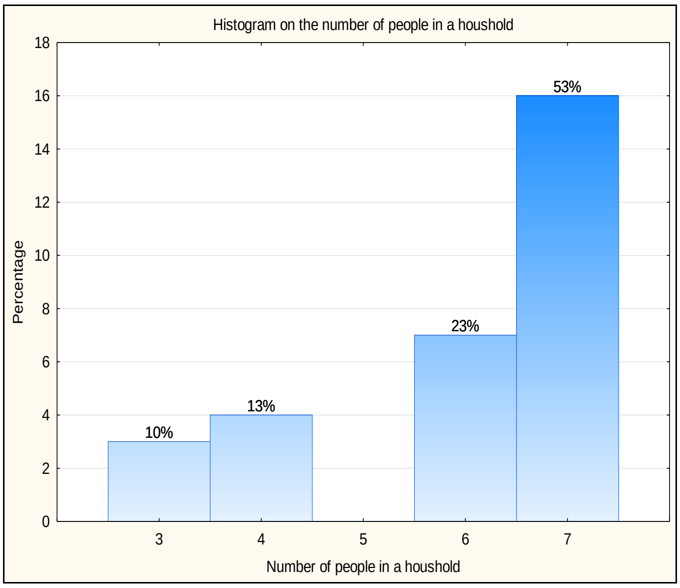


Figure 7.10: The number of people in a household

But, if the solar Stirling is to be priced expensively then only a small number of people will be able to afford it.

7.3 The community's perception of the Stirling System

Before launching a new product, it is important to find out what the customers' perception is of such a product. The product can seem to have value, but if the customers do not agree, then it will not sell. Sometimes the product is just not needed in the market or too expensive. The perceptions of the customers can be used to improve the product design.

Therefore it is important that the amount of agreement and disagreement in a sample for any proposition are measured. Likert scales are analysed either by using descriptive statistics or by non-parametric tests. The choice depends on how one wants to evaluate the Likert scale questions. Even though the Likert scale responses are regarded as interval data, individual responses to the Likert scale question are treated as ordinal data (Bertram, 2007).

The results of this study showed that the community members are highly interested in the technology. This can be seen in Figure 7.11 and in Appendix L under the heading 'Interest'. The results revealed that 70 % of the respondents indicated that they strongly agree, 27 %

agreed and 3 % strongly disagree. Both the median and the upper quartile were 5, while the lower quartile was found to be 4 (on a scale of 1 to 5). The upper quartile (75^{th}) is the number that divides the upper half of the data into two equal halves. The lower quartile (25^{th}) is the number that divides the lower half of the data into two equal groups.

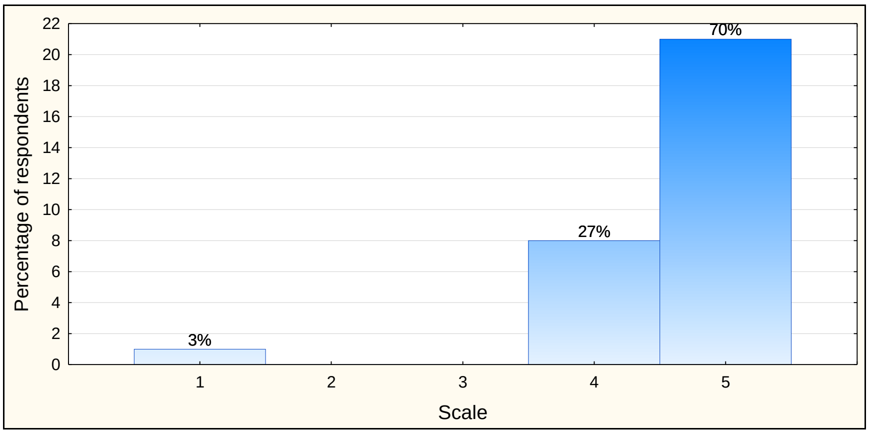


Figure 7.11 The number of people interested in using Stirling system technology

The community members indicated that even though the costs involved are high, they are interested in having access to electricity. The majority of the respondents would prefer that the Stirling system operates the whole day. The evidence suggested that people in this community would use electricity to run household appliances. The respondents however strongly indicated that there is a high incidence of theft and vandalism of property. As familiarity with the technology increases, there is a possibility that installed Stirling system are at risk of being vandalised or stolen. However, since the Stirling systems are not portable, a larger effort would have to be made than for typical solar panel installations, if someone were to try to steal them.

The respondents also indicated that they would prefer to purchase the Stirling system themselves. However, it would be even more preferable to them if government could subsidise the payment or if there could be some form of incentive for the users of the Stirling system. The respondents also indicated that they would prefer the product to be locally manufactured and to have customer services available.

7.4 The requirements of the community members that were incorporated in the design

Individual questions of the Likert scale were measured using the type central tendencies namely the mode, the upper and lower quartiles. The list of the requirements from the respondents was constructed using the descriptive statistical table in Appendix L. The list appears in Chapter 8, section 8.4.

7.5 Chapter summary

The findings from the mini-survey revealed that community members are interested in obtaining electricity generated by the Stirling system. It was found that the community members try to meet their energy demands by using various types of energy sources. It was also noted that wood is the main source of energy regardless of the type of household. It was clear that rural communities are not ideal places to introduce expensive technology with the intention of community members purchasing such products, because people tend barely to survive on their low incomes. The next chapter will discuss how the perceptions of the community members were implemented in the design of the Stirling system.

CHAPTER 8

A SIMPLIFIED HOUSE OF QUALITY FRAMEWORK

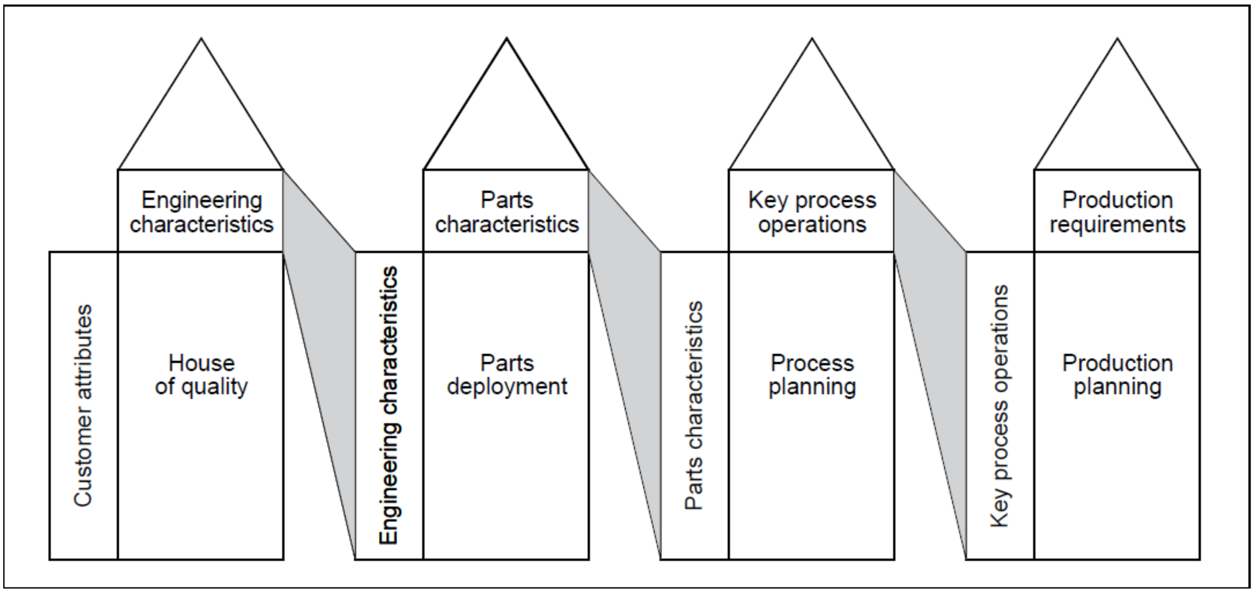
8.1 Introduction

The purpose of this chapter is to describe the development a simplified House of Quality (HOQ) matrix used to design a quality product namely the free piston Stirling engine and concentrator. The focus of the study was to build a product based on what the customers suggested. The ideas of the customers were incorporated into those of the designer. Though a simplified HOQ necessarily excludes some of the features of a full HOQ, it was nevertheless useful in selecting ideas to best satisfy the cost and performance requirements The HOQ technique also made it possible for the designers to identify which requirements should be regarded as having a higher priority. A product designed using an HOQ was likely to perform better in the market by virtue of the fact that it was developed according to the customer's requirements. The HOQ technique also decreases designing time and costs involved in designing the product.

Quality Function Deployment (QFD) was invented by Dr Yoj Akao in Japan during the late 1960s (Cristiano *et al.*, 2000); (Adiano & Roth, 1994). It was developed from a method called Total Quality Control (TQC). The Japanese manufacturers wanted:

- a system that enables proper planning before producing a product
- a system for producing what customers needed; and
- a control plan.

The QFD applications are known to encourage team work, shorten designing times and to reduce initial capital costs (Chan & Wu, 2002). The QFD consequently leads to more producible and competitively superior products. The QFD is made up of linking stages, see Figure 8.1. The different stages describe the customer's wants, product requirements, the process and the design. Apart from regarding the desires of the customer, the QFD also takes into consideration what the competitors are offering and the required technical specifications before advancing to the stage of manufacturing the product (Adiano & Roth, 1994).



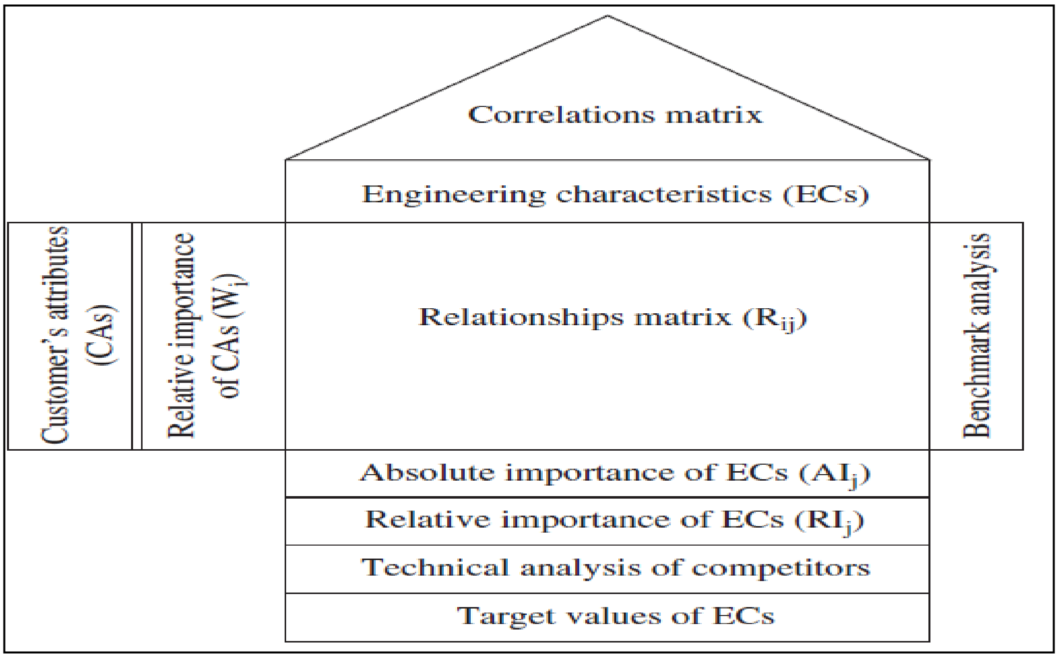
(Adiano & Roth, 1994)

Figure 8.1: The different stages of the quality function deployment

8.2 The development of the House of Quality

The QFD consists of four houses. The first house, called the HOQ, captures the voice of the customer, see Figure 8.2. The voice of the customers gives an indication of the products and services that customers need or expect. The needs of the customers are determined by personal interviews or by focus groups. The voice of the customers is converted to the voice of the engineer, where the needs of the customers are changed into measurable requirements and design attributes (Hauser, 1993).

It was difficult to design a single, simplified HOQ for the whole Stirling system because the Stirling engine and concentrator have separate functions. Therefore, two separate Houses of Quality were developed, namely for the free-piston engine and for the concentrator. These components function differently. In some cases, the customer requirements and engineering characteristics varied for the Stirling engine and concentrator.



(Bottani & Rizzi, 2006)

Figure 8.2: The different sections of the House of Quality

8.3 Identify the customers: who are they?

Some products have more than one kind of customer. Therefore, it is crucial to know exactly who the customers are for any product. The word 'customer' refers not only to the product buyers (product consumers), but also to all those who are involved in the development and design of the product along its value chain. Customers can therefore include the sales personnel, the designer and the service personnel (Ullman, 2003).

In this study, the customers were identified as people without access to electricity. The customers were also defined as interested stakeholders, such as people with access to electricity but who want to use electricity generated from a Stirling system.

8.4 Determine the customers' requirements: what do the customers want?

At this stage information is collected from the potential customers to determine what they want. Such data is collected through observations, surveys or focus groups. Surveys are applied to get the views and information from a specific target group. The questions in the survey are constructed in such a way that it is easy to extract the needs of the customers. The surveys make use of different types of questionnaires depending on a target group. The questionnaires can either be sent through mail, conducted over the phone or through personal interviews (Ullman, 2003).

The questions contained in the questionnaire of this study were formulated in such a way that they elicited from the customers information about the expected functionality and physical properties of the Stirling system. This meant that the respondents were not responsible for providing a list of the requirements, but had to choose from an already prepared list. The customers' requirements in the form of qualitative and quantitative data were extracted from the questionnaires. Table 8.1 provides a list of the requirements that were suggested by customers. The customers' requirements are referred to as customers' attributes (CAs) and the functional requirements as engineering characteristics (ECs). The designer's requirements were included with the customers' requirements.

Table 8.1: The customer's requirements

Customer requirements	**Source**
Prone to theft	Questionnaire number :V2
Cheap operating cost	Questionnaire number :V12
Affordable	Questionnaire number :V10
Less maintenance and reduced operation	Questionnaire number :V16
Long life expectancy	Questionnaire number :V17
Can be used whole day	Questionnaire number :V41
Sufficient electricity	Questionnaire number :V21
Reliable	From the concentrator designer
High quality of heat	From the concentrator designer
Easy to set-up	From the concentrator designer
Safe	From the concentrator designer
Silent operation	From the engine designer
Small size	From the engine designer
Portable	From the engine designer

8.5 Determine relative importance of the requirements: who versus what?

The customer requirements are weighted according to how important they are to the customers by means of a weighting factor, which is referred to as the weighted average($\boldsymbol{W_i}$), where the i, stands for the customer requirements. In the study, the weighted factors were normalised to be equal to 1, see Tables 8.2 and 8.3. This technique made it possible to easily identify the level of importance of each customer requirement relative to other requirements. According to Ullman (2003), the advantage of evaluating the customers' requirements is to establish how much money, time and effort to allocate to each requirement.

Rahaju and Dewi (2012) have discussed in more detail how to apply the following formulas to determine relative importance:

$$Answers\ in\ percentage\ \ from\ respondent = \left(\frac{No\ of\ repondents}{Total\ population}\right) \times 100 \qquad (8.1)$$

Formula 5.1 was applied determined by allowing each of the designers (of the Stirling engine and concentrator) to rate how important each requirement was to them on a scale of 1:5.

$$W_i = (\ Likert\ scale\ rating \times percentage\ answers\ from\ respondents\ ) \qquad (8.2)$$

For example the W_i for the customer requirement labelled "not prone to theft" for the concentrator was calculated in the following way:

$$W_i = [(16,667\% \times 1) + (0\% \times 2) + (\ 10\% \times 3) + \ (16,667\ \% \times 4) + (56,667\ \% \times 5)] \qquad (8.3)$$

$$W_i = [0,167 + 0 + 0,3 + 0,667\ + 2,883] \qquad (8.4)$$

$$W_i = 3,967 \qquad (8.5)$$

$$Total\ W_i = \sum(\ W_i) \qquad (8.6)$$

$$Normalised\ weight\ = \frac{W_i}{Total\ \ W_i} \qquad (8.7)$$

Table 8.2: Normalized relative importance weights of the customer requirements for the free-piston Stirling engine

	Likert scale rating - % answers from respondents						
Customer requirements	**1**	**2**	**3**	**4**	**5**	**Weighted average**	**Normalised weight**
Not prone to theft	17%	0%	10%	17%	57%	3,967	0,104
Cheap operating cost	7%	3%	3%	27%	60%	4,300	0,112
Affordable	3%	0%	3%	20%	73%	4,600	0,120
Little maintenance and reduced operation	0%	0%	10%	20%	70%	4,600	0,120
Long life expectancy	0%	0%	3%	7%	90%	4,867	0,127
Produce adequate electricity	27%	0%	0%	3%	70%	3,900	0,102
Silent operation	0%	0%	0%	100%	0%	4,000	0,105
Small size	0%	0%	0%	100%	0%	4,000	0,105
Portable	0%	0%	0%	100%	0%	4,000	0,105
Total						38,233	1,000

The requirement of producing adequate electricity was determined by using requirements of a typical the stove. Among the electrical appliances, it was a heavy electricity consumer and a popular choice amongst the respondents during the survey.

Table 8.3: Normalized relative importance weights of customer requirements for the concentrator

	Likert scale rating - % answers from respondents						
Customer requirements	**1**	**2**	**3**	**4**	**5**	**Weighted average**	**Normalised weight**
Not prone to theft	17%	0%	10%	17%	57%	3,967	0,125
Cheap operating cost	7%	3%	3%	27%	60%	4,300	0,136
Affordable	3%	0%	3%	20%	73%	4,600	0,145
Long life expectancy	0%	0%	3%	7%	90%	4,867	0,153
Reliable	0%	0%	0%	0%	100%	5,000	0,158
High quality of heat	0%	0%	100%	0%	0%	3,000	0,095
Easy to set-up	100%	0%	0%	0%	0%	1,000	0,032
Safe	0%	0%	0%	0%	100%	5,000	0,158
Total						31,733	1,000

8.6 Identify and evaluate the competition

How satisfied is the customer now? At this stage competing products are judged against customers' requirements. The competitors are evaluated the different attributes and services they provide (Ullman, 2003). The competitors are also compared with each other, with 0 being the lowest rating and 5 the highest rating.

According to Ullman (2003), the purpose of studying existing products that can compete with the product is:

- to provide a platform of available products (the 'now') and
- to provide a chance for improvement of existing products.

Dulin, Hove and Lilley (2013) developed a HOQ for the free-piston Stirling engine. In their study, the competitors of the free-piston engine were identified as the other types of Stirling engine configurations: alpha, beta and gamma. The same report was used as a guideline to construct the customer competition assessment for this study.

The free-piston engine performed way better on the customer competitive assessment than the other Stirling engine configurations. This is noticeable on Figure 8.3 the red (mostly right side) line which corresponds to the free-piston appeared mainly in the 3 last lines on the graph. Overall, the free-piston engine had higher ratings than other configurations. The gamma configuration was the second best performer and therefore it was seen as the biggest competitor to the free-piston. Given that the blue line (alpha engine) was predominately below the other lines it qualified for being the least suitable for the Stirling system.

Free-piston	Alpha	Beta	Gamma
3	3	3	3
5	2	3	3
4	3	4	5
5	2	3	3
5	3	4	4
4	3	3	3
5	3	4	4
4	2	3	5
4	2	3	5

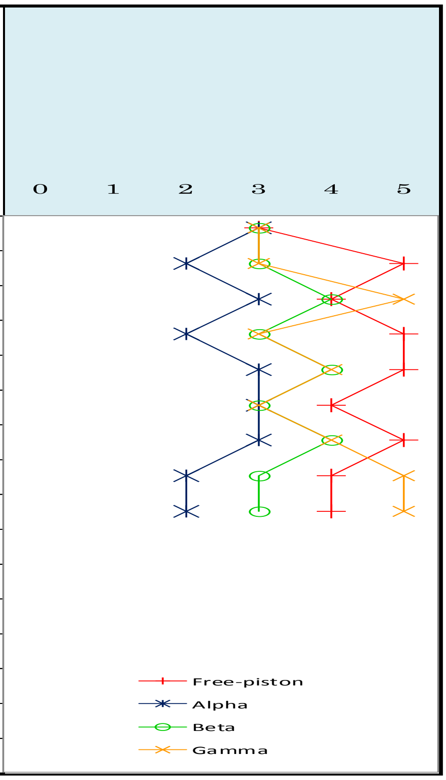


Figure 8.3 Customer competitive assessment of the free-piston Stirling engine

The competitors of the concentrator were the other solar thermal concentrator: Parabolic trough collector, heliostats field collector and linear Fresnel reflector. The dissertation by (Nixon, 2012) that evaluates the various solar thermal concentrators based on their technical, financial and environmental factors was used as reference to construct a simplified HOQ for the concentrator. The other useful information that was used in the HOQ was taken from the following studies: The information about the area of collector and the life expectancy were referenced from a journal by (Purohit *et al.*, 2013). The information about the temperature of the different concentrators was taken from (Zhang *et al.*, 2013) . The information concerning the safety of the solar thermal technologies was adopted from a report by the (International Renewable Energy Agency (IRENA, 2012).

The following abbreviations were used on the customer’s competitive assessment to represent the different concentrators:

1. Parabolic dish collector - PDC
2. Parabolic trough collector - PTC
3. Heliostats field collector - HFC
4. Linear Fresnel reflector - LFR

The line of the parabolic dish collector, represented by the red line outperformed the other lines. The greatest threat of the parabolic dish concentrator was the parabolic trough see, Figure 8.4.

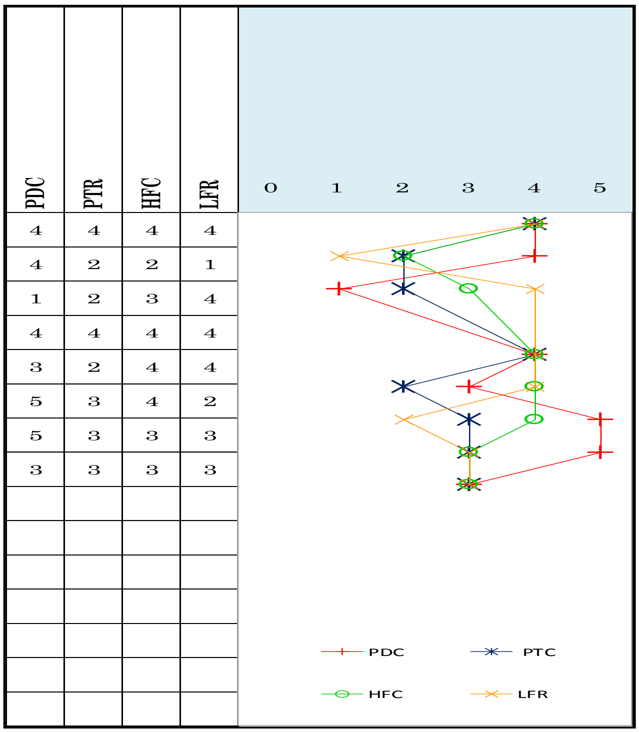


Figure 8.4 Customer competitive assessment of the concentrator

8.7 Generate engineering specifications

How will the customers' requirements be met? They are met by changing these requirements into technical parameters (engineering characteristics or functional requirements) that are measureable (Ullman, 2003). The carefully selected engineering characteristics were matched with the customers' requirements. See Figures 8.5 and 8.6 for the engineering characteristics of the free-piston engine and concentrator.

Functional requirements / Customer requirements	Durable	Hermetically seled	Few moving parts	No lubricant	Centering	No water usage	Power density	Material used	Self-starting	Efficient	Hybridised	Cost	Power produced
Direction of improvement	▲	◇	◇	◇	◇	◇	▲	▲	▲	▲	▲	▲	▲

Figure 8.5: The engineering characteristics of the free-piston Stirling engine

Functional requirements / Customer requirements	Dual-axis tracking system	Concentration ratio	Produce adequate power	Optical efficiency	Overcome strong winds	Easy to transport	Easy to assemble /disassemble	Optimised for cost	Durable	Reach high temperature	Mirror absorption
Direction of improvement	▲	◇	▲	◇	▲	▲	▲	▼	▲	▲	▲

Figure 8.6: The engineering characteristics of the concentrator

8.8 Relate customers' requirement to engineering specifications

How to measure what? The following symbols are used to describe the relationship between the technical parameters and customers' requirements (Ullman, 2003). This section is known as the relationship matrix, R_{ij}.

The interpretation of the graphic designs

●- Strong relationship

○- Moderate relationship

▽- Weak relationship

Blank cell - No relationship

The relationship levels in the relationship matrix were determined by the designers of the free-piston Stirling engine and concentrator because they had more technical knowledge than the researcher, see Figures 8.7 and 8.8.

Customer requirements \ Functional requirements	Durable	Hermetically seled	Few moving parts	No lubricant	Centering	No water usage	Power density	Material used	Self-starting	Efficient	Hybridised	Cost	Power produced
Prone to theft	▽							▽		▽		▽	
Cheap operating cost	●	●	○	○		●					●	○	
Affordable	▽			▽				●		○	▽	●	
Little maintenance		○	○	○	○	○		○					▽
Long life expectancy		●	●	●	●		○	●				○	
Sufficient electricity- magnets							●	●		●			
Silent operation		●	●										
Small size						●	●	●		●			
Portable							●	●		○		▽	

Figure 8.7: The relationship matrix of the free-piston Stirling engine

Functional requirements / Customer requirements	Dual-axis tracking system	Concentration ratio	Produce adequate power	Optical efficiency	Overcome strong winds	Easy to transport	Easy to assemble /disassemble	Optimised for cost	Durable	Reach high temperature	Mirror absorption
Not prone to theft						▽	▽		▽		
Cheap operating and maintenance costs					●			○	●		
Affordable	○					▽	▽	●	○		
Long life expectancy	▽				●			○	●		
Reliable	●	●	●	●	○			▽	●	●	●
High quality of heat	●	●	●	●	▽			○		●	●
Easy to set-up						○	●				
Safe				▽	○					●	○

Figure 8.8: The relationship matrix of the concentrator

8.9 Set engineering targets: how much is good enough?

Determine a target value for each engineering measure (Ullman, 2003). The target values are used to minimise or maximise the improvements of the engineering requirements or to keep the engineering requirements at a target value. The directions of improvement were determined by the designers. The different types of improvements for each engineering characteristic are given in Figures 8.9 and 8.10.

Interpretation of the graphic design

▲ –Minimise improvements

◇ – Maximise improvements

▼- Stay at a target value

A blank cell - No relationship

8.10 Identify relationships between engineering requirements:

How are the ‘hows’ dependent on each other? If two engineering specifications are dependent on each other, a symbol describing their correlation is placed at their intersection cell (Ullman, 2003). This makes it easy to identify which engineering requirements are in conflict with others and which are not. The designers had more technical knowledge so they determined the type of correlation between the engineering requirements, see Figures 8.9 and 8.10. The ‘durability’ and ‘power produced’ characteristics had a positive correlation with a high number of the free-piston engine’s engineering characteristics. However, there was a negative correlation between some of the engineering characteristics, namely ‘durable’ and ‘no lubricant’. Conversely, on the correlation matrix of the concentrator, ‘dual-axis tracking system’ and ‘produce adequate power’ had the greatest number of relationships with other engineering characteristics. The following engineering requirements had a negative correlation: ‘dual-axis tracking system’ and ‘overcome strong winds’, ‘dual-axis tracking system’ and ‘durable’, ‘produce adequate power’ and ‘overcome strong winds’, ‘produce adequate power’ and ‘optimised for cost’, ‘optical efficiency’ and ‘optimised for cost’, ‘optimised for cost’ and ‘durable’, and ‘optimised for cost’ and ‘mirror absorption’.

The interpretation of the graphic designs

+ Positive correlation

− Negative correlation

A blank cell - No relationship

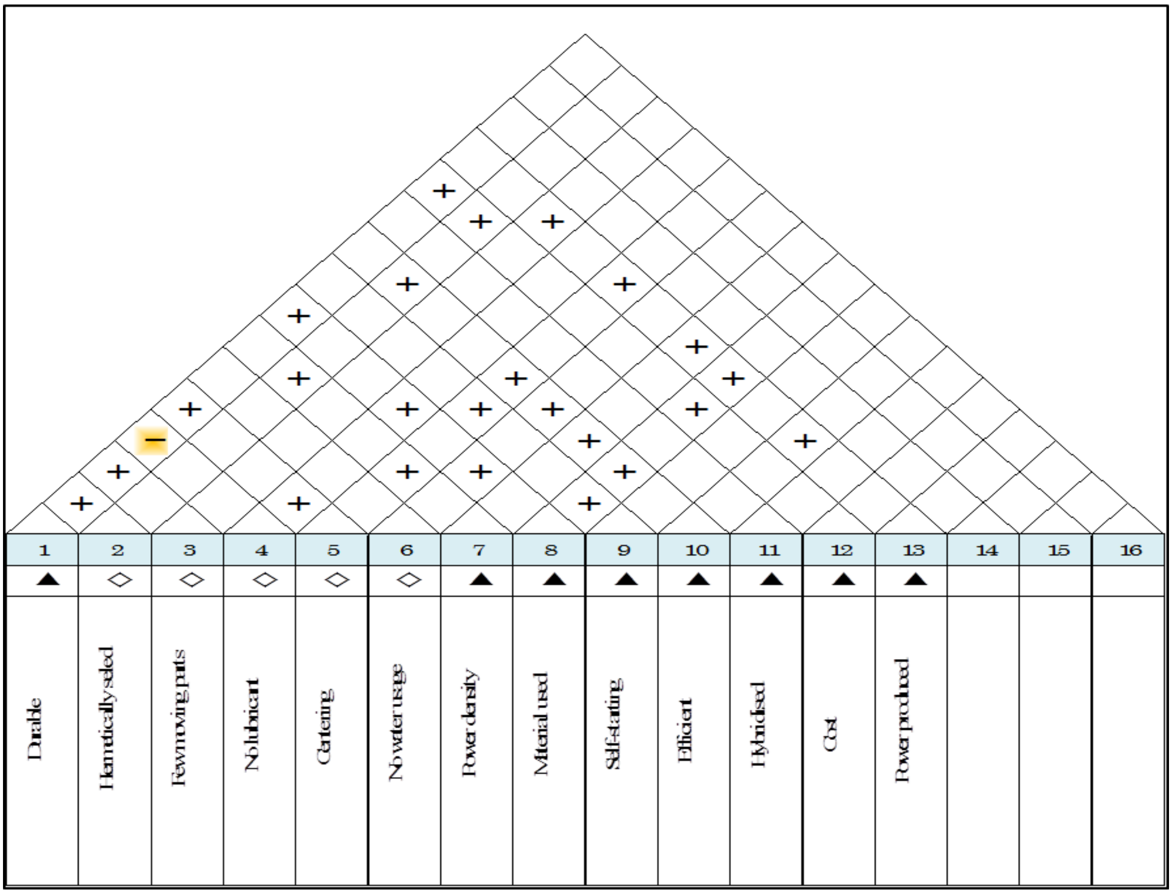


Figure 8.9: The correlation matrix for the free-piston Stirling engine

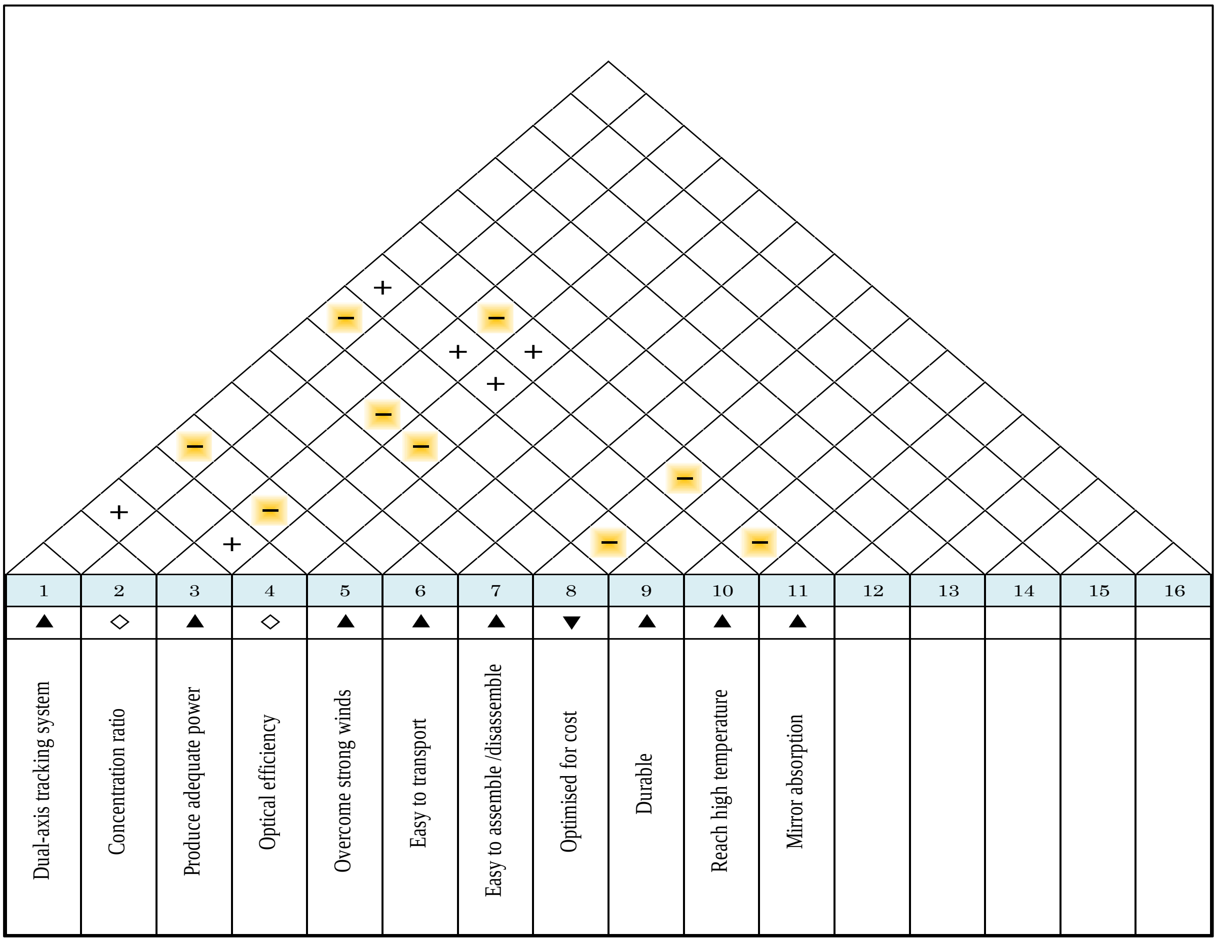


Figure 8.10: The correlation matrix for the concentrator

8.11 Technical competitive assessment

Technical competitive assessment investigates how the product performs when compared with other competitors based on technical requirements. The free-piston engine was the best performer compared to other engines and the gamma configuration engine was the worst performer, see Figure 8.11.

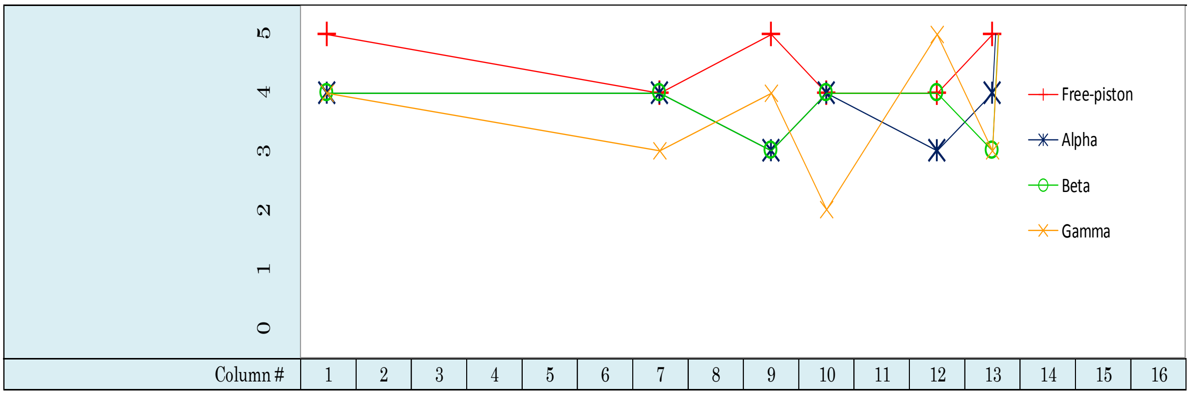


Figure 8.11: The technical competitive assessment of the free-piston Stirling engine

The most suitable solar thermal collector was the parabolic dish reflector and the least suitable one was found to be the Linear Fresnel reflector (see Figure 8.12).

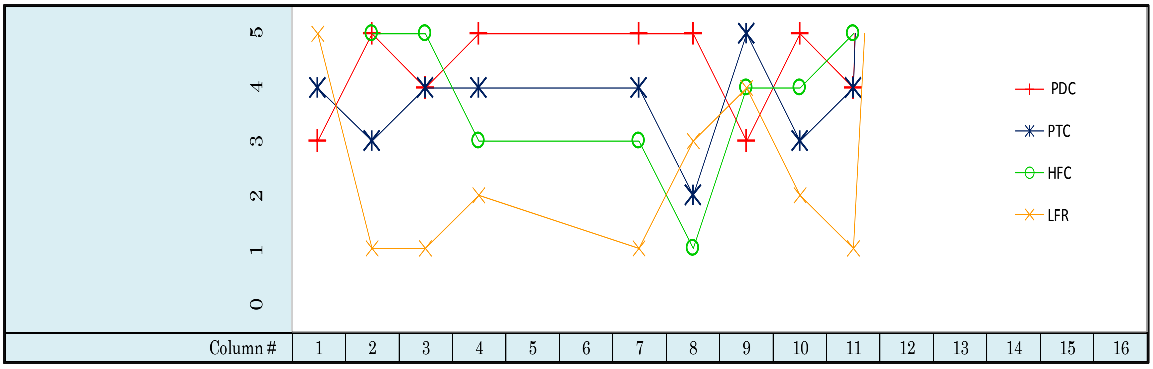


Figure 8.12: The technical competitive assessment of the concentrator

8.12 Final evaluation of the simplified House of Quality

Technical importance rating: The technical importance rating is also referred to as being of absolute importance, thus AI_j (Bottani & Rizzi, 2006):

$$AI_j = \sum_{i=1}^{n} W_i R_{ij}\,, \qquad j = 1, \dots m \tag{8.8}$$

The relative weight: In some cases, relative weight is referred to as being of relative importance, thus RI_j (Bottani & Rizzi, 2006):

$$RI_j = \frac{AI_j}{\sum_{j=1}^{m} AI_j}, j = 1, \dots, m \qquad (8.9)$$

The relative weights for the functional requirements were evaluated in order to determine which of the decisions of the designer needed to be prioritised. A target value was set for each engineering characteristic. The target values acted as a benchmark or as a value that an engineering characteristic should reach, see Figures 8.13 and 8.14.

Target	10 -15 years	Welded closed	Two moving parts: piston and displacer	Air bearings	Flexure bearings	Air cooled	High charge pressure	Best combination of cost and suitability	Low coefficients of static friction	Engine with a 25 % efficiency	Powered by multiple fuels	Less than R15 000	3 kW
Max relationship	9	9	9	9	9	9	9	9		9	9	9	1
Technical importance rating	123.6	346	278.6	196.4	150.7	231.5	318.3	549.4	0	263.8	113.3	201	12.03
Relative weight	4%	12%	10%	7%	5%	8%	11%	20%	0%	9%	4%	7%	0%
Weight chart													
Free piston	5						4		5	4		4	5
Alpha	4						4		3	4		3	4
Beta	4						4		3	4		4	3
Gamma	4						3		4	2		5	3

Figure 8.13: Decision matrix of a free-piston Stirling engine

Target	(Azimuth 360 degrees + Zenith 180 degrees) at 0, 12 degrees	1%	12 kWt at noon	Reflectivity of 94 %	Survive in 144km/h of wind	The parts can be disassambled	Can be installed by one person	Utilizing the cheapest materials possible	10-15 years	600 degrees	6%
Max relationship	9	9	9	9	9	3	9	9	9	9	9
Technical importance rating	253.7	201.5	201.5	215.5	323.2	65.95	149.9	232	406.5	327.4	243.5
Relative weight	10%	8%	8%	8%	12%	3%	6%	9%	16%	12%	9%
Weight chart											
Parabolic dish reflector-PDC	3	5	4	5			5	5	3	5	4
Parabolic trough collector- PTC	4	3	4	4			4	2	5	3	4
Heliostats field collector- HFC		5	5	3			3	1	4	4	5
Linear Fresnel reflector-LFR	5	1	1	2			1	3	4	2	1

Figure 8.14: Decision matrix of the concentrator

The priority attributes of the parabolic dish and free-piston Stirling engine are given in the following descending order as depicted in Tables 8.4 and 8.5. For the free-piston Stirling engine high priority should be given to the 'material used' and 'hermitically sealed unit'. The two priorities for the concentrator were 'durable' and 'reach high temperature'. The full HOQ of the concentrator and engine are found on Appendix M and N.

Table 8.4: The functional requirements of free-piston Stirling engine ranked in descending order

Functional requirements	Relative weight
Material used	20 %
Hermitically sealed unit	12 %
Power density allows more pressure	11 %
Few moving parts in the engine	10 %
Efficient	9 %
No water usage	8 %
No lubricant	7 %
Cost	7 %
Centering	5 %
Durable	4 %
Hybridized	4 %
Self-starting	0 %
Power produced	0 %
Total	100 %

Table 8.5: The functional requirements of the concentrator ranked in descending order

Functional requirements	Relative weight
Durable	16%
Reach high temperature	12 %
Overcome strong winds	12%
Dual axis tracking system	10%
Mirror absorption	9 %
Optimized for cost	9%
Optical efficiency	8%
Concentration ratio	8%
Produce adequate power	8%
Easy to assemble /disassemble	6%
Easy to transport	3%
Total	100 %

8.13 Chapter summary

After the design requirements were identified and ranked, it became easier for the designers apply these priorities to design the product. Furthermore, the customers could be more satisfied with the product since the designers had considered their needs relating to the product. It was also less challenging to design the manufacturing plan for the Stirling system, which is discussed in the next chapter.

CHAPTER 9

MANUFACTURING FACILITIES DESIGN

9.1 Introduction

According to Stephens and Meyers (2013), manufacturing facilities design is defined as the "organization of the company's physical assets to promote the efficient use of resources such as people, material, equipment, and energy". Facilities design takes account of plant location, building design, plant layout and material handling systems (Stephens & Meyers, 2013). Following the determination of the attributes for the Stirling engine and the concentrator, a manufacturing facilities design was set up. The manufacturing plan is a guideline on how the Stirling system can be manufactured. The plan aimed at producing the product in the most economical way and using as much local content (materials and labour) as possible.

The manufacturing design focused mainly on the manufacturing processes, tools, and mechanical equipment. By developing a manufacturing design beforehand, it was easy to determine the cost of manufacturing one Stirling system and comparing this cost to the cost of manufacturing Stirling systems in large quantities. The objective of the manufacturing design was to produce a product that is of high quality, that is cheap to produce and that uses the least amount of resources.

ISO 9001:2000 could be implemented to maintain the quality standards. The certification of the factory with such standards will contribute to the high quality of the Stirling system.

Design for Six Sigma (DFSS) is a Six Sigma tool. DFSS has two methods that are used achieve quality; one of them is known as DMADV. DMADV is used mainly for innovation and invention of new products, processes and services (Johnson, Gitlow, Widener & Popovich, 2006). DFSS was applied in this project to decrease problems and increase the chances of designer and customer satisfaction. The structure of this section is based on the five phases of DMADV, as follows:

Define (D): The new product manufactured was identified as the 3 kW solar Stirling system intended to generate clean energy (electricity).

Measure (M): A mini-survey was conducted to determine the people's perception of the Stirling system, customer requirements and the energy overview in rural areas. The rest of the attributes were contributed by the designers and combined with the customer's needs. All the requirements were evaluated to assign priority when designing the product. The size of the target market was estimated. The manufacturing capability was defined in terms of availability of raw materials, labour capability and production.

Analyse (A): A simplified HOQ framework was developed to ensure that the designers meet the customers' requirements.

Design (D): Although there are numerous designs for Stirling engines and parabolic dishes, the designers created designs based on the existing proven models.

Verify (V): At the end, the pilot product would be tested, the expectations verified, the performance of the product recorded and the necessary changes would be made to the product. Since the prototype is not yet complete, this section will be completed by the mechanical engineering students.

9.2 Cost analysis for materials, manufacturing and production process of the Stirling system

The cost analysis is a combination of all the costs involved in manufacturing the Stirling system including the purchasing of materials, and the manufacturing and production processes.

Material costs are the costs of all the materials used in making the different structures of the Stirling system. The costs were added up from the invoices as provided by the suppliers. For the material costs see Appendix O, P, Q and R.

Manufacturing costs are the costs involved in the machining processes that were executed in the factory. In addition, manufacturing costs include the amount spent on outsourcing services (machining), see Appendix P, Q and R. **Production costs** include the labour and electricity costs.

9.2.1 Manufacturing cost of the concentrator

Welding was the only manufacturing process that was carried out during the concentrator production in the workshop. The time taken to weld one unit was taken as 5,5 hours. The manufacturing cost for the concentrator refers to the cost of labour and electricity. The calculations of the manufacturing costs and number of days available for workers are available on Appendix R.

Table 9.1: The calculation of the welding costs of a concentrator for two options, namely 1 worker and 4 workers

Description:	**Value**	**Value**
Number of workers	1	4
Welding units /hour given number of workers	0,182	0,727
Manhours to weld 1000 units	5500	5500
Regular labour costs R/hour for number workers	R56,08	R224,32
Overtime labour costs R/hour	R 84,12	R 84,12
Total labour costs at 85 % of hours	R 362 870,59	R 362 870,59
Overheads given the number of days to manufacture	R 36 287,06	R 9 071,76
Electricity costs c/kWh	127,71	127,71
Total number of days to weld 1000 units	688	172
Total electricity costs	R 96 000,00	R 96 000,00
Total manufacturing costs for the concentrator	R 495 157,65	R 467 942,35
Manufacturing cost for one concentrator	R 495,16	R467,94
Number of units produced in a day	1	5

9.2.2 Manufacturing cost of the Stirling engine

The manufacturing cost was broken down into sections each representing the different types of machining done to manufacture the engine. Some of the machining processes were independent of each other; for example, this meant that one worker could start with drilling while another was busy milling. Table 9.1 and 9.2 only includes some of the information. This is due to the casting process that will be considered in the future to replace some manufacturing processes the number of workers and hours turning process on Table 9.2. The current manufacturing process requires 23 workers and 36,75 hours for the turning process. The casting process will reduce the total turning time from 36,75 hours to 10,15 hours per engine, cutting the number of artisans required from 23 to seven.

Table 9.2: The calculation of the machining costs of an engine

Description:	**Value**	**Value**	**Power required by machine**
Welding units /hr (one unit takes 3.5 hours to weld)	0,286	0,857	20 kW
Time taken to weld 1000 units	3500	3500	
Regular labour costs R/hr	R 56,08	R 56,08	
Total regular labour costs	R 230 917,65	R 230 917,65	
Total labour and overheads cost	R 254 009,41	R 238 614,90	
Number of workers required	1	3	
Turning units/hr (one unit takes 10,15) hours for turning)	0,099	0,690	3 kW
Time taken to turn 1000 units	10150	10150	
Total regular labour costs	R 669 661,18	R 669 661,18	
Total labour and overheads cost	R 736 627,29	R 679 227,76	
Number of units produced in day	0,8	6	
Number of workers required	1	7	
Milling units/hr (one unit takes 6 hours for milling)	0,167	0,667	3 kW
Time taken to mill 1000 units	6000	6000	
Total regular labour costs	R 395 858,82	R 395 858,82	
Total labour and overheads cost	R 435 444,71	R 405 755,29	
Number of workers required	1	4	
Drilling units/hr (one unit takes 7 hours for drilling)	0,143	0,714	2 kW
Time taken to drill 1000 units	7000	7000	
Total regular labour costs	R 461 835,29	R 461 835,29	
Total labour and overheads cost	R 508 018,82	R 471 072,00	
Number of workers required	1	5	
Tapping and drilling units/hr (one unit takes 9 hours for tapping and drilling)	0,111	0,667	2 kW
Time taken to tap and drill 1000 units	9000	9000	
Regular labour costs R/hr	R 56,08	R 56,08	
Total regular labour costs	R 593 788,24	R 593 788,24	
Total labour and overheads cost	R 653 167,06	R 603 684,71	
Number of workers required	1	6	
Total number of days it will take to weld 1000 units	1269	188	

Total number of days it will take to weld 1000 units	1269	188	
Total manufacturing costs for the Stirling engine	R 2 242 092,59	R 2 082 869,37	
Total cost for manufacturing one Stirling engine	R 2 242,09	R 2 082,87	

Subsequent to determining the costs (material, manufacturing and production), the selling price of the Stirling system was calculated using the following formulas, see Table 9.3. The following formula was adopted from (Stephens & Meyers, 2013) :

$$\begin{aligned} &Total\ manufacturing\ cost\ of\ one\ dish \\ &\quad = (\ cost\ of\ manufacturing\ engine \\ &\quad + cost\ of\ manufacturing\ \ concentrator\ ) \\ &\quad + 10\ \%\ manufacturing\ overheads \end{aligned} \tag{9.1}$$

$$\begin{aligned} &Total\ material\ cost\ of\ one\ dish \\ &\quad = (material\ cost\ of engine + material\ cost\ concentrator\ ) \\ &\quad + 10\ \%\ manufacturing\ overheads \end{aligned} \tag{9.2}$$

The cost of the new product should be determined during the early phase of the project. This is important for determining the profitability of the project (Stephens & Meyers, 2013). The 30 % mark-up rate is optional depending on how much profit the business wants to generate.

$$Selling\ price = (manufaturing\ cost\ of\ one\ dish) + 30\ \%\ profit \tag{9.3}$$

Table 9.3: The calculation of the selling price of the Stirling System

Parameters	Value
Cost of manufacturing one concentrator	R 467,94
Cost of manufacturing one engine	R 2 082,87
Including 10% overheads	R 2 805,89
Material cost of concentrator	R 40 190,63
Material cost of engine	R 15 258,47
Including 10 % overheads	R 60 994,01
Total costs of manufacturing dish	R 63 799,90
Profit	30%
Selling price per unit	R 83 000,00

Therefore selling price = R83 000,00. The selling price excludes transport and installation costs because the idea is to sell a self-install product.

The total time taken for turning (machining process) different parts of the Stirling engine was 36,75 hours per engine. This time is too long and makes the manufacturing process uneconomical. Therefore, if the factory is to reach the target of manufacturing five solar Stirling systems per day, it means that there should be 23 artisans hired for turning, an untenable situation. Thus, an alternative method was recommended to replace this method. To produce a prototype Stirling system, it is acceptable to manufacture some parts through the turning process. However, once the factory is ready to upscale, it will be more economical if the casting method can replace the turning method. However, piston, cylinder and displacer assemblies that require a precise-fitting cannot be manufactured through casting only, but can be finished using a single pass milling operation.

9.3 Casting cost estimation

Investment casting is identified as the suitable process for manufacturing the various engine parts. Investment casting makes use of cheap wax to produce products with high quality, complexity and smooth surfaces (Pattnaik *et al.*, 2012). Casting processes are less costly than other manufacturing processes (Chougule & Ravi, 2006). These authors developed a method that estimates the pre-casting costs of the product. The cost is calculated as follows:

(9.1)

(9.2)

$$C_{casting} = C_{material} + C_{labour} + C_{energy} + C_{tooling} + C_{overheads}$$

(9.3)

(9.4)

The above-mentioned cost categories are described as follow:

- **Material cost**: is the sum of direct and indirect materials. The unit is expressed in R/kg.
    - ***Direct materials***: Materials that appear in the final product such as the alloy or cast metal.
    - ***Indirect materials***: Materials that are used for production but are not part of the final product such as sand moulding and cores.
- **Labour cost:** refers to the equipment, labour and time used for the production. The unit is expressed in R/hour.
- **Energy cost:** refers to the energy required to melt the metal. The unit is expressed in R/joule.
- **Tooling cost:** refers to the tooling materials.
- **Overhead cost:** is the sum of administrative overheads and depreciation costs. The unit is expressed in R/kg.

The cylinder component is made of cast iron. Therefore, the cost of casting was estimated to determine whether it is a cheaper option, given the different casting parameters in Appendix T.

The values regarding the cylinder were actual values from the prototype manufacturing. Otherwise, the rest of values were assumed or based on the articles where the formulas were extracted from. The motivation for this is that the casting cost estimated in the article by Chougule and Ravi (2006) is made of the same material as the cylinder

$$C_{material} = C_{direct} + C_{indirect} \quad (9.5)$$

$$C_{direct} = C_{unit-metal} \times f_m \times f_p \times f_f \quad (9.6)$$

$$C_{indirect} = C_{mould-sand} + C_{core-sand} + C_{miscellanous} \quad (9.7)$$

C_{direct} = R9, 00 and $C_{indirect}$ = R1,07

$$C_{labour} = f_r \times (\sum_{act=1}^{n} f_{rej-act} \times C_{unit-labour} \times l_{act} \times t_{act} \quad (9.8)$$

Therefore, C_{labour} = R29,39

$$C_{melting} = C_{unit-energy} \times f_n \times W_{cast} \times f_y \times f_r \times f_m \times f_p \times f_f$$
$$\times [C_{ps} \times (t_{melt} - t_{room}) + L + C_{pl} \times (t_{tap} - t_{melt})] \quad (9.9)$$

Therefore, $C_{melting}$ = R17,57.

$$C_{tooling} = C_{index} + \frac{C_{rel-tool-cost}}{Q} \quad (9.10)$$

$$C_{rel-tool-cost} = \exp(0.629 \times V_{cast} + 0.048 \times C_{ac} + C_s + 0.023 \times 0.739) \quad (9.11)$$

Therefore the $C_{tooling}$ = R21,62.

$$C_{overheads} = C_{adminstration} + C_{depreciation} \tag{9.12}$$

$$C_{adminstration} = W_{cast} + C_{adminstration-rate} \tag{9.13}$$

$$C_{depreciation} = W_{cast} + C_{depreciation-rate} \tag{9.14}$$

Therefore the $C_{overheads}$ = R0,42.

Therefore, $C_{casting}$ = R 62,14/ cylinder is a cheaper option as comparing to the current method which required 2 hours of turning in the workshop and 7 hours outsourced for drilling, grinding and tapping. The price of casting a cylinder at a foundry costs R 327,50, see Appendix U. The outsourced service cost R 2 599,20.

9.4 The determination of the installation cost

The installation cost is the cost involved in installing the Stirling system. The installation cost is excluded from the price of the Stirling system to make provision for customers who can do the installing for themselves. This will also cater for the idea that the Stirling system is to produce a do-it-yourself product (Prinsloo *et al.*,2014). The installation cost per unit was calculated as follows:

$$\begin{aligned} &Installation\ cost\ per\ unit \\ &= (total\ time\ taken\ to\ install\ (hours) \times labour\ wages(R)) \\ &+ concrete\ support \end{aligned} \tag{9.15}$$

Table 9.4: The calculation of the installation cost

Item	Value	Unit	Remark
Time taken to bolt	9,15	hours	
Time taken to apply foundation	2	hours	
Time taken to install the engine	1	hour	
Time taken to install mirrors	5	hours	
Total time for installations	17,15	hours	Rounded off to nearest whole number
Cost of concrete support	2 000,00	R	Estimation
Labour wages (85% efficiency factor)	43,85	R/hour	Overtime labour rate
Installation fee	2 838,63	R	
Installation cost per unit	5 000,00	R	Rounded off to nearest whole number
Installation cost per unit	1666,67	R /kW	

9.5 Chapter summary

The manufacturing facilities design was effectively carried out. Africa has the capability of producing the Stirling system with a high local content. The manufacturing costs are likely to decrease with mass production because several of the manufacturing processes of the prototype were outsourced.

CHAPTER 10

THE ENERGY STORAGE OPTIONS FOR A STIRLING SYSTEM

10.1 Introduction

A Stirling system is powered by solar energy and therefore typically works for about six hours on a day when sunlight is available. One way to make the Stirling system more economical is by increasing the daily electricity output in a day. This could be accomplished by increasing the number of hours that the system works in a day by means of improving energy storage.

10.2 Application of batteries for energy storage

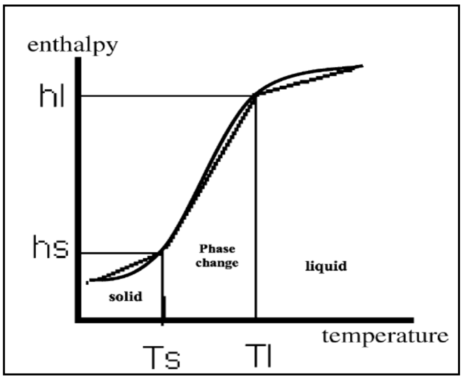
Batteries store chemical energy. The batteries suitable for solar energy generation should possess the following qualities: they should be able to be used repeatedly, charged before use, discharged and recharged (cycled) (Er & SHYAM, 2013). Lead acid batteries have energy efficiency in the range of 85-90 %, require little maintenance and are cheaper than other batteries. Lead acid batteries have a long lifespan of about five to 15 years (Hadjipaschalis *et al.*, 2009). This deep-cycle battery is a type of lead acid battery. Therefore deep-cycle are one of the best suited type of batteries for off-grid applications because they are able to tolerate the harsh conditions of rural areas. They are cheap and last longer when compared to other batteries (Rolland, 2011). They can be used for storing excess electrical energy produced from the Stirling system during the day (Trieb *et al.*, 1997).

10.3 Thermal storage using phase change materials

The other option for storing energy generated from the Stirling system is storing thermal energy using phase change materials (PCMs). Since solar energy is only available during the day, the Stirling system can be hybridised with phase change material that charges during the day and discharges heat at night to produce electricity. The electricity demand in a household varies depending on the time of day. There is a low electricity demand during the midnight hours compared to the early morning and during the day. In addition, the energy demand and consumption in a household also depends on the climate. Cold regions require heating systems and hot regions require cooling systems. It is therefore important for an energy system to have the capability of producing sufficient electricity during peak hours. One possibility of achieving this lies in using PCMs (Farid & Husian, 1990).

Thermal energy storage occurs during the change in the internal energy of the material, as sensible heat, latent and thermochemical storage. The most efficient way to store thermal energy is by using latent heat storage (LHS) system. The benefits of using such a system are high-energy storage density and the isothermal nature of the storage process. LHS is the heating and cooling of a material that then undergoes a transition phase either from solid to liquid or liquid to gas. However, the phase change from solid to liquid is the most cost-effective option available for thermal energy storage. PCMs materials absorb large amounts of thermal energy without significantly changing the temperature. In the PCM container, a heat transfer medium is added to transmit heat to and from the PCM (Sharma, *et al.*, 2009).

Figure 10.1 illustrates an example of an impure substance going through a solid-liquid phase transition. This is an example of how a PCM stores thermal energy during the day. The solid matter melts during the day as it absorbs the thermal energy. An impure substance solidifies over a range of temperatures which causes a two-phase zone between the solid and liquid phases (Zalba *et al.*, 2003).



(Zalba et al., 2003)
Figure 10.1: Solid-liquid phase change in a phase change material

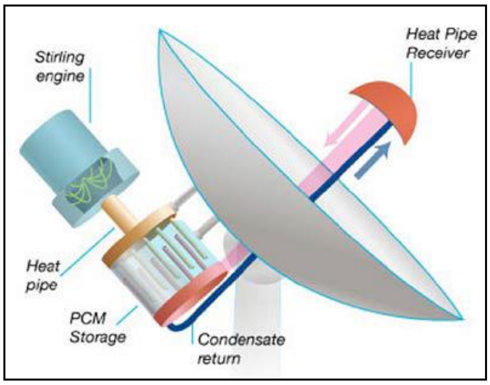
10.4 Metallic phase change materials

Metallic materials are examples of inorganic PCMs. This group includes low melting metals and metal eutectics (Rathod & Banerjee, 2013). Metal PCMs have a high latent heat capacity which makes them suitable for storing energy. The high latent heat capacity of metal PCMs requires less volumetric storage. During the solid-liquid transition of the metal PCMs there is a slight increase in temperature and volume (Ge *et al.*, 2013). One of the possible metallic PCMs identified as suitable for a Stirling system is the metal element lead (Pb).

PCM metal alloys were preferred over salts because the salts have the following limitations: they are poor heat conductors, they are corrosive, and they take up more space when they expand during the melting phase (Kenisarin, 2010) .

10.5 Possible thermal energy storage for Stirling system

A project was carried out which incorporated a 3 kW Infinia free-piston Stirling engine with thermal energy storage. It was found that the PCM's salts, NaF and NACI, have the capability of storing 12 kWh of energy. During the day the thermal energy from the receiver is transferred to the PCM with the help of heat pipes which results in the phase where salt changes phase solid to liquid. At night as the salt starts to freeze and releases thermal energy which is transferred from the PCM through the heat pipes to the Stirling engine. This is referred to as the heat process discharge phase (Qiu *et al.*, 2013).



(Andraka et al.,2013)
Figure 10.2: The dish concept incorporated with thermal energy storage

Sandia National Laboratories is in the process of designing 25 kW Stirling systems that are capable of providing six hours of storage using PCMs. The Stirling dish was designed with a rear-mounted storage unit and the engine was placed on top of the dish, see Figure 10.2. Salt or metallic eutectic PCMs were used. Sandia National Laboratories envisage that these types of storage systems will lead to cost-effective Stirling system operation by decreasing the LCOE to 0,01kWh (0,1 R/kWh) and increasing the output by 0,02 US $/kWh (0,20 R/kWh) (Andraka *et al*., 2013).

Table 10.1 is a summary by Andraka *et al.*, (2013) of the criteria that a PCM for a Stirling system should meet. It seems that the concept of thermal energy storage incorporated with the Stirling engine will be unable to use organic products such as paraffin wax as a PCM.

Table 10.1 Criteria for determining the phase change materials used in a Stirling dish

Criterion	**Implications**
Melting point	Needs to match Stirling cycle. Ideally between 750 °C and 800 °C.
Heat of fusion	Equal to the gravimetric density, determines the mass of the storage media needed to meet the storage requirements. Implications of system support structure and system balance.
Volumetric storage density	Gravimetric storage density times the mass density of the material. This impacts the size of the storage media, and therefore the quantity of containment material as well as the thermal losses by conduction.
Thermal conductivity	Low conductivity leads to higher temperature drops on charge and discharge, impacting exergetic efficiency. Can be mitigated with a higher density of heat pipe condensers and evaporators, but at a system monetary cost.
Material compatibility	The PCM must have compatibility at temperature with reasonable containment materials over long periods.
Stability	The PCM must not break down over time at temperature. This includes major changes such as separation of components and changes in composition, as well as minor issues such as outgassing and changes in melting point.
Coefficient of thermal expansion	This can impact the design of the containment and may require volumetric accommodation of size changes with temperature.
Phase change volumetric expansion	This can lead to voids, increasing thermal resistance through the solid phase, and can potentially cause damage to the heat pipe tubes.
Vapour pressure	Related to stability, a high vapour pressure can lead to containment issues and/or higher cost for containment.
Cost	The cost of the PCM directly impacts the LCOE of the system.

(Andraka et al., 2013)

10.6 Determining the amount of phase change material required to run a 3 kW Stirling system

It is assumed that the thermal energy storage system for a Stirling system will operate from 18:00 until 23:00 i.e. for five hours after sunset. These five hours are sufficient for activities such as watching television, cooking and charging cell phones. From the mini-survey that was carried out, it was noted that 70 % of the households in the community prefer electricity that runs all day for the purpose of cooking, heating and catering for all household appliances. According to (Nfah *et al.,* 2007) a typical household's daily energy consumption is between 0,3 kW and 0,6 kW therefore after sunset the house will consume approximately half of the daily energy consumption.

The total time required for thermal energy storage (t*) was estimated to five hours. The time is short because the storage energy will be required for limited applications such as cooking.

Practically, the Stirling system with storage unit will operate for about 11,5 hours per day. It will operate for six and a half hours during the day and for five hours after sunset. Then at night the energy demand is estimated to be 250 Watt or 0,25 kW. The electricity required for each household after hours is calculated as follows:

$$E_{Wh} = t^{*} \times E \tag{10.1}$$

$$E_{Wh} = 250\, Watt \times 5\, hour \tag{10.2}$$

$$E_{Wh} = 1250\ Wh \tag{10.3}$$

The electricity is converted into kilojoules:

$$E_{kJ} = 1250\, Wh \times \frac{3,6\, kJ}{Wh} \tag{10.4}$$

$$E_{kJ} = 4500\, kJ \tag{10.5}$$

Lead is a natural occurring metal, but since direct exposure to lead is harmful to human beings, the lead used for heat storage is encased in a sealed tank and is not exposed to the outside environment. The following are calculations for the volume required for storing energy using the metal lead (Pb):

Given that: ΔH of Lead = 23 kJ/kg, T_{m} = 327 ^{0}C and D = 11340 kg/m^3

$$m = \frac{E_{kJ}}{\Delta H\ of\ \text{lead}} \tag{7.6}$$

$$m = \frac{4500\, kJ}{23\, \frac{kJ}{kg}} \tag{7.7}$$

$$m = 195,65\, kg \tag{7.8}$$

Therefore, the volume of lead is determined using:

$$V = \frac{m}{d} \tag{7.9}$$

$$V = \frac{195,65\ kg}{11340\ \frac{kg}{m^3}} \tag{7.10}$$

$$V = 0,017\ m^3 \tag{7.11}$$

Table 10.2 gives the prices of the potential PCM that can be used to store thermal energy in the Stirling system. One potential eutectic metal alloy to store thermal energy that was identified was AlSi12. AlSi12 alloy remains stable under varying temperatures (Kotzé *et al.*, 2013). Even though AlSi12 is cheaper than lead and also requires less storage volume, Lead was the preferred PCM for this research group.

$$\begin{aligned} &Cost\ of\ PCM\ required\ for\ a\ 3\ kW\ Stirling\ dish \\ &\quad = cost\ of\ PCM\ \times mass\ of\ the\ PCM\ required \end{aligned} \tag{7.12}$$

$$\begin{aligned} &Selling\ price\ for\ Stirling\ system\ with\ a\ lead\ storage\ unit \\ &\quad = selling\ price\ of\ standard\ Stirling\ system \\ &\quad + cost\ of\ PCM\ required\ for\ a\ Stirling\ dish \end{aligned} \tag{7.13}$$

$$Selling\ price\ for\ Stirling\ system\ with\ a\ lead\ storage\ unit = R83\ 000,00 + R\ 4200,00 \tag{7.14}$$

$$Selling\ price\ for\ Stirling\ system\ with\ a\ lead\ storage\ unit = R87\ 200,00 \tag{7.6}$$

Table 10.2: Price list of the phase change materials

PCM	Cost of phase change material	Cost required for a 3 kW Stirling system
AlSi12	US $ 2270 /Tonne	US $ 18,24
Lead	US $ 2103/ Tonne	US $ 411,45

(Kotzé et al., 2013); (Mineral fund advisory,2014)

10.7 Chapter summary

The thermal storage option would make Stirling system it more attractive to customers since the Stirling system would have longer functional hours. The PCMs are affordable and can be made from available materials such as Lead. Furthermore, a Stirling system with storage has a lower LCOE compared to a standard Stirling system.

CHAPTER 11

ESTIMATING THE END-USER COST OF USE OF A 3 KW RESIDENTIAL STIRLING SYSTEM

11.1 Introduction

Economic considerations are important in selecting the right technology. Therefore, it is essential to determine whether the Stirling system is economical and if the electricity it generates can compete with competing technologies. The economic analysis set out in this section includes the net present value (NPV), internal rate of return (IRR), total life-cycle cost (TLCC), levelised cost of energy (LCOE) and a simple payback period evaluated over a period of 20 years. A sensitivity analysis is also provided in this section. The key assumptions regarding economical parameters used were based in a South African context, see Table 11.1.

Table 11.1: The estimated values used for economic analysis

Item	Value	Remarks
Stirling system	R 83 000, R87 200,with a storage unit	The selling price of a standard Stirling system The selling price of a Stirling system with a lead storage unit. The lead price is based on the cost of PCM in Table 7.2
Annual electricity output of the Stirling system	7 118 kWh, 12 593 kWh	Standard Stirling system with 6,5 hours of operating time Stirling system, fitted with a lead storage unit, with 11,5 hours of operating time
Electricity price for domestic purposes	1,43 R/kWh	City of Cape Town electricity tariff
Discount rate /interest on loan	10 %	
Inflation	3 %	South Africa's inflation is too high compared to other countries
Electricity increase	5 %	Electricity increase volatile, value based on the average inflation rate
Total number of payment for the loan	20	Per annum
Preventive maintenance	R1 00,00	Stirling engine is excluded. 3 % inflation increment per annum.
Life expectancy of the system	20 years	Stirling systems have been tested to exceed this period

Preventive maintenance for Stirling system owner

The Stirling system will receive an annual inspection which includes 10-15 minutes of maintenances work. The maintenance activities include inspecting the concentrator, tracking system and electro drive (motor and gearbox), as well as cleaning of the mirrors, and greasing various components. The Stirling engine does not require maintenance if it is well built. For calculation purposes it is estimated by the student designing the concentrator that the maintenance fee will amount to R100 and will increase annually with inflation.

The Stirling system generates ten times more electricity than required per household. Thus it was incorrect to assume that one individual household will save 3 kW worth of energy. Since as mentioned before that according to Nfah, Ngundam and Tchinda (2007) that typical household's daily energy consumption is between 0,3 kW. Therefore, a Stirling system be installed in a rural community and shared among 10 households. As the earlier mini-survey revealed that the majority of the community members are unable to afford the Stirling system once-off. Therefore, a scenario was established whereby a homeowner could be allowed to take out a loan that is payable within 20 years. The annual mortgage was based on a 20 year period and with a 10 % interest rate. The combined annual mortgage (payback payment) was calculated as follow:

$$Combined\ annual\ mortgage\ = (rate, nper, pv, type) \tag{11.1}$$

$$Combined\ annual\ mortgage\ = (\ 10\ \%, 20{,}83\ 000, 0) \tag{11.2}$$

$$Combined\ annual\ mortgage\ = R\ 9\ 749{,}15 \tag{11.3}$$

The combined annual mortgage was divided by 10 to provide individual amount for each homeowner. Where rate is interest rate for loan, nper is total number of payment for the loan, pv is the present value and type at the end of the period.

$$Value\ of\ energy\ generated = (\,selling\ price\ of\ electricity\ ({}^{R}/_{kWh}) \times (\,1 + electricity\ increase)^{n-1}\ \times annual\ energy\ output(kWh)) \tag{11.4}$$

$$Present\ value\ interest\ factor\ = \frac{1}{(\,1 + discount\ rate)^{n}} \tag{11.5}$$

The selling price of the Stirling system expressed in terms of R/kWh over its lifetime. Assuming conservatively that only 4 working hours is available per day, then the total output is calculated as following.

$$Annual\ electricity\ output\ (kWh) = \frac{4h}{day} \times 3\ kw \times 365 \frac{days}{year} \times 20\ years \tag{11.6}$$

$$Selling\ price\ of\ standard\ Stirling\ system\ = \frac{Selling\ price\ in\ rand\ (R)}{Annual\ electricity\ output\ (kWh)} \tag{11.7}$$

$$Selling\ price\ of\ standard\ Stirling\ system\ = \frac{R\ 83\ 000,00}{87\ 600\ kWh} \tag{11.8}$$

$$Selling\ price\ of\ standard\ Stirling\ system\ = R\ 0{,}95\ /kWh \tag{11.9}$$

$$Selling\ price\ of\ standard\ Stirling\ system\ with\ a\ storage\ unit = \frac{Selling\ price\ in\ rand\ (R)}{Annual\ electricity\ output(kWh)} \tag{11.10}$$

$$Selling\ price\ of\ standard\ Stirling\ system\ with\ a\ storage\ unit = \frac{R\ 87\ 200,00}{87\ 600\ kWh} \qquad (11.11)$$

This gives a very competitive price of 99c per kWh as seen below.

$$Selling\ price\ of\ standard\ Stirling\ system\ with\ a\ storage\ unit = R\ 1{,}00/kWh \qquad (11.12)$$

Table 11.2: The economic analysis calculations for the of the standard Stirling system over a five year period

Year	0	1	2	3	4	5
Initial investment	R83000,00					
Preventive maintenance (a)		R 0,00	R 100,00	R 103,00	R 106,09	R 109,27
Payback payment (b)		R 9 749,15	R 9 749,15	R 9 749,15	R 9 749,15	R 9 749,15
Total expenses (c) = (a + b)		R 9 749,15	R 9 849,15	R 9 852,15	R 9 855,24	R 9 858,42
Value of energy generated (d)		R 10 178,03	R 10 686,93	R 11 221,27	R 11 782,34	R 12 371,45
Value of net energy savings (e) = (d-c)		R 428,88	R 837,78	R 1 369,12	R 1 927,10	R 2 513,03
Present value interest factor (f)		0,9091	0,8264	0,7513	0,6830	0,6209
Discounted net annual savings (g) = (e×f)		R 389,89	R 692,38	R 1 028,64	R 1 316,23	R 1 560,39

Table 11.3: The economic analysis calculations for the Stirling system with storage over a five year period

Year	0	1	2	3	4	5
Initial investment	R87200,00					
Preventive maintenance (a)		R 0,00	R 100,00	R 103,00	R 106,09	R 109,27
Payback payment (b)		R 10 242,48	R 10 242,48	R 10 242,48	R 10 242,48	R 10 242,48
Total expenses (c) = (a + b)		R 10 242,48	R 10 342,48	R 10 345,48	R 10 348,57	R 10 351,75
Value of energy generated (d)		R 18 007,28	R 18 907,64	R 19 853,02	R 20 845,67	R 21 887,96
Value of net energy savings (e) = (d-c)		R 7 764,80	R 8 565,16	R 9 507,54	R 10 497,10	R 11 536,20
Present value interest factor (f)		0,9091	0,8264	0,7513	0,6830	0,6209
Discounted net annual savings (g) = (e×f)		R 7 058,91	R 7 078,64	R 7 143,16	R 7 169,66	R 7 163,07

11.2 Net present value

Net present value (NPV) is a method used to examine the future discounted cash outflows and cash inflows. NPV is a good approach to evaluate the economical features of projects (Short, Packey & Holt, 2005). The formula for calculating NPV was based on the formula in (Short, Packey & Holt, 2005) :

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{11.13}$$

Where F_n is the net cash-flow in year n, N is the analysis period and d is the discount rate.

Table 11.4: NPV for a standard Stirling system over a five years period

Year	**1**	**2**	**3**	**4**	**5**	**Total for 20 years**
Discounted net annual savings	R 389,89	R 692,38	R 1 028,64	R 1 316,23	R 1 560,39	R 39 743.75

Table 11.4 represents an economical evaluation of the Stirling system for a period of five years. The complete table represents a 20 year period. The NPV for a standard Stirling system was R 39 350,75 given R1,37 per kWh and 8% increase per year in grid costs. A positive NPV means purchasing the Stirling system is economical. The NPV for a Stirling system with storage had a higher NPV of R 129 799,28. The NPV calculations for the Stirling system with and without storage were calculated in a similar way.

11.3 Total life-cycle cost

The total life-cycle cost (TLCC) analysis considers all the costs acquired over the lifetime of a system. It also considers the income generated from the system. Both the costs and incomes generated are discounted to present values. TLCC analysis is recommended for ranking or selecting between systems with similar benefits and returns (Short, Packey & Holt, 2005). TLCC is calculated as follows:

$$TLCC = \sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \qquad (11.14)$$

Where C_n is the cost acquired in period n, N is the analysis period and d is the discount rate.

Table 11.5: TLCC for a standard Stirling system over a five years period

Year	0	1	2	3	4	5	Total after 20 years
Initial investment	R 83 000,00						R 83 000,00
Discounted cost of preventive maintenance	R 0,00	R 10,00	R 10,30	R 10,61	R 10,93	R 0,00	R 10,00
TLCC							R 83251,17

The initial investment capital considered for this research was the manufacturing cost, excluding installation cost. The selling price of the Stirling system was determined by adding a 30 % profit rate to the initial cost. It was assumed that the Stirling system had no battery storage. The total life cycle cost of a Stirling system is a combination of the initial investment capital, operation and maintenance costs and, replacement costs. The TLCC as described by Krishnaiah, Rao and Madhumurthy (2012) appears in Table 11.6.

Table 11.6: The TLCC cost for a Stirling System

TLCC costs	Type of costs
Initial investment capital	Costs of manufacturing: concentrator, receiver, engine, generator, electrical system, land cost, system installation etc. Plus a 28 % profit to the total initial investment capital.
Operation and maintenance	Labour cost, material cost, maintenance , taxes, insurance etc.
Replacement	Cost of battery replacement (not applicable in this case)

Using Table 11.5, the TLCC for the standard Stirling system amounted to R 83 251,17, while it amounted to R 87 468,70 for a Stirling system with a storage unit.

11.4 Internal rate of return

The Internal rate of return (IRR) is the expected rate of return on the project's investment. The IRR is the rate when NPV is equal to zero (Short, Packey & Holt, 2005). The IRR was calculated using 'what-if analysis' in Excel by setting the NPV to zero and calculating the new discount rate, which in this case was the IRR. The IRR for the Stirling system with storage was 15 % and 25 % for a standard Stirling system. Furthermore, an IRR that is greater than the discount rate makes the project attractive to private investors.

11.5 Levelised cost of energy

LCOE is an economic indicator that makes it possible for a comparison of alternative energy systems (Short, Packey & Holt, 2005) . LCOE is simply the cost estimation price per unit of electricity generated over the lifetime of a system. The formula that was used to determine LCOE is well discussed in a manual by Short, Packey and Holt (2005) namely:

$$LCOE = \left(\frac{TLCC}{Q_n}\right) \times UCRF \quad (11.15)$$

Where TLCC is the total life-cycle cost, Q_n is the energy output or output saved in a year, and UCRF is the uniform capital recovery factor.

The $UCRF$ is expressed as:

$$UCRF = \frac{d(1+d)^N}{(1+d)^N - 1} \quad (11.16)$$

$$UCRF = 0{,}117 \quad (11.17)$$

Where d is the discount rate and N is the total number of years/ analysis rate, in this case 20 years. The total annual revenue from the Stirling system is the total amount of electricity produced in a year multiplied by the price of electricity. The total annual revenue actually equal/represents the amount that the combined owners could have paid for grid electricity.

$$LCOE = \left(\frac{R\ 83\ 000}{7118\ kWh}\right) \times 0{,}117 \quad (11.18)$$

The LCOE of the standard Stirling system was 1,37 R/kWh and 0,82 R/kWh for a Stirling system with storage.

11.6 Simple payback period

The simple payback period is defined as the number of years necessary to recover the project cost of an investment under consideration (Short, Packey & Holt, 2005). The simple payback period was calculated as follows by Short, Packey and Holt (2005):

$$Simple\ payback\ period = \sum_n \Delta I_n \leq \sum_n \Delta S_n \qquad (11.19)$$

Where Δ I represents the incremental investment costs, Δ S is the net annual savings of future annual costs (savings in this case).

Table 11.7 The simple payback calculation of a Stirling system with a storage unit

Year	**0**	**1**	**2**	**3**	**4**	**5**
Net energy savings	-R 87 200,00	R 7 764,80	R 8 565,16	R 9 507,54	R 10 497,10	R 11 536,20
Cumulative value of net energy savings	-R 87 200,00	-R 79 435,20	-R 70 870,04	-R 61 362,50	-R 50 865,40	-R 39 329,20
Payback period	7,9					

The payback period of the standard Stirling system was 16 years while the Stirling system with storage was 7,9 years, see Table 11.7. Investors prefer projects with short payback periods of about 10 years or less.

11.7 Sensitivity analysis

A sensitivity analysis was used to show the variation in the cost or benefit measure as the values of input variables, such as the discount rate change (Short, Packey & Holt, 2005) .

11.7.1 Variation of electricity increase rate

The selling price of electricity was analysed under three different electricity increase rates, see Figure 11.1. It was estimated that a 5 % electricity increase rate is currently used. The red (centre) line is the price of grid electricity which is equivalent to the domestic price of electricity from Eskom. The green (top) line is the selling price when buying the Stirling system on a loan basis as the one proposed in Table 11.1. The grid electricity and residential dish electricity generated was found to be more sensitive to electricity increase rates. The residential dish has a LCOE of 1,37 R/kWh, see section 11.5. The blue (bottom) line is the price of electricity of Stirling system that is purchased once-off and is unaffected by the electricity increase rate.

$$Annual\ energy\ output\ = 3\ kW \times 6.5\ hours/day\ \times 365\frac{days}{year} \times 20\ years \qquad (11.20)$$

$$LCOE = \frac{Selling\ price\ of\ standard\ Stirling\ system\ +total\ maintencence\ cost\ for\ 20\ years}{Annual\ energy\ output\ for\ 20\ years} \qquad (11.21)$$

$$LCOE = \frac{R\ 85\ 511{,}69}{142350\ kWh} \qquad (11.22)$$

$$LCOE = 0{,}60\ R/kWh \qquad (11.23)$$

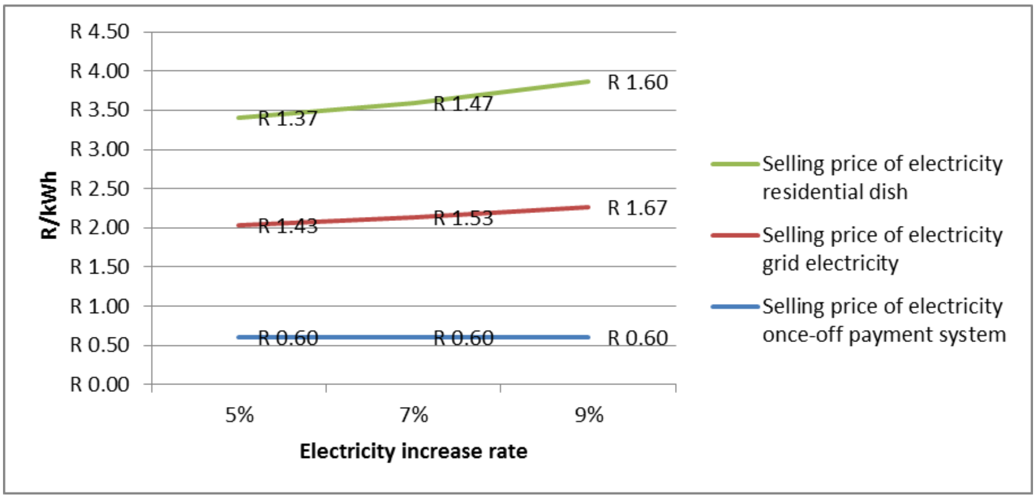


Figure 11.1: Sensitivity analysis of the selling price of electricity

11.7.2 Variation of levelised cost of energy with capital cost

The sensitivity of the LCOE was investigated with the number of years in Figure 11.2. The capital costs of the Stirling system has declined over a number of years in the past. The capital costs will continue to decrease once the Stirling system gets commercialised or is mass produced by the year 2024. In 2014 the LCOE was at 1,37 R/kWh based on the calculations in section 11.5, then the LCOE started decreasing between 5 % and 10 %.

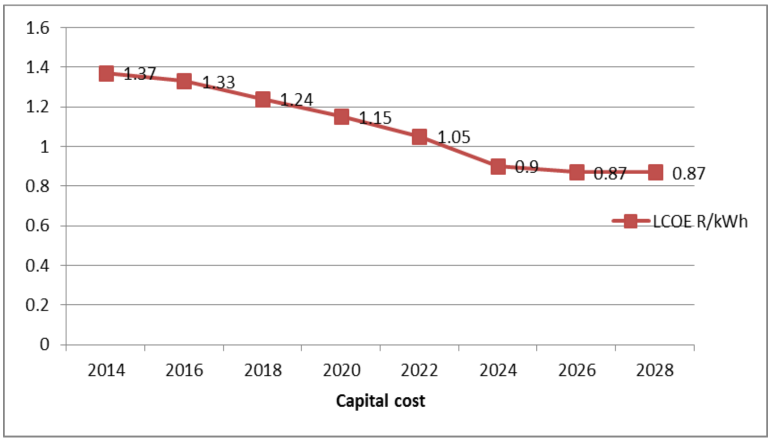


Figure 11.2: Sensitivity of levelised cost of energy with capital cost variation

11.7.3 Variation of levelised cost of energy with change from average sunlight hours

Figure 11.3 shows how the LCOE changes as the solar radiation varies from its normal average of six hours per day. The line between 1 and 3 hours is steeper, resulting in a higher LCOE. Less change is seen on the line between nine and 12 hours, indeed the LCOE is clearly approaching a limit. Therefore LCOE is more sensitive in the region of a daily average of less than 6 hours. The direct normal irradiance varies across Africa and the number of hours of sunlight will differ depending on the region.

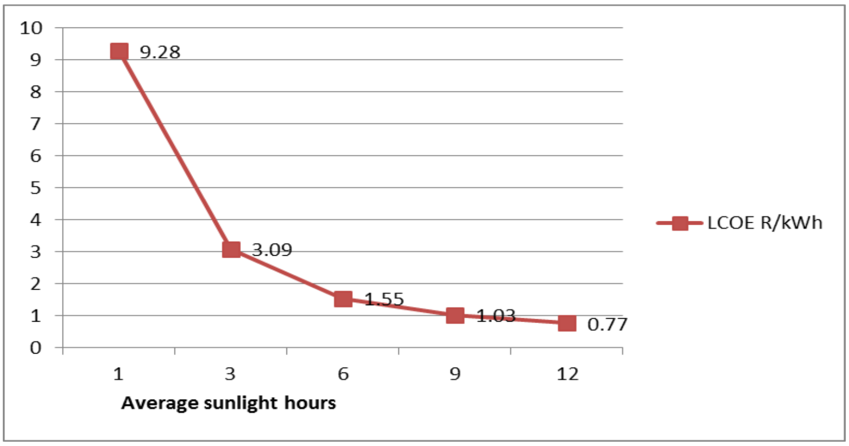


Figure 11.3: Sensitivity of LCOE to average sunlight hours per day

11.8 Chapter summary

The selling price of the Stirling system with a storage unit was merely an estimate; the price could actually be higher than the value in section 11.1, Table 11.1. The proposed price for the Stirling system is high, but if the community members are allowed to pay the purchase price in instalments or a number of households shared a system, then then a greater number of people would be prepared to make the purchase. The LCOE was found to be sensitive to the number of sunlight hours per day. The payback period for the standard Stirling system is 8 years longer than for the system that incorporates storage; investors prefer payback periods of 10 years or less. Various economic evaluations done in this chapter demonstrate that the Stirling system is an attractive technology and is worth owning where grid electricity is not available.

CHAPTER 12

ENVIRONMENTAL LIFE CYCLE ASSESSMENT

12.1 Introduction

Environmental friendliness lends significant competitive advantage to new renewable technology over the competing conventional technologies. Other factors favouring these new technologies are: the new environmental laws and increasing environmental threats such as global warming, climate change, water scarceness and carbon dioxide emissions. This section focuses on the understanding of the life cycle of the Stirling system. This cycle runs from the manufacturing process up to product disposal. Furthermore, an analysis of the effect that the Stirling system has on the environment is explained. It will be difficult to classify the Stirling system as green technology or clean technology based on its operations, without considering all the processes in its life cycle.

The environmental life cycle assessment (LCA) study is usually performed to provide an analysis of the environmental damage caused by products and services during their whole life cycle. The LCA consists of four phases (Carvalho *et al.*, 2011) namely:

1. Goal and scope definition;
2. Life cycle inventory (LCI);
3. Life cycle impact assessment (LCIA); and
4. Interpretation of results.

12.2 Goal and scope definition

Goal and scope refers to the purpose of the LCA study (Baumann & Tillman, 2009). Since no study was found that conducted an LCA for a 3kW Stirling system, the data were obtained from a study done by Cavallaro and Ciraolo (2006). The same study looked at the environmental evaluation of a stand-alone 10 kW Stirling system that was compared with a photovoltaic panel of the same size. It was assumed that both electricity facilities had a lifetime of 30 years. However, it should be noted that the data are likely to differ and be incomparable with some of the findings of the present study. The reasons for this are the following: a 3kW Stirling System and engine is smaller in size, the system is made-up of fewer materials in lesser quantities, and it is likely that different materials and processes might have been used for the two types of Stirling systems. This environmental evaluation thus only considered the construction, assembly and disposal phase.

12.2.1 Construction, assembly, and disposal phase

Figure 12.1 illustrates the different materials and processes utilized in manufacturing the 10 kW Stirling system. However, it should be noted that, the study done by Cavallaro and Ciraolo (2006) was limited owing to the fact that data regarding operation and maintenance of the Stirling System were regarded as classified information and therefore were unavailable to the public.

	Materials (s)	**Quantity (kg)**	**Process (es)**
Concrete settlement	Concrete	150,000	
Metallic structure	Steel	3700	Cold workking
Dish receiver	Glass fiber	113,4	
Engine			
Sub-components			
Heat exchanger	Nickel alloy	12	Cold working
			Casting
			Electric welding
			Brazing
Cylinder/piston	Steel	200	Cold working
			Forging
			Machining
Connecting rods	Steel	100	Cold working
Electric generator	Steel copper	5050	Cold working
			Casting
Regenerator	Steel	30	Cold working
Ceramic cavity	Ceramics	15	

(Carvalho et al., 2011)

Figure 12.1 The materials and process used in manufacturing the 10 kW Stirling system

Table 12.1 provides similar information for a 3 kW Stirling system as Figure 12.1. It summarises the main materials and the type of production processes that were used to produce them. The main components of the Stirling system were identified as the engine, parabolic dish and the metallic structures. At this point no concrete had been used on the prototype.

Table 12.1: The materials and process used in manufacturing the 3 kW Stirling system

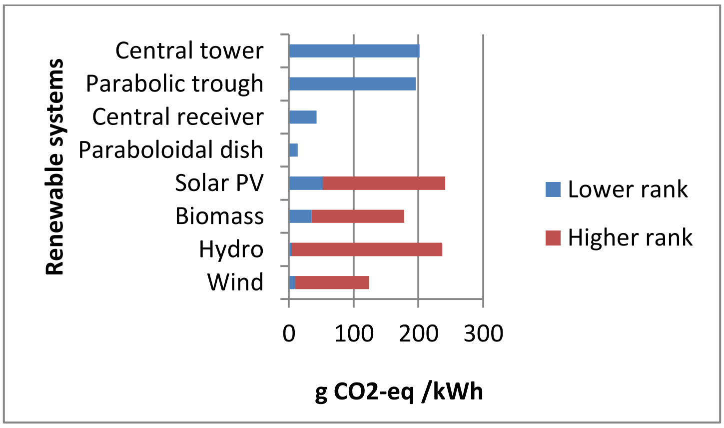
Components	**Materials**	**Weight**	**Process**
	Concentrator and support		
80 small mirrors	Aluminium	10-50 kg	Bolted
Stirling support (stand)	Mild steel	200-300 kg	Welding
Receiver	Fibre glass	50-150 kg	Assembly
Concrete settlement (not available for prototype)	Concrete	50-100 kg	
Approximate weight		400 kg	
	Stirling engine		
Saddle assembly	Mild steel	5,631 kg	Welded
Flexure assembly	Spring steel	0,237 kg	Laser cut
Alternator assembly	Copper wire	0,669 kg	Wound
Cylinder assembly	Cast iron	0,774 kg	Turning, grinding, drilling, tapping
Piston assembly	N35 magnet	0,669 kg	Glued on
Other assemblies	Stainless steel	4,326 kg	Machining
Determined weight		12,306 kg	

Some of the materials are re-usable and recyclable at the end of the lifespan of the Stirling systems. Steel, cast iron and copper for example are 100 % recyclable.

12.3 Interpretation of results

The chapter summary ends with the last stage of the LCA, which entails the interpretation of the results. The raw data under the interpretation of the result were refined into one useful result such as a bar diagram (Baumann & Tillman, 2009) .

In renewable technologies, the emissions are mainly generated during the construction and installation phase. However during the operating phase the emissions are negligible. Figure 12.2 illustrates the comparative of CO_2 emissions of renewable technologies in gram. The gaseous emissions from the Stirling system are lower than those of most other renewable systems. The only renewable energy systems that can compete with the Stirling system (paraboloidal dish) are the wind and hydro systems at lower rank. The small facility size is one reason why some renewable technologies in Figure 12.2 have low emissions. The total life cycle emission from the Stirling system for 1 MW plant was 13,6 gram $CO_{2\text{-}eq}$/ kWh, which is significantly lower than that of other solar thermal technologies (Bravo *et al.*, 2012).



(Varun et al., 2009)
Figure 12.2 Comparison of carbon emissions from renewable systems

12.4 Chapter summary

In the light of the different analyses discussed earlier, it may be feasible for the designers of the Stirling systems to alter the manufacturing process and raw materials to achieve a 'greener technology'. The Stirling system has a similar environmental impact as a PV panel, but it requires less land to operate on. Cavallaro and Ciraolo (2006) recommended that hybridising the Stirling system with other renewable sources and creating an option for thermal storage will greatly decrease the negative impact on the environment. One of the benefits of carrying out the LCA was identifying the environmental impact of the Stirling system and consequently finding room for improvement in the development of future Stirling systems.

CHAPTER 13

SWOT ANALYSIS OF THE STIRLING SYSTEM IN AFRICA

13.1 Introduction

The purpose of this chapter is to develop a SWOT analysis to identify the strengths and weaknesses of the research project, and the opportunities and threats involved if African investors plan to embark on manufacturing the Stirling system. Such a SWOT analysis helps to identify the strengths and weakness associated with internal factors, while pinpointing the opportunities and threats in external environment. Strengths are factors that the business can mobilise to boost success. Weaknesses are factors within the business that may hold back successes. Opportunities are available factors which the business can use to achieve success. Threats are external factors that exist that hinder the business from succeeding. After identifying the SWOT factors various approaches may be adopted to build on the strengths, eliminate the weaknesses, exploit the opportunities and counter the threats (Dyson, 2004) .

For the purpose of this study, three SWOT analysis matrices (see Table 13.1, Table 13.2 and Table 13.3) were developed partly with data adopted from previous developed SWOT analyses based on concentrated solar power technologies. The first SWOT analysis matrix (see Table 13.1) focused on determining the strengths and opportunities that exist in South Africa in addition considering the weaknesses and threats. The second SWOT analysis matrix (see Table 13.2) focused on the implementation of the production of the product in Africa. The third SWOT analysis matrix (see Table 13.3) focused on determining whether it is economical for businesses to survive in Africa. Thus, only information that seemed to fit within the Stirling system was used and incorporated into the two different SWOT analyses. The data were selected from South Africa and MENA (Middle East and North Africa), Algeria, Egypt, Morocco and Tunisia. From three developed SWOT analysis it can be concluded that the manufacturing and selling the Stirling system is a viable option because the right manufacturers and suppliers exist and some components such as electronics parts are produced by companies without concentrated solar power knowledge.

Table 13.1: SWOT analysis for the production of a 3 kW Stirling system South Africa

STRENGTHS	**WEAKNESSES**
1. Direct normal irradiance in South Africa, especially in the Northern Cape. 2. There are various active concentrated solar power enthusiasts in the local concentrated solar power market. 3. There are a number of well-established steel. In fact, South Africa has some of the largest steelwork and electric cable manufacturers in Africa. 4. High-quality research on CSPs is presently being conducted at various universities in South Africa. 5. Stellenbosch University has a good reputation of with R&D in CSPs (Stirling system included). 6. High electricity demand in South Africa is leading to investments in the energy sector.	1. High costs of raw materials (e.g. steel) compared with European or Asian markets. 2. Lack of qualified skilled labour and a lack of training schemes. 3. High dependence on international technologies and expertise.
OPPORTUNITIES	**THREATS**
1. Export potential exists by road and sea in sub-Saharan countries. There are well established routes such as Trans-African Highway and Trans- Kalahari Corridor. 2. Concentrated solar power is a new technology – a big opportunity for first movers. 3. South Africa’s electricity is coal based. 4. Cheaper products through the use of mass production. 5. Larger market demand has led to a large number of “external investors, developers and manufacturers ”	1. Future cost reduction in PV panels and other competing renewable technologies 2. Competition with cheaper suppliers from other countries. 3. Suppliers failing to deliver on time and in the right quantity. 4. Lack of direct financing for the development Stirling system technologies.

(Ernst & Young et al., 2013);(Kulichenko & Wirth, 2012)

Table 13.2 SWOT analysis for the production of a 3 kW Stirling system in Africa

STRENGTHS	WEAKNESSES
1. Africa has various areas with high direct normal irradiance. 2. Africa has a large workforce, and labour costs are cheap. 3. There is a possibility of thermal storage using phase change materials. 4. The Stirling system is a green technology therefore it has minimal impact on the environment.	1. High costs of raw materials (e.g. steel) compared to European or Asian markets. 2. A high dependence on international technologies and expertise. 3. Uncertainty about the funding of solar energy projects. 4. No established roadmap for a solar plan for Africa. 5. Lack of incentives for Stirling system developments. 6. Insufficient infrastructure in some parts of Africa.
OPPORTUNITIES	**THREATS**
1. A huge potential market, a high number of people without access to electricity in rural areas. 2. CSP is a new technology – a big opportunity for "first movers". 3. The prices of electricity and fossil fuels keep increasing. 4. New better laws and policies supporting CPSs. 5. Create green jobs across the value chain. 6. High tech electric and electronic industries could start manufacturing CSP components. 7. Financing opportunities from oil and gas industries.	1. Competition from other off-grid technologies such as PV and diesel generators. 2. Future cost reduction in PV and other competing renewable technologies. 3. Suppliers failing to deliver on time and in correct quantity. Similar risks lie with the independent installation contractors. 4. Lack of financing for Stirling system utilization. 5. Grid extensions to rural areas. 6. Sudden change in prices of materials.

(Ernst & Young et al., 2013); (World Bank, 2011b); (ElShazly. 2011)

Table 13.3: SWOT analysis for the business opportunity of a 3 kW Stirling system in Africa

STRENGTHS	**WEAKNESSES**
1. There are a number of well-established steel manufacturers. For example in some countries such as South Africa has some of the largest steelwork and electric cable manufacturer in Africa. 2. Highly staffed companies with qualified product engineers available for the design, development of product. 3. Qualified welders and semi-skilled workers for the production stage are available. 4. Cheap products can be produced through economy of scale. 5. Products can be manufactured locally.	1. High costs of raw materials (e.g. steel) compared to European or Asian markets. 2. Income in the rural areas. 3. High dependence of rural households on traditional and conventional fuels. 4. Risky dependency on sub-contracting and outsourcing. 5. Uncertainty regarding the funding of solar energy projects.
OPPORTUNITIES	**THREATS**
1. There is a large potential market. 2. Export potential both on road and through the sea in sub-Saharan countries. There are well established routes such as Trans-African Highway and Trans- Kalahari Corridor. 3. CSP is a new technology – thus a big opportunity exists for first movers. 4. The prices of electricity and fossil fuels keep increasing. 5. Green jobs across the value chain can be created. 6. There are a high number of people without access to electricity in rural areas.	1. Competitors that produce Stirling systems such as Infinia. 2. Future cost reduction in PV panels and other competing renewable technologies. 3. Competition with cheaper suppliers from other countries. 4. The threat of future grid extensions to rural areas the use of the Stirling system.

(Ernst & Young et al., 2013); (World Bank , 2011b) ; (ElShazly. 2011)

13.2 Chapter summary

South Africa and the MENA countries are suitable places to start off with the manufacturing of the Stirling system. These countries have the appropriate resources and expertise. They are presently running other CPS facilities and invest considerable funds and R & D. Africa is a suitable place to introduce the Stirling system and to manufacture the Stirling system.

CHAPTER 14

FINANCIAL ANALYSIS

14.1 Introduction

The whole business of manufacturing and selling the Stirling system was evaluated to determine whether it is viable and worth investing in. The economic evaluation covered a 10 year period. This was done by determining the NPV and IRR of the expected cash-flow of the business.

14.2 Cash-flow statement

It is envisioned that after the first year the price of the Stirling system would drop which is a typical pattern among off-grid electricity technologies. The cash-flow is based on the sales of the product. The 'What-if analysis' tool in Excel was used to simulate the likely outcomes, see Appendix B. The definitions for calculating cash-flow were descripted below:

14.2.1 Unit sales

The sales income and direct expenses were based on the data provided by the mechanical engineering students who paid for materials and services. From available data, it was forecast that for the first two years the business will sell fewer units than the targeted number of 1000 units. It was also calculated that the business would start to make a profit from the third year. It is possible that the sale of the products would first increase and then drop after competitors enter the market. However, the company would have the advantage of early entry benefits.

14.2.2 Selling price

The selling price of the Stirling system was based on the price determined in this study. The selling price was calculated in Chapters 9, 10 and 11 and depicted in Tables 9.1 to 9.4.

14.2.3 Total revenue

$$Total\ revenue = unit\ sales\ \times selling\ price \tag{14.1}$$

14.2.4 Direct costs

For the first few years, money will be allocated to R & D to enhance product development. The raw materials and manufacturing costs were based on the data provided by mechanical engineering students (designers), see Tables 9.1 to 9.4. The direct costs were calculated to be lower when the volumes of the products were between about 300 and 500.

14.2.5 Indirect costs

The indirect costs are the costs that are not directly part of manufacturing. Total expenses are the sum of the direct and indirect costs.

14.2.6 Net income after tax

$$Net\ taxable\ income = total\ income - total\ expense \tag{14.2}$$

$$Income\ tax = 29\ \%\ \times net\ taxable\ income \tag{14.3}$$

$$Net\ income\ after\ tax = net\ taxable\ income\ - income\ tax \tag{14.4}$$

14.3 Break-even analysis

Break-even analysis is the determination of a break-even point at which revenue is equal to cost. In a manufacturing environment if break-even is not attained, the production is unprofitable. Also, if the time to reach break-even increases, the risk for the business increases. It is important to evaluate risk by determining the minimum selling price, units sold and fixed costs that are required for the business to be profitable. The parameters in Table 14.1 were used to calculate the break-even points. The 'What-If' analysis function called 'goal seek' was used to investigate the break-even analysis when the profit was set to zero in each scenario. The purpose of this break-even analysis was to investigate the effect of the various parameters on the profit. This type of business is not yet commercialised nor marketed. It is therefore essential to determine various profit scenarios in order to determine the type of funding to be sought for the business. Unlike government and non-government organisations, private funders will demand profitable scenarios. Five scenarios were considered:

Scenario 1: This scenario was the base case, where original data was provided by the mechanical engineering students and used to calculate the other scenarios.

Scenario 2: This scenario describes the minimum sales price that the business should charge for producing a Stirling system, assuming the rest of the variables are similar to those in Scenario 1. The 'What-If' analysis function was used again to investigate the break-even analysis using scenario 1 by setting the profit to zero and varying the selling price.

Scenario 3: This scenario describes the minimum volume of units that the business can sell and still make a profit, assuming the rest of the variables are similar to those in Scenario 1. The 'What-If' analysis function called goal seek was used to investigate the break-even analysis using scenario 1 by setting the profit to zero and varying the number of units sold.

The parameters on Table 14.1 were determined in the following way:

The variable costs:

$$Variable\ costs = total\ \ cost\ of\ manufacturing\ dish\ (\,Table\ 9.4) \times 1000\ (units\ sold) \tag{14.5}$$

$$Variable\ costs = (R\ 63\ 799{,}90 \times 1000\ ) \tag{14.6}$$

The fixed costs:

$$Fixed\ costs = 10\ \%\text{of}\ \ variable\ cost\ at\ capacity \tag{14.7}$$

$$Fixed\ costs = (10\%\ \text{of}\ R\ 63\ 799{,}90) \tag{14.8}$$

Cost per unit:

$$Cost\ per\ unit = total\ \ cost\ of\ manufacturing\ dish\ (\,Table\ 9.4) \tag{14.9}$$

Table 14.1: Profit calculation in various scenarios

Scenario	Scenario 1 base data	Scenario 2 minimum selling price required	Scenario 3 minimum volume of unit sale required
Selling price	R 83 000	**R 70 180**	R 83 000
Units sold	1000	1000	**332**
Revenue	R 83 000 000	R 70 179 893	R 27 580 027
Cost per unit	R 63 800	R 63 800	R 63 800
Variable costs	R 63 799 903	R 63 799 903	R 21 200 037
Fixed costs	R 6 379 990	R 6 379 990	R 6 379 990
Profit	R 12 820 107	R 0	R 0

The results of the scenarios in Table 14.1 are explained below:

Scenario 1: The business is selling the product at a high price and selling a large number of units. Therefore, it is suitable for a manufacturing business that is strictly looking at making profit.

Scenario 2: The numbers in bold indicate the new selling price. Since it is not the aim of the business to make a profit it therefore sells a high number of products at a low price. The business is thus a manufacturing concern that is funded either by a non-governmental organization or government.

Scenario 3: The numbers in bold indicate the new volume of units sold. The business will start making a loss when the number of units sold diminishes to fewer than 332.

14.4 Sensitivity analysis for unit sales and fixed costs

The sensitivity of the profit to unit sales and fixed costs was investigated in three possible scenarios. The range of the scenarios was ± 50 % to the base scenario, see Table 14.2:

Table 14.2 The three scenario for the unit sales and fixed costs

Scenario	Unit sales	Fixed costs
Worst case	**500**	R 3 189 995
Base case	**1000**	R 6 379 990
Best case	**1500**	R 9 569 985

Table 9.2 was used to construct Figure 14.1 and Figure 14.2. During low unit sales in the worst case scenario, the company still makes some profit. While during the high unit sales in the best case, the company makes a massive profit. Therefore, profit is very sensitive to unit

sales. The company makes profit during the worst and best case scenario of the fixed costs, though the maximum profit is not as high as for changes in units sold. Therefore the fixed costs have a less pronounced effect on profit.

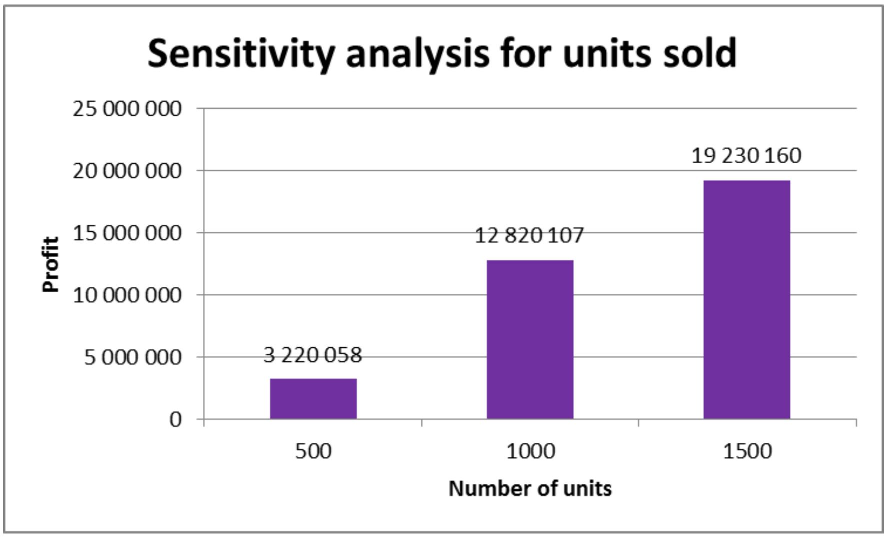


Figure 14.1 Sensitivity analysis for unit sales

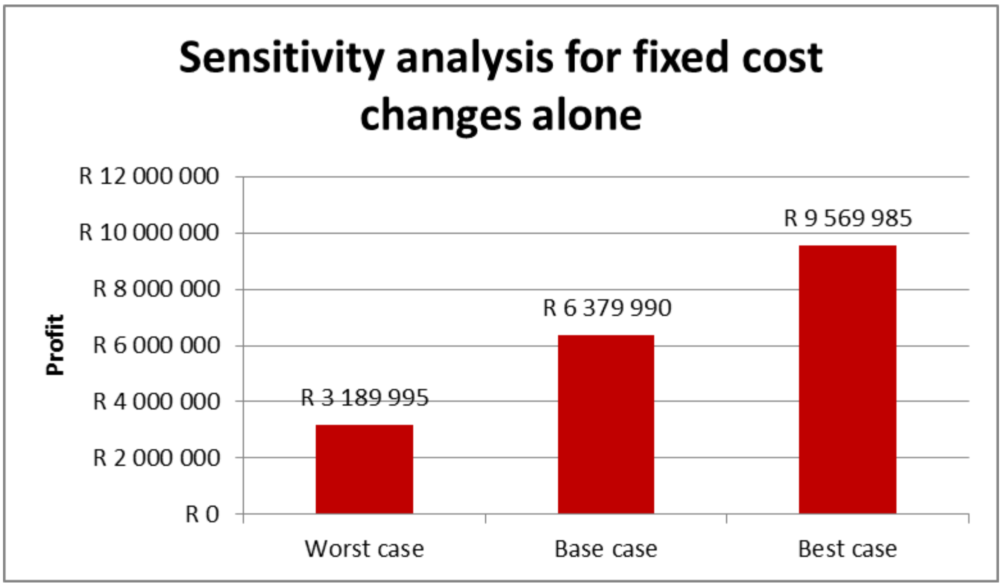


Figure 14.2 Sensitivity analysis for fixed costs

14.5 Sensitivity analysis for total costs

Total costs are the sum of fixed costs and total variable costs. Fixed cost remains constant over a range of 1 to 1000 units output and then rises to a new level. As the produced quantities rises the number of workers increases and thus their salaries. The fixed costs are independent of the output produced; thus they are paid even when there is no production. The production facility also expands and therefore the costs for rent could increase at set volumes. The variable costs are depended on the output produced and thus increase proportionally.

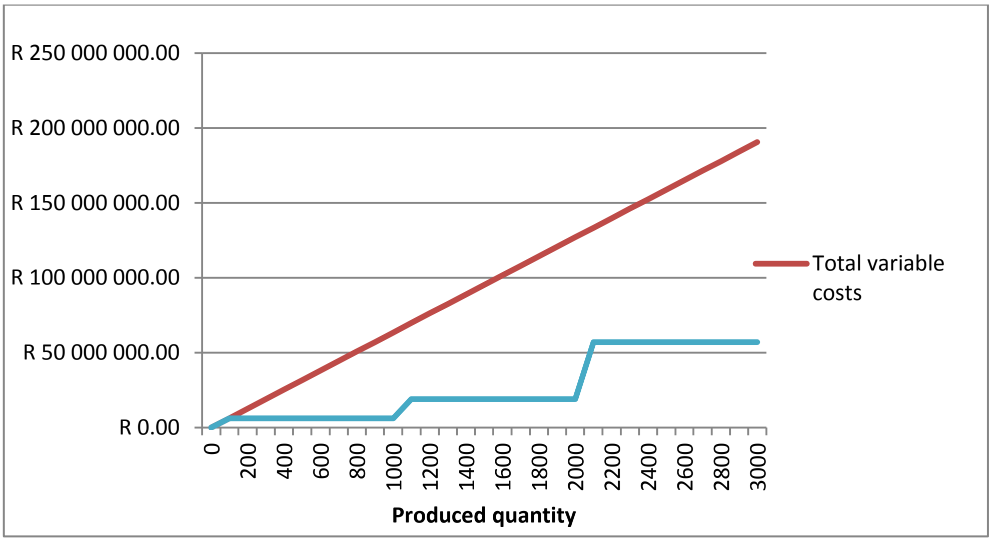


Figure 14.3 Produced quantities and costs

14.6 Chapter summary

Given the design and manufacturing constraints resulting from the design process, the business of manufacturing the Stirling system requires high capital input to start-up. The investor should have enough money to sustain the business for the first three years. This type of business is highly dependent on the volume of units sold, expences and the selling price. A large portion of money should also be allocated to marketing activities that are also essential for this type of business to survive.

CHAPTER 15

RISK ANALYSIS

15.1 Introduction

Risk is an uncertain event that if it occurs has a negative effect on the project objectives such as scope, schedule, cost or quality. According to the ISO 31000:2009, risk analysis is a critical exercise for any project regardless of its size to manage risk. A risk analysis should be implemented at the planning phase of the business development. Therefore this chapter aims to identify risks associated with the development and implementation of a Stirling system manufacturing business in Africa. It is a good practice for an investor to be aware of the risks linked in the project to prior to an investment decision.

The following risk analysis process was considered:

1. Risk identification
2. Risk analysis and evaluation
3. Risk response and treatment
4. Risk monitoring and risk review

15.2 Risk identification

"The risk cannot be managed unless it is first identified" (Wales & Alliance, 2005). Eight objectives were identified to assist the business growth. The risks were brainstormed and sub-categorised within those eight identified objectives:

1. **Profitability**

   The main aim of the business is to generate profit. It is also important that the company continues to make profit. The revenues of the company should always exceed the expenses.

2. Productivity

The success of this business relies on production. Therefore, relevant resources should be available for production.

3. Customer service

A customer is the most important stakeholder for any business. Hence, the customer should be satisfied with the product at all times by selling quality products at affordable prices and providing customer support services. The revenue of the business is generated from sales.

4. Employee retention

The best employee a business possesses is its existing employees. When employees are valued and respected they become productive and reliable. Hiring new employees requires training and time for them to adjust.

5. Core values

The core values of the business are stipulated in the vision, mission and values of the business.

6. Growth

The business aims to grow and get manufacturing factories across Africa hence be closer to its customers.

7. Marketing

This is a critical activity for the business to grow and generate sales. It is also should be a continuous process and ensure that the prospective customers in remote areas are reached.

8. Competitive analysis

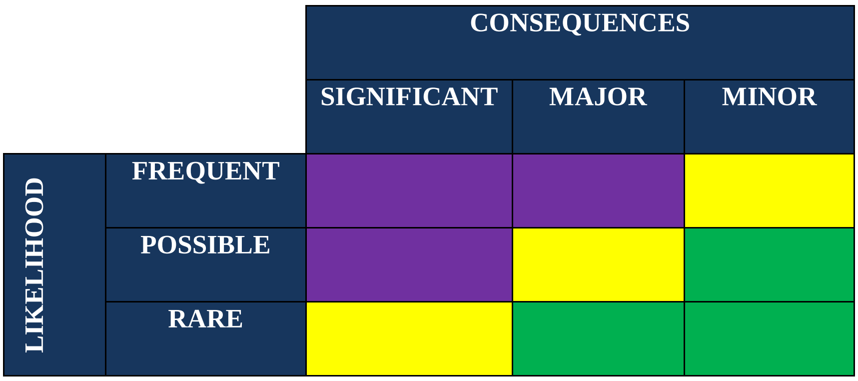
Competitive benchmarking should be investigated to understand where the product stands in the market.

15.3 Risk analysis and evaluation

The identified risks were given reference codes. Each risk was linked to the eight objectives. “The risk analysis step will assist in determining which risks have a greater consequence or impact than others” (Wales & Alliance, 2005). The risk analysis step involves combining the possible consequences of an event, with the likelihood of that event occurring (Wales & Alliance, 2005) . Hence, risk is quantified as follow:

$$Risk = consequence \times likelihood \quad (15.1)$$

The likelihood and consequence were classified according to the risk analysis matrix, refer to Figure 15.1. Figure 15.2 depicts the level of risk.



(Wales & Alliance, 2005)

Figure 15.1 Risk analysis matrix for determining level of risk

RISK RATING
High
Medium
Low

Figure 15.2 Colour coded risk rating

The risk evaluation includes the list of identified risks that requires further action. The level of each risk was determined. A total of 27 risks were identified and nine were categorised as high level risks. Refer to Appendix V for the risk profile.

15.4 Risk response and treatment

Risk treatment involves identifying ways to treat or control risks that were not considered acceptable or tolerable. This is done to reduce or prevent a negative consequence (Wales & Alliance, 2005). Mitigation strategies for high level risks were compiled as depicted in Appendix W.

The four responses to negative situations:

1. Avoid
2. Mitigate
3. Transfer
4. Accept

15.5 Risk monitoring and risk review

Risk should be continuously monitored and the effectiveness of the risk treatment plan reviewed in order to manage risk effectively. Not all risks would remain static, therefore the risk management process should be regularly re-visited so that new risks are identified and managed.

15.6 Chapter summary

The purpose of this chapter was to identify and implement ways to reduce risk. Appendix W summarises the detail of these strategies. Similarly, this chapter addresses possible obstacles that could hinder the success of the business. The risk analysis should not only be practiced at the initial phase of the project but should be continually implemented and updated and should only be terminated at the end of the business. Finally, the presence of a risk management plan alerts investors to issues they need to consider, but also attracts investors since it indicates realism and due diligence.

CHAPTER 16

CONCLUSIONS AND RECOMMENDATIONS

16.1 Introduction

The aim of this section is to provide a concluding summary of the research study. This section will focus on how the research objectives were, conclusions, limitations, the new information the study is contributing to the body of knowledge and recommendations for future studies.

16.2 Meeting the research objectives

This study had two objectives:

(1) Determine if there is a viable market in Africa for the Stirling system

One conclusion from the study, both from literature and from the survey, revealed that Africa has a high number of potential buyers of the Stirling system. The market size was explained in detail in Chapter 4. Since most of the potential buyers survive on a low income the market size could be increased by decreasing the selling price of the Stirling system.

(2) Africa Economic viability of manufacturing the Stirling system in Africa

Another conclusion is that according to Chapter 9 and Chapter 14, manufacturing of this product is possible in Africa. Additionally, Africa has the technical knowledge and experts to manufacture the Stirling system. Furthermore, Africa has the relevant suppliers, cheap labour, infrastructure and advanced research in the CSP field is in progress. Africa has suitable locations where manufacturers could be located.

A range of multidisciplinary fundamental engineering principles were applied in this project. These specific skills and techniques include using designing a simplified House of Quality, developing an Osterwalder’s Business Generation Canvas, conducting a market survey, analysing data, in-depth research on relevant topics, conducting an economic analysis of a 3 kW residential Stirling system doing a risk assessment, doing a financial analysis and applying managerial skills and so forth.

16.3 Contribution to the body of knowledge the in Real World

This study has strived to contribute new knowledge regarding the business potential of manufacturing a Stirling system in Africa. It has dealt particularly with the knowledge of potential customers in Africa through the analysis of a mini-survey conducted in a rural community. Literature on such information is limited. A manufacturing plan for an African context was comprehensively described in this study. This study also provides a summary of the market potential of the Stirling system in Africa.

16.4 Limitation

One of the limitations of the survey was the difficulty of explaining an unknown technology to survey respondents during the interviews. It was difficult because the researcher could not physically demonstrate how the Stirling system works. However, the illustration of the Stirling system that appeared at the front of each questionnaire managed to give an overview of the product. The results of the survey were limited to those communities where the survey was conducted. The situation could be similar or different in other villages in Africa.

16.5 Recommendations

The selling price for the Stirling system was found to be too high, as compared to its competitor, the PV panel system. The selling price of a 0,3 kW solar panel is about R3 000; this makes it more than thirty times cheaper than the Stirling system. For future research, it is recommended that ways be investigated to decrease the manufacturing costs of the Stirling system and hence to decrease its selling price.

16.6 Concluding remarks

Even though the photovoltaic solar panels are affordable for rural communities they are easily prone to theft. In some instances the owners of PV panels claims that the money they spent on guarding the PV panels exceeds the costs of purchasing them. A high number of the

PV panels that are distributed in rural areas are unable to generate enough energy for cooking due to their small sizes. Further, the primary need for energy in rural areas is for cooking. However, the Stirling system is able to generate energy adequate for cooking. Additionally, the Stirling system is good option for the diversification of energy supply which will create a bigger opportunity of uninterrupted energy in rural areas.

It is the responsibility of each country to provide its citizens with electricity. Therefore, if the people in off-grid communities are unable to afford the Stirling system, their governments or non-governmental organisation can purchase the Stirling systems from business manufacturers. The governments or non-governmental organisation can then sell electricity generated from the Stirling system plant to the communities. This will be is a cheaper option for community members to acquire electricity. Ideally, as mentioned before it will be more affordable for ten households to combine funds to purchase and share 3 kW Stirling system. This idea will remain a challenge for communities with dispersed households. South Africa has introduced such a programme, called the Non-grid Electrification Programme, whereby the Department of Energy buys the PV panels on behalf of the households through a service provider. In return the households are charged an affordable monthly fee for access to electricity.

The market survey has indicated selling the Stirling system to majority of homeowners in rural areas is not feasible because a high number survive on a low income. However, the Stirling system is a good investment for other target markets such as farmers. From a business perspective, if sales are more than about 332 units per year, it is worthwhile investing in a business that manufactures Stirling systems. A business model for this business was compiled, which could be presented to the sponsors or investors. The risk analysis provides potential investors in the business with important aspects to consider. From a business perspective and taking into account all the aspects explained in the report, developing a Stirling system manufacturing business could be financially feasible, and would allow rural or off-grid households to be more energy secure.

CHAPTER 17

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Appendix A: Africa's electricity access

Africa's Electricity Access in 2010 (IEA, 2013a)

Region	Population without electricity millions	Electrification level %	Urban electrification level %	Rural electrification level %
Sub-Saharan Africa	589	31,8	64,2	12,9
Angola	11	40	63	8
Benin	7	28	57	7
Botswana	1,1	45	68	10
Burkina Faso	13	15	28	10
Cameroon	10	49	73	14
Congo, Rep	2,4	37	54	10
Cote d'Ivoire	9	59	85	32
DR of Congo	58	15	37	4
Eritrea	4	32	86	17
Ethiopia	65	23	85	11
Gabon	0,6	60	64	34
Ghana	10	61	85	35
Kenya	34	18	65	5
Lesotho	1,7	17	43	7
Madagascar	17	17	40	8
Malawi	13	9	35	2
Mauritius	0,01	99	100	99
Mozambique	20	15	36	2
Namibia	1,2	44	78	23
Nigeria	79	50	78	23
Senegal	6	54	83	32
South Africa	12	76	88	56
Sudan	28	36	48	28
Tanzania	38	15	46	4
Togo	5	28	54	8
Uganda	29	9	46	3
Zambia	11	19	48	2
Zimbabwe	8	37	79	11
Other Africa	96	13	35	4
North Africa	1	99,4	100	98,7
Algeria	0,2	99,3	100	98
Egypt	0,3	99,6	100	99
Libya	0,0	99,8	100	99
Morocco	0,4	98,9	100	97
Tunisia	0,1	99,5	100	99
Africa	590	42,9	72,1	23,6

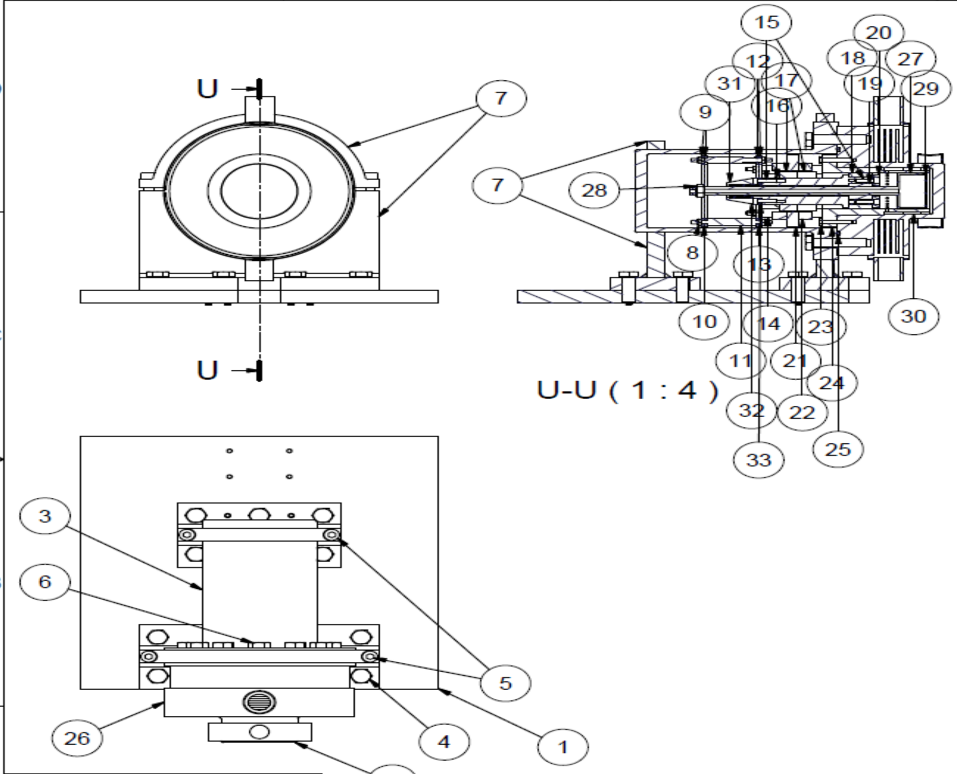
Appendix B: Forecast cash-flow for the business

Years	1	2	3	4	5
Cash flow statement					
Unit sales	300	500	1000	1000	1000
Selling price per unit	R 83 000	R 85 000	R 88 000	R 91 000	R 94 000
Sales revenue	R 24 900 000	R 42 500 000	R 88 000 000	R 91 000 000	R 94 000 000
Total income	R 24 900 000	R 42 500 000	R 88 000 000	R 91 000 000	R 94 000 000
Direct costs					
Research and Development	R 100 000	R 150 000	R 100 000	R 50 000	R 50 000
Raw Materials costs	R 25 000 000	R 32 000 000	R 63 766 470	R 63 766 470	R 63 766 470
Manufacturing costs	R 3 000 000	R 4 000 000	R 6 306 390	R 6 306 390	R 6 306 390
Total Direct costs	R 28 100 000	R 36 150 000	R 70 172 860	R 70 122 860	R 70 122 860
Indirect costs					
Marketing and Promotions	R 100 000	R 50 000	R 30 000	R 30 000	R 15 000
Reworks on faulty items	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000
Logistics	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000
Total Indirect costs	R 200 000	R 150 000	R 130 000	R 130 000	R 115 000
Total expenses	R 28 300 000	R 36 300 000	R 70 302 860	R 70 252 860	R 70 237 860
Net taxable income	R -3 400 000	R 2 800 000	R 17 697 140	R 20 747 140	R 23 762 140
Income Tax (29 %)	R 0	R 812 000	R 5 132 171	R 6 016 671	R 6 891 021
Net income after tax	R -3 400 000	R 1 988 000	R 12 564 969	R 14 730 469	R 16 871 119

Appendix C: Total office space

	Stations	W	L	Area in m^2
GENERAL SERVICES				
Bathrooms		2	5	10
Kitchen		5	5	25
PRODUCTION SERVICES				
Equipment and tool		4	5	20
Receiving and storing		5	8	40
Warehouse and shipping		5	8	40
Maintenance		5	5	25
Offices				112
Total production space 150 % allowance				355,5
MANUFACTURING				
Welding machine	6	0,3	0,565	1,017
Welding table	4	1,5	2,5	15
Bench for inventory	4	1	2	8
Bench for auxiliary	4	1	2	8
Bench for welded parts	2	1	2	4
Turning/Lathe machine	6	1,2	3	21,6
Bench for inventory	3	1	2	6
Bench for auxiliary	3	1	2	6
Bench for parts	2	1	2	4
Milling machine	4	1,86	1,8	13,392
Bench for inventory	2	1	2	4
Bench for auxiliary	2	1	2	4
Bench for parts	2	1	2	4
Drilling machine	5	0,4	1,93	3,86
Bench for inventory	3	1	2	6
Bench for auxiliary	3	1	2	6
Bench for parts	2	1	2	4
Total manufacturing space 50 % allowance				178,30
Total plant space				600

Appendix D: Free-piston full assembly



ITEM	BESKRYWING	AANTAL	MATERIAAL / SPESIFIKASIES
33	PISTON INNER FLEXURE RING	1	SS 304
32	REAR PISTON SPACER	1	SS 304
31	PISTON POSITIONING CONE	1	SS 304
30	REGENERATOR MESH	1	80# x 0.12 SS
29	DISPLACER END CAP	1	SS316
28	DISPLACER NUT M8	1	SS 304
27	DISPLACER	1	SS 316
26	WATER JACKET	1	SS 304
25	O-RING	1	VITON 95X3.5
24	CYLINDER	1	CAST IRON
23	CYLINDER BOLT (M4x25)	4	SS 304
22	ALTERNATOR COIL	4	COPPER WIRE 0.355
21	ALTERNATOR LAMINATION	16	M530-65A
20	PISTON END CAP	1	SS 304
19	INNER PISTON BUSH	1	?
18	OUTER PISTON BUSH	1	?
17	MAGNET (HALBACH CONFIGURATION)	1	N36
16	PISTON	1	SS 304
15	PISTON BOLT (M4x16)	8	SS 304
14	FRONT ROD SPACER	4	SS 304
13	PISTON FLEXURE	1	SS 302 SPRING STEEL
12	PISTON FLEXURE RING	2	SS 304
11	REAR ROD SPACER	4	SS 304
10	DISPLACER FLEXURE	1	SS 302 SPRING STEEL
9	DISPLACER FLEXURE RING	2	SS 304
8	FLEXURE ASSEMBLY NUT M4	12	SS 304
7	SADDLE ASSEMBLY	1	MILD STELL
6	SHELL BOLTS (M10x45 HIGH TENSILE)	12	SS 316
5	SADDLE BOLTS (M8x25)	4	SS 304
4	FLOOR BOLTS (M10x45)	13	SS 304
3	REAR SHELL	1	SS 304
2	FRONT SHELL	1	SS 316
1	FLOOR	1	-

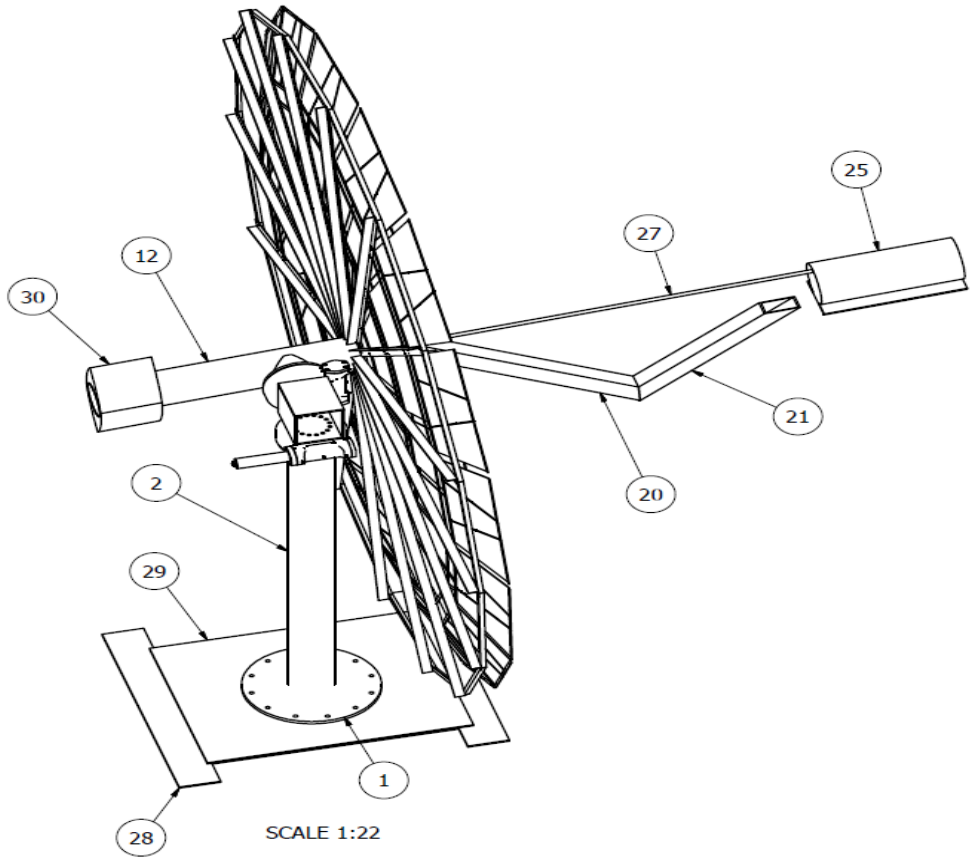
UNLESS OTHERWISE STATED
TOLERANCES ± 0,1
ANGLES 1˚

UNIVERSITEIT VAN STELLENBOSCH

SKAAL OP A3 1:2	MATE IN mm	TITEL: FULL ASSEMBLY	
STUDENTE No. 15071618	TEKENAAR IN DEETLEFS	NAGESIEN	
DATUM 8/5/2013	VEL No. 1 VAN 1 VELLE	No.	

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

Appendix E: Concentrator full assembly



SCALE 1:22

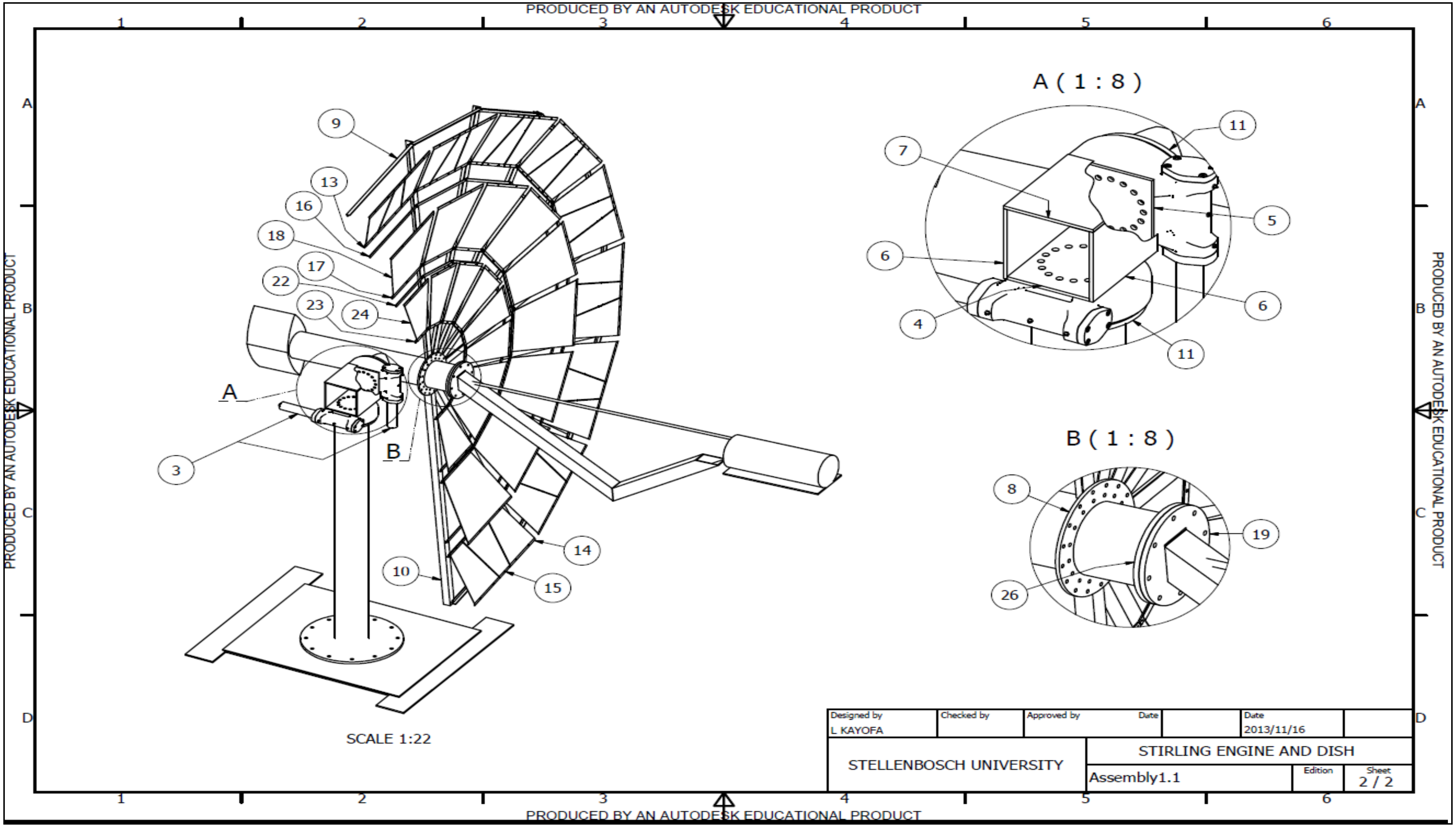
PARTS LIST

ITEM	QTY	PART NUMBER
1	1	Footplate
2	1	Bottom half pipe
3	2	SE9A-61-R-24H.77.35
4	1	Driver transition 5 (1)
5	1	Driver transition 5 (2)
6	2	Driver transition 5 (3)
7	1	Driver transition 5 (4)
8	1	Dish centre piece
9	16	Driver Spoke Secondary
10	16	Driver Spoke Main
11	2	Flange
12	1	Dish pipe
13	16	Driver Spoke Tersiary 2
14	32	Mirror mounting (outer)
15	16	Mirror mounting (outer2)
16	16	Driver Spoke Tersiary 3
17	16	Driver Spoke Tersiary
18	16	Mirror mounting (middle)
19	1	Stirling support flange 2
20	1	Stirling support arm
21	1	Stirling support arm 2
22	16	Driver Spoke Tersiary 4
23	16	Driver Spoke Tersiary 5
24	16	Mirror mounting (inner)
25	1	Stirling engine
26	1	Stirling support flange
27	1	Stirling calibration rod
28	1	Stand
29	1	Stand 2
30	1	Counterweight

Designed by	Checked by	Approved by	Date	Date
L KAYOFA				2013/11/16

STELLENBOSCH UNIVERSITY	STIRLING ENGINE AND DISH		
	Assembly1.1	Edition	Sheet 1 / 2

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



Designed by	Checked by	Approved by	Date	Date
L KAYOFA				2013/11/16
STELLENBOSCH UNIVERSITY	STIRLING ENGINE AND DISH			
	Assembly1.1	Edition	Sheet 2 / 2	

Appendix F: Time taken for assembly and manufacture the Stirling engine

Assembly	**Total (hours)**	**Type of machining**	**Total (hours)**
Shell Assembly	38	Turning	36,75
Piston Assembly	12	Tapping and drilling	6
Cylinder Assembly	9	Drilling	3
Saddle Assembly	7	Bending	7
Displacer Assembly	5,25	Welding	9
Regenerator Assembly	3	Milling	3,5
Water Jacket Assembly	2,25	Tapping	0,5
Flexure Assembly	2		
Flame Cover Assembly	1		
Alternator Assembly	0		
Fittings	0		
Total time	77,25		65,75

Appendix G: The list of suppliers and alternative suppliers for the concentrator

Alternative suppliers	Main supplier
Dynamic Convergence (PTY) LTD	Electromechanica (Cape) (Pty) Ltd
Steel & Pipes (Cape Town)	Fabrinox (Pty) Ltd
SKF group and Kinematics Manufacturing Inc.	Jiangyin Huang New Energy Hi-Tech Equipment Co., Ltd
Patent specific product	Netram Technologies
Patent specific product	Process Pipe (PTY) LTD
Allen-Bradley	Siemens South Africa
Patent specific product	Solar MEMS Technologies S.L.
MACSTEEL	Stalcor (PTY) LTD

Appendix H: The list of suppliers and alternative suppliers of the Stirling engine

Alternative suppliers	**Main supplier**
NDE STAINLESS STEEL , Stainless Crazy cc	Macsteel
Bearing Man Group	Gasket & Shim Industries
Bolesco ,Paarl	BOLTFAST (PTY)LTD
Meshcape Industries (Pty) Ltd	FLSmidth
Loxton Irrigation	Swagelok
SA GAUGE	WIKA Instruments (Pty) Ltd
Andre Engelbrecht Engineering cc	Izumi Engineering and Manufacturing cc

Appendix I: The questionnaire sample

(Infinia)
Figure 0.1 Solar Stirling dish

Familiarisation: The solar dish makes use of the sun's heat energy to generate electricity. The dish is responsible for reflecting and concentrating the solar radiation, the thermal energy is then transferred to the engine. Finally, the engine converts the thermal energy into electricity. Solar Stirling dish with battery storage have the capability to produce electricity at night. This particular solar Stirling dish produces 3 kW of electricity, which is sufficient to generate electricity for one household.

Dear community member

I am a student at Stellenbosch University studying Engineering Management. As part of my research study, I am conducting an anonymous survey that would investigate the potential deployment of a solar dish in off-grid areas. This affordable renewable alternative uses solar energy to generate electricity.

The purpose of this survey is for stand-alone power supply in rural areas and townships without access to electricity in Africa.

The objective of this study: is to determine the demand for this product by communities who do not have access to electricity. The result of this survey will determine whether it would be feasible to provide this product to impoverished communities.

If you have any questions or queries regarding this research, please feel free to contact:

Researcher's contact details: Ms Lilongeni Kayofa

Phone: 27 733 798 6

E-mail: 14845431@sun.ac.za

Supervisor's contact details: Theuns Dirkse van Schalkwyk

Tel: +27 21 808 2189 I Fax: +27 21 808 4245

Email: theuns@sun.ac.za

Department of Industrial Engineering

Stellenbosch University

- ✓ I understand that this is an anonymous survey.
- ✓ I understand and read the content of this questionnaire.
- ✓ I understand that I have the right to withdraw from participating in this survey at any time and refusal to participate in this survey will not in any way compromise me.

Thank you for your time.

SECTION 1

Instruction: Please place a tick where appropriate.

1. Gender — Male / Female

2. Age

3. What type of housing structure do you live in?

Traditional house	1
Corrugated iron house	2
Wood house	3
Brick house	4
Others	5

4. How many people live in this house?

1	1
2-3	2
3-4	3
5-6	4
More than 6 people	5

5. What is the total monthly income for this household?

R 0- R 2000	1
R 2001- R 5000	2
R 5001- R 8000	3
R 8001- R 11000	4
Above 11001	5

6. Approximately how much do you spend in Rand per month on?

	Rand
Wood	
Candles	
Paraffin	
Cow dung	
Crop residue	
Diesel	
Liquefied Petroleum Gas (LPG)	
Disposable batteries	
Biogas system	
Solar panels	

7. What is the amount are you willing to loan out to pay for the solar dish?

R 0	1
Less than R 2000	2
R 2001- R 4000	3
R 4001- R 6000	4
R 6001- R 8000	5
R 8001- R 10000	6
More than R 10000	7

8. Approximately how much energy do you consume per month?

	Units	Familiar Units
Wood	kg	Bundle
Candles	g	Count
Paraffin	litre	Container
Cow dung	kg	Baskets
Crop residue	kg	Bundle
Diesel	litre	Container
Liquefied Petroleum Gas (LPG)	kg	Cylinder
Disposable batteries	g	Count
Biogas system	kg	Cylinder
Solar panels	watts	Count panels

SECTION 2

Instructions: Carefully read the statements and place a tick on the appropriate box. To what extent do you agree or disagree with each of the following statements.

Please indicate your answer using the following 5-point scale where:

Strongly disagree	Disagree	Undecided/Neutral	Agree	Strongly agree
1	2	3	4	5

9. The following statements are true:

Statement	SCALE					For official use only
I am interested in owning the solar dish	1	2	3	4	5	V1
Solar panel theft is a problem in my area	1	2	3	4	5	V2
Battery theft is a problem in my area	1	2	3	4	5	V3
Vandalism is a problem in my area	1	2	3	4	5	V4

10. The following statements are true about why I don't have electricity:

Statement	SCALE					
It is unaffordable	1	2	3	4	5	V5
The layout of my house doesn't support an electricity setup	1	2	3	4	5	V6
I have applied for an electricity connection	1	2	3	4	5	V7
I live in an off-grid area	1	2	3	4	5	V8
I don't need electricity	1	2	3	4	5	V9

11. I am willing to use a solar dish if:

Statement	SCALE					
The government is prepared to subsidise the purchasing of the solar dish	1	2	3	4	5	V10
The government provides incentives for using this solar dish	1	2	3	4	5	V11
The government will be liable for all the operating expenses	1	2	3	4	5	V12
I have to purchase the solar dish myself	1	2	3	4	5	V13
The solar dish will be manufactured/ produced locally	1	2	3	4	5	V14
The customer support services will be available	1	2	3	4	5	V15
The solar dish maintenance is affordable	1	2	3	4	5	V16
The solar dish will have a long life-span/durable	1	2	3	4	5	V17

12. I need electricity mostly for the following :

	SCALE					
TV	1	2	3	4	5	V18
Radio	1	2	3	4	5	V19
Cellphones	1	2	3	4	5	V20
Stove	1	2	3	4	5	V21
Iron	1	2	3	4	5	V22
Fridge	1	2	3	4	5	V23
Fan	1	2	3	4	5	V24
Hair appliance (clippers, hair brush, hair dryer etc.)	1	2	3	4	5	V25
Heater	1	2	3	4	5	V26
Kettle	1	2	3	4	5	V27

13. I use the following energy resources to generate energy for my house:

	SCALE					
Wood	1	2	3	4	5	V28
Candles	1	2	3	4	5	V29
Paraffin	1	2	3	4	5	V30
Cow dung	1	2	3	4	5	V31
Crop residue	1	2	3	4	5	V32
Diesel generator	1	2	3	4	5	V33
LPG stove	1	2	3	4	5	V34
Disposable batteries	1	2	3	4	5	
Solar Panels	1	2	3	4	5	V35

14. I need electricity during the following times:

	SCALE					
Morning (05:00 am to 11:59 am)	1	2	3	4	5	V36
Afternoon (12: 00am to 17:59 pm)	1	2	3	4	5	V37
Evening (18:00 pm to 19:59 pm)	1	2	3	4	5	V38
Night (20:00 pm to 04:59 am)	1	2	3	4	5	V39
Whole/Full day	1	2	3	4	5	V40
Anytime	1	2	3	4	5	V41

Appendix J: Research consent

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jou kennisvennoot • your knowledge partner

Approval Notice
New Application

16-Apr-2013
KAYOFA, Lilongeni

Protocol #: DESC_Kayofa2013

Title: **Feasibility study and business plan for manufacturing a 3 kW-electrical solar Stirling engine and dish, for off-grid electric supply units**

Dear Miss Lilongeni KAYOFA,

The **New Application** received on **02-Apr-2013**, was reviewed by members of **Research Ethics Committee: Human Research (Humanitie** review procedures on **16-Apr-2013** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **16-Apr-2013 -15-Apr-2014**

Standard provisions
1. The researcher will remain within the procedures and protocols indicated in the proposal, particularly in terms of any undertakings made in terms confidentiality of the information gathered.
2. The research will again be submitted for ethical clearance if there is any substantial departure from the existing proposal.
3. The researcher will remain within the parameters of any applicable national legislation, institutional guidelines and scientific standards relevant to t of research.
4. The researcher will consider and implement the foregoing suggestions to lower the ethical risk associated with the research.

You may commence with your research with strict adherence to the abovementioned provisions and stipulations.

Please remember to use your **protocol number** (**DESC_Kayofa2013**) on any documents or correspondence with the REC concerning your rese

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or m conduct of your research and the consent process.

After Ethical Review:
Please note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required.
The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected ra external audit.

National Health Research Ethics Committee (NHREC) number REC-050411-032.

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Rese Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must be obtained from the relevant authorities (Western Cape Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Depa Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 : Research that will be conducted at any tertiary academic institution requires approval from the relevant parties. For approvals from the Western C: Department, contact Dr AT Wyngaard (awyngaar@pgwc.gov.za, Tel: 0214769272, Fax: 0865902282, http://wced.wcape.gov.za).

Institutional permission from academic institutions for students, staff & alumni. This institutional permission should be obtained before submitting an ethics clearance to the REC.
Please note that informed consent from participants can only be obtained after ethics approval has been granted. It is your responsibility as researc signed informed consent forms for inspection for the duration of the research.

We wish you the best as you conduct your research.
If you have any questions or need further help, please contact the REC office at 0218089183.

Included Documents:

Research proposal
informed consent
questionnaire

Sincerely,

Susara Oberholzer
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

Appendix K: Community consent

Efidi-lomulunga village
ONGWEDIVA
20 April 2013

Research Ethics Committee: Human Research (Humaniora)
Stellenbosch University
Private Bag X1
Matieland
7602
South Africa

RE: COMMUNITY CONSENT TO CARRY OUT SURVEY IN EFIDI-LOMULUNGA VILLAGE

It is my pleasure to grant Miss Lilongeni Kayofa, a student researcher from Stellenbosch University, permission on behalf of the whole community to carry out a survey in Efidi-Lomulunga village during the period of May-June 2013.

According to my understanding, the survey is on the "***Feasibility study and business plan for manufacturing a 3 kW-electrical solar Stirling engine and dish, for off-grid power supply units***" and is performed as an obligation for her master's degree. I also understand that the survey will be carried out using questionnaires to interview the community members. The researcher will be asking questions related to the energy sources, energy demand, energy usage and socio-economic questions. I believe that my community can benefit immensely from the output of this survey and from the potential technological advances that will come out of it.

Yours faithfully

THE HEADMAN
Mr Simon Mwatotele
EFIDI-LOMULUNGA

HEADMAN / ELENGA
S. K. MUATOTELE
ONGWEDIVA
25 MAY 2013
P. O. Box 424, Oshakati
Oshana Region
Republic of Namibia

Appendix L: Discreptive statistics

Question number	Valid N	Mean	Median	Minimum	Maximum	Lower - Quartile	Upper - Quartile	Std.Dev.
1 Interests	30	4,600	5,000	1,000	5,00	4,000	5,000	0,814
2 Theft	30	3,967	5,000	1,000	5,00	3,000	5,000	1,497
3 Battery	30	3,600	4,000	1,000	5,00	2,000	5,000	1,610
4 Vandalism	30	3,500	4,000	1,000	5,00	3,000	5,000	1,570
5 Unaffordable	24	4,417	5,000	1,000	5,00	5,000	5,000	1,349
6 Layout	18	1,667	1,000	1,000	5,00	1,000	1,000	1,372
7 Applied	22	2,045	1,000	1,000	5,00	1,000	4,000	1,759
8 Off-grid	22	4,455	5,000	1,000	5,00	4,000	5,000	0,963
9 Don’t need	30	1,000	1,000	1,000	1,00	1,000	1,000	0,000
10 Subsides	30	4,600	5,000	1,000	5,00	4,000	5,000	0,855
11 Incentives	30	4,567	5,000	1,000	5,00	4,000	5,000	0,898
12 Liable	30	4,300	5,000	1,000	5,00	4,000	5,000	1,149
13 Purchase	30	3,133	3,500	1,000	5,00	1,000	5,000	1,676
14 Locally	30	4,267	5,000	1,000	5,00	4,000	5,000	1,143
15 Support	30	4,400	5,000	1,000	5,00	4,000	5,000	1,003
16 Maintenance	30	4,600	5,000	3,000	5,00	4,000	5,000	0,675
17 Life-span	30	4,867	5,000	3,000	5,00	5,000	5,000	0,434
18 T	30	4,000	5,000	1,000	5,00	3,000	5,000	1,554
19 Radio	30	4,833	5,000	4,000	5,00	5,000	5,000	0,379
20 Cell phone	30	4,967	5,000	4,000	5,00	5,000	5,000	0,183
21 Stove	30	3,900	5,000	1,000	5,00	1,000	5,000	1,788
22 Iron	30	4,433	5,000	1,000	5,00	5,000	5,000	1,223
23 Fridge	30	4,300	5,000	1,000	5,00	5,000	5,000	1,466
24 Fan	30	3,633	5,000	1,000	5,00	1,000	5,000	1,810
25 Hair	30	3,433	5,000	1,000	5,00	1,000	5,000	1,870
26 Heater	30	3,467	5,000	1,000	5,00	1,000	5,000	1,889
27 Kettle	29	4,034	5,000	1,000	5,00	4,000	5,000	1,679
28 Wood	30	4,867	5,000	1,000	5,00	5,000	5,000	0,730
29 Candles	30	3,667	5,000	1,000	5,00	1,000	5,000	1,863
30 Paraffin	30	2,367	1,000	1,000	5,00	1,000	5,000	1,903
31 Cow dung	30	3,533	5,000	1,000	5,00	1,000	5,000	1,961
32 Crop residue	30	3,767	5,000	1,000	5,00	1,000	5,000	1,794
33 Diesel generator	29	1,138	1,000	1,000	5,00	1,000	1,000	0,743
34 LPG stove	30	3,267	5,000	1,000	5,00	1,000	5,000	2,016
35 Solar panel	30	1,667	1,000	1,000	5,00	1,000	1,000	1,516
36 Morning	30	1,233	1,000	1,000	5,00	1,000	1,000	0,774
37 Afternoon	30	1,267	1,000	1,000	5,00	1,000	1,000	0,785
38 Evening	30	1,467	1,000	1,000	5,00	1,000	1,000	1,224
39 Night	30	2,033	1,000	1,000	5,00	1,000	2,000	1,691

40 Full day	30	3,867	5,000	1,000	5,00	2,000	5,000	1,776
41 Anytime	30	1,533	1,000	1,000	5,00	1,000	1,000	1,224
42 Disposable batteries	30	3,733	5,000	1,000	5,00	1,000	5,000	1,837

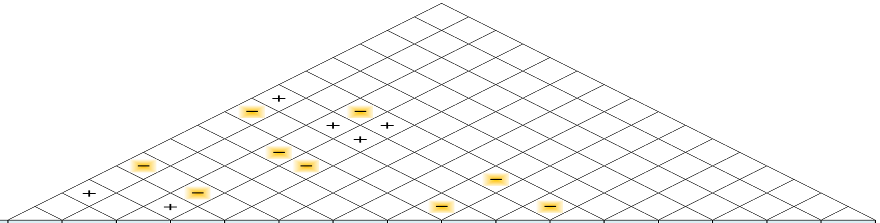
Appendix M: House of Quality of the concentrator

Revision:
Date:

Correlations	
Positive	+
Negative	−
No Correlation	

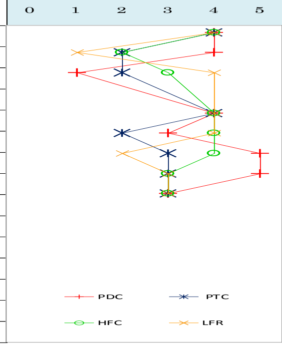
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



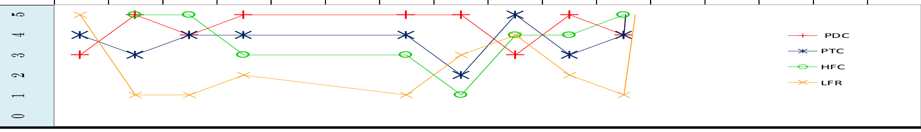
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Dual axis tracking system	Concentration ratio	Produce adequate power	Optical efficiency	Overcome strong winds	Easy to transport	Easy to assemble /disassemble	Optimized for cost	Durable	Reach high temperature	Mirror absorption						Parabolic dish reflector	Parabolic trough collector	Heliostats field collector	Linear Fresnel reflector	Row #
					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16					
					Direction of Improvement	▲	◇	▲	◇	▲	▲	▲	▼	▲	▲	▲										
1		11%	0.11	1	Not prone to theft						▽	▽		▽								4	4	4	4	1
2		12%	0.12	9	Cheap operating and maintenance costs					●			○	●								4	2	2	1	2
3		13%	0.13	9	Affordable	○					▽	▽	●	○								1	2	3	4	3
5		14%	0.14	9	Long life expectancy	▽				●			○	●								4	4	4	4	5
6		14%	0.14	9	Reliable	●	●	●	●	○			▽	●	●	●						3	2	4	4	6
7		8%	0.08	9	High quality of heat	●	●	●	●	▽			○		●	●						5	3	4	2	7
8		14%	0.14	9	Easy to set-up						○	●										5	3	3	3	8
9		14%	0.14	9	Safe				▽	○					●	○						3	3	3	3	9
10																										10
11																										11
12																										12
13																										13
14																										14
15																										15
16																										16

Customer Competitive Assesment



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Target	(Azimuth 360 degrees + Zenith 180 degrees) at 0.12 degrees	1%	12 kWt at noon	Reflectivity of 94 %	Survive in 144km/h of wind	The parts can be disassembled	Can be installed by one person	Utilizing the cheapest materials as possible	10-15 years	600 degrees	6%					
Max Relationship	9	9	9	9	9	3	9	9	9	9	9					
Technical Importance Rating	253.7	201.5	201.5	215.5	323.2	65.95	149.9	232	406.5	327.4	243.5					
Relative Weight	10%	8%	8%	8%	12%	3%	6%	9%	16%	12%	9%					
Weight Chart																
Parabolic dish reflector- PDC	3	5	4	5			5	5	3	5	4	39				
Parabolic trough collector- PTC	4	3	4	4			4	2	5	3	4	33				
Heliostats field collector- HFC		5	5	3			3	1	4	4	5	30				
Linear Fresnel reflector-LFR	5	1	1	2			1	3	4	2	1	20				

Technical Competitive Assesment



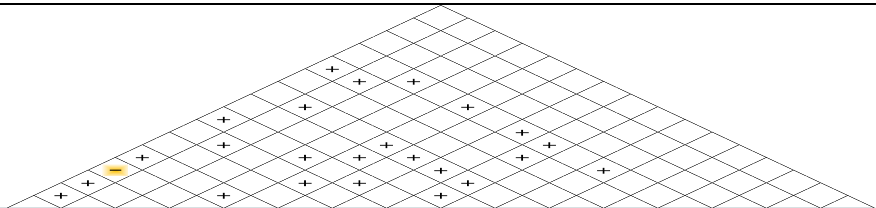
Template Revision: 0.9 Date: 4/23/2010

Appendix N: House of Quality of the engine

Correlations	
Positive	+
Negative	−
No Correlation	

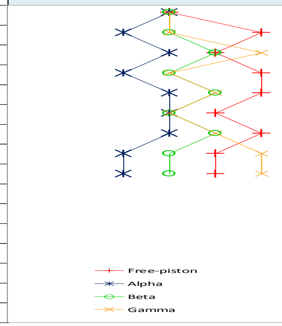
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



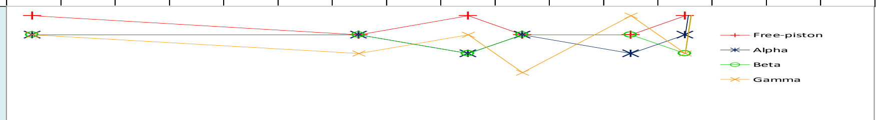
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	1 Durable	2 Hermitically sealed unit	3 Few moving parts	4 No lubricant	5 Centering	6 No water usage	7 Power density	8 Material used	9 Self starting	10 Efficient	11 Hybridized	12 Cost	13 Power produced	14	15	16	Free-piston	Alpha	Beta	Gamma	Row #
					Direction of Improvement	▲	◇	◇	◇	◇	◇	▲	▲	▲	▲	▲	▲	▲								
1		10%	0.104	1	Prone to theft	▽							▽		▽		▽					3	3	3	3	1
2		11%	0.112	9	Cheap operating cost	●	●	○	○		●					●	○					5	2	3	3	2
3		12%	0.120	9	Affordable	▽			▽				●		○	▽	●					4	3	4	5	3
4		12%	0.120	3	Little maintenance		○	○	○	○	○		○					▽				5	2	3	3	4
5		13%	0.127	9	Long life expectancy		●	●	●	●		○	●				○					5	3	4	4	5
6		10%	0.102	9	Sufficient electricity- magnets							●	●		●							4	3	3	3	6
7		10%	0.105	9	Silent operation		●	●														5	3	4	4	7
8		10%	0.105	9	Small size						●	●	●		●							4	2	3	5	8
9		10%	0.105	9	Portable							●	●		○		▽					4	2	3	5	9
10																										10
11																										11
12																										12
13																										13
14																										14
15																										15
16																										16

Customer Competitive Assesment



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Target	10-15 years	Welded closed	2 moving parts: piston and displacer	Air bearings	Flexure bearings	Air cooled	High charge pressure	Best combination of cost and suitability	Low coefficients of static friction	Engine with a 25% efficiency	Powered by multiple fuels	Less than R15 000.00	3 kW			
Max Relationship	9	9	9	9	9	9	9	9		9	9	9	1			
Technical Importance Rating	123.6	346	278.6	196.4	150.7	231.5	318.3	549.4	0	263.8	113.3	201	12.03			
Relative Weight	4%	12%	10%	7%	5%	8%	11%	20%	0%	9%	4%	7%	0%			
Weight Chart																
Free piston	5						4		5	4		4	5	27		
Alpha	4						4		3	4		3	4	22		
Beta	4						4		3	4		4	3	22		
Gamma	4						3		4	2		5	3	21		

Technical Competitive Assesment



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Appendix O: The bill of materials for the concentrator

Item number on assembly drawing	Part name	Quantity	Unit Price	Total Price	Vendor
	Metal enclosing	1	R 28,00	R 87,71	Electro mechanica
	Slotted enclosing	1	R 825,00	R 884,71	Electro mechanica
	Motor Driver	2	R 605,00	R 1210,00	Netram technologies
	Sun sensor	1	R 825,00	R 3559,60	Solar MEMS technologies S,L,
	Compact CPU	1	R 2502,00	R 2502,00	Siemens
	Power Module	1	R 738,00	R 738,00	Siemens
2	Bottom half pipe	1	R 4387,72	R 4387,72	Process Pipe
3	Slew driver	2	R 1340,00	R 8381,69	H-fang
9	Aluminium angle	8	R 214,71	R 11827,03	Stalcor
10	Aluminium flat bar	8	R 39,25	R 423,35	Stalcor
12	Dish pipe	1	R 236,09	R 1641,77	Process Pipe
22,23	Aluminium angle	3	R 103,81	R 420,83	Stalcor
	Total material costs per unit			R 34682,72	

Appendix O: The bill of material for the outsourced services for the concentrator

Item number on assembly drawing	Part name	Quantity	Unit Price	Total Net Price	Vendor
11	Top plate/flange	1	14,05	25,23	Frabinox
	Tracker assessment mounting	1	72,52	82,67	Frabinox
1	Foot plate	1	25,13	36,31	Frabinox
4	Driver transition 1	1	124,50	143,43	Frabinox
5	Driver transition 2	1	107,30	126,23	Frabinox
6	Driver transition 3	2	104,34	225,61	Frabinox
7	Driver transition 4	1	100,20	119,13	Frabinox
8	Dish centre piece	1	208,04	306,41	Frabinox
14	Mirror mounting Outer	1	96,36	107,54	Frabinox
15	Mirror mounting outer 2	1	89,74	100,92	Frabinox
18	Mirror mounting middle	1	153,69	164,87	Frabinox
24	Mirror mounting inner	1	100,00	111,18	Frabinox
14	Mirror mounting Outer	1	96,36	107,54	Frabinox
8	Dish centre	1	191,60	289,97	Frabinox
26	Stirling support flange	1	468,71	567,08	Frabinox
28/29	Stand 2	1	1447,71	2993,79	Frabinox
	Total material costs per unit			R 5 507,91	

Appendix P: The breakdown of the cost of materials Stirling engine

Item number on assembly drawing	Part name	Quantity	Unit price	Total price	Vendor
	Shell Assembly				
2	Front shell	1		R 1269,00	Macsteel
3	Rear shell	1		R 1299,06	Macsteel
25	O-ring	1	R 29,24	R 29,24	Gasket & Shim Industries (Pty) Ltd
6	Shell bolts	12		R 57,48	BOLTFAST (PTY)LTD
7	Saddle Assembly				
	Welded parts	1	R 446,33	R 446,33	Fabrinox
4	Floor bolts	13	R 3,00	R 39,00	BOLTFAST (PTY)LTD
6	Saddle bolts	4	R 1,66	R 6,64	BOLTFAST (PTY)LTD
	Flexure Assembly				
9	Displacer flexure rings	2	R 9,01	R 18,02	Fabrinox
10	Displacer Flexure	1	R 73,87	R 73,87	Fabrinox
12	Piston flexure rings	2	R 9,45	R 18,90	Fabrinox
13	Piston Flexure	1	R 75,31	R 75,31	Fabrinox

11	Rear spacer rod	4	R 25,95	R 103,8	Macsteel
14	Front spacer rod	4	R 25,95	R 103,8	Macsteel
8	Assembly nuts	12	R 0,12	R 1,44	BOLTFAST (PTY)LTD
	Piston Assembly				
16	Piston	1	R 76,6	R 76,6	Macsteel
17	Magnets	1	R 1393,88	R 1393,88	NINGBO KETIAN MAGNET CO,,LTD (CHINA)
18	Outer bush	1			-
19	Inner bush	1			-
20	Piston end cap	1	R 16,78	R 16,78	Fabrinox
15	Piston bolts	8	R 0,34	R 2,72	BOLTFAST (PTY)LTD
33	Piston inner flexure ring	1	R 3,94	R 3,94	Macsteel
32	Rear piston spacer	1	R 14,65	R 14,65	Fabrinox
31	Piston positioning cone	1m	R 10,00	R 10,00	Macsteel
	Alternator Assembly				
21	Laminations	16	R 212,31	R 212,31	OCEANTECH ENERGY
22	Copper wire (insulated)	250 m		R 213,14	Wilec Technical Solutions Provider
	Cylinder Assembly				
24	Cylinder	1	R 131,10	R 131,10	Macsteel
23	Cylinder bolts	4	R 2,04	R 2,04	BOLTFAST (PTY)LTD
26	Water Jacket Assembly				
	Jacket sheet	1			Macsteel
	Pipe fittings	2	R 10,00	R 10,00	Macsteel
	Displacer Assembly				
27	Displacer	1	R 210,25	R 210,25	Macsteel
29	Displacer end cap	1	R 2,88	R 2,88	Fabrinox
28	Displacer nut	1	R 0,40	R 0,40	BOLTFAST (PTY)LTD
	Flame Cover Assembly				
	Welded parts	1	R 31,92	R 31,92	Fabrinox
	Regenerator Assembly				
30	Mesh	1m	R 339,72	R 339,72	FLSmidth
	FITTINGS				
	Wire feedthroughs	1		R 3519,01	TC Ltd (UK)
	Charging tubes	2	R 35,98	R 246,11	NATIONAL DAIRY EQUIPMENT (PTY) LTD
	Total material costs per unit			R 9 979,34	

Appendix Q: The bill of materials for the service that were outsourced in manufacturing of the Stirling engine

Item number on the	Product	Quantity	Total	Vendor

assembly drawing			**Price**	
Broaching	Front shell	1	R 2234,40	Izumi engineering & manufacturing cc
Drilling, grinding , turning	Cylinder	1	R 2599,20	Industrial hard chrome
Laser cutting	Mesh	1	R 445,53	Fabrinox
Total machining costs per unit			R 5 279,13	

Appendix R : Manufacturing cost analysis calculations

The factory plans to have a capacity of 1000 units per year. The normal working time is nine hour per day (five days per week). The lunch breaks lasts for one hour and 30 minutes of other breaks (tea break and meeting). It is estimated that the workers have an effective efficiency of 85 %. The regular labour wage rates for a qualified artisan (falls under the rate code A) were based on what was stipulated by the Metal and Engineering Industries Bargaining Council (*New industry wage, 2014*) . The electricity cost based on commercial tariffs is 127,71 R/kWh, as stipulated by the City of Cape Town (City of Cape Town, 2014). Some of the following formulas were adopted from Stephens and Meyers (2013):

Welding units/hour given Number of workers.

$$\frac{Welded\ units}{Hour} = \left(\frac{units}{time\ taken\ \ to\ weld\ 1\ unit\ (hour)}\right) \times number\ of\ workers \qquad (14.1)$$

$$\frac{Welded\ units}{Hour} = \frac{1\ \ unit}{5.5\ hour} \times 1 \qquad (14.2)$$

$$\frac{Welded\ units}{Hour} = \ 0.182\ unit/hour \qquad (14.3)$$

$$\frac{Welded\ units}{Hour} = \frac{1\ \ unit}{5.5\ hour} \times 4\ workers \tag{14.4}$$

$$\frac{Welded\ units}{Hour} = \ 0{,}727\ unit/hour \tag{14.5}$$

Time standard is defined as "the time required to produce a product at a workstation with the following three conditions: carried out by a qualified, well trained operator, working at normal pace and doing a specific task". Below is an example how the results on Table 6.2 were obtained (number of workers 4):

$$Time\ taken\ to\ weld\ 1000\ units = \frac{total\ units\ (1000\ )}{\frac{1\ units}{5{,}5\ hour}} \tag{14.6}$$

$$Time\ taken\ to\ weld\ 1000\ units = \frac{1000\ hour}{0{,}182} \tag{14.7}$$

$$Time\ taken\ to\ weld\ 1000\ units = 5500\ hours \tag{14.8}$$

$$Regular\ labour\ cost\ = regular\ labour\ cost\ (R) \times number\ of\ workers \tag{14.9}$$

$$Regular\ labour\ cost\ = R\ 56{,}08 \times number\ of\ workers \tag{14.10}$$

$$Total\ regular\ labour\ cost = (time\ standard\ to\ weld\ 1000\ units\ \ \times regular\ labour\ cost\ (R)) \tag{14.11}$$

$$Total\ regular\ labour\ cost\ for\ 1\ worker = ((\ 5500\ hours \times 56{,}08 \frac{R}{hours}) \div 85\ \%) \tag{14.12}$$

$$Total\ regular\ labour\ cost\ = R\ 362\ 870{,}59 \tag{14.13}$$

$$Total\ regular\ labour\ cost\ for\ 4\ workers = (((\frac{5500}{4\ workers}) \times 4\ workers \times R\ 56.08)\ \div 85\ \%) \quad (14.14)$$

$$Total\ regular\ labour\ cost = R\ 362\ 870{,}59 \quad (14.15)$$

$$Overheads\ given\ the\ number\ of\ days = \frac{total\ labour\ costs \times 10\ \%}{numbers\ of\ workers} \quad (14.16)$$

$$Overheads\ given\ the\ number\ of\ days = \frac{R\ 362\ 870{,}59 \times 10\ \%}{1\ worker} \quad (14.17)$$

$$Overheads\ given\ the\ number\ of\ days = \ R\ 36\ 287{,}06 \quad (14.18)$$

$$Overheads\ given\ the\ number\ of\ days = \frac{R\ 362\ 870{,}59 \times 10\ \%}{4\ workers} \quad (14.19)$$

$$Overheads\ given\ the\ number\ of\ days = \ R9\ 071.76 \quad (14.20)$$

$$Total\ number\ of\ days\ to\ weld\ 1000\ units = \left(\frac{5500\ hours/worker}{8\ hours/day}\right) \div 1\ workers \quad (14.21)$$

$$Total\ number\ of\ days\ to\ weld\ 1000\ units = \ 688\ days \quad (14.22)$$

$$Total\ number\ of\ days\ to\ weld\ 1000\ units = \left(\frac{5500\ hours/worker}{8\ hours/day}\right) \div 4\ workers \quad (14.23)$$

$$Total\ number\ of\ days\ to\ weld\ 1000\ units = 172\ days \quad (14.24)$$

The total kWh required for the concentrator was calculated to be 161 kWh in Appendix T. It the maximum rated power of machine was estimated to be 60 %.

Table 0.1 Total power required to weld a concentrator

Time taken to weld in hours	Power required by machine in kW	total power required kW	Power required in the time given kW
0,5	38,104	19	11,4
0,5	38,104	19	11,4
2	14,549	28	16,8
0,5	38,104	19	11,4
1	38,104	38	22,8
0,5	38,104	19	11,4
0,5	38,104	19	11,4
		161	96,6

$$Total\ power\ required\ in\ kW = time\ taken\ to\ weld\ in\ hours\ \times power\ required\ by\ machine\ in\ kW \quad (14.25)$$

$$\text{Power required in the time given } in\ kW = total\ power\ required\ in\ kW\ \times 0{,}6 \quad (14.26)$$

$$Total\ electricity\ cost = 1000\ units \times 96\ kWh \quad (14.27)$$

$$Total\ electricity\ cost = 96\ 000\ kWh \quad (14.28)$$

The power required in the time given in kW for the Stirling engine section was estimated.

$$Total\ manufacturing\ cost = total\ regular\ labour\ cost\ (R) + overheads + total\ electricity \quad (14.29)$$

$$Total\ manufacturing\ cost = R\ 467\ 942{,}35 \quad (14.30)$$

Therefore,

$$Manufacturing\ cost\ of\ one\ concentrator = \frac{total\ manufacturing\ cost\ (R)}{number\ of\ units\ (units)} \quad (14.31)$$

$$Manufacturing\ cost\ of\ one\ concentrator = \frac{R\ 467\ 942{,}35}{5\ units} \tag{14.32}$$

$$Manufacturing\ cost\ of\ one\ concentrator = \ R\ 467{,}94 \tag{14.33}$$

$$Number\ of\ units\ produced\ in\ a\ day = \frac{number\ of\ units}{total\ number\ of\ days\ to\ weld\ 1000\ units} \tag{14.34}$$

$$Number\ of\ units\ produced\ in\ a\ day = \frac{1000\ units}{172\ days} \tag{14.35}$$

$$Number\ of\ units\ produced\ in\ a\ day = 5{,}82 \tag{14.36}$$

A daily output was calculated using equation (14.35) to reach the factory's annual output (1000 units) .The daily output was determined to be 5 units per day. Therefore, this is how the actual number of workers required to meet the daily output was calculated using data from the section with one worker as follows:

$$Actual\ number\ of\ workers\ required = \frac{time\ to\ weld\ one\ unit\ \times number\ of\ units\ required\ in\ a\ day}{8\ hours/day} \tag{14.37}$$

$$Actual\ number\ of\ workers\ required\ = \frac{5{,}5\ hours\ \times 5\ units/\ day}{8\ hours/day} \tag{14.38}$$

$$Actual\ number\ of\ workers\ required\ = \ 3{,}44\ workers \tag{14.39}$$

This number was then rounded off to 4 workers. If takes one worker to produce a unit per day, than it is cheaper to hire four workers to weld instead of five. Since this is a continuous operation, one worker will work overtime to finish the 5th unit. In table 6.2 shows the welding costs of having one welder and having 4 welders. It is cheaper to employ more than one welder. Even though a shift has 9 hours each worker has only 6, 38 hours to work. Thus a worker a minimal idle time, see Table 36.

Table 0.2 Effective time available for each worker per shift

Item	Data
9- hour shift	9 hours
Lunch break	1 hour
Other breaks	0, 5 hours
Effective efficiency	85 %

Effective time available	6, 38 hours

Total number of days available for a worker to work per year in South Africa was determined, see Table 37. There are approximately 200 days available for work which is closer to the 172 days available to manufacture the products.

Table 0.3 Number of working days available in a week and year

Remark	Value
Days per week	5 days
Weeks per year	52 weeks

$$\text{Total number of days available in a year} = \frac{5 days}{week} \times 52\ weeks/year \quad (14.40)$$

$$\text{Total number of days available in a year} = \ 260\ days/year \quad (14.41)$$

Therefore total number of days available to work was determined by subtracting all the leave days from 260 days.

Table 0.4 Total number of days available to work

Public holidays in South Africa	12 days 9 hours per day
Leave days per year	21 days at 9 hours per day
Further leave days for family responsibilities	3 days
Paid public holiday	12 days
Sick leave days	12 days
Total number of days available to work	200 days

Appendix S: Total welding time of the concentrator

Component	Thickness	Time taken to weld	Current used to weld	Power required by machine (kW)
Foot plate	20 mm	Weld 3 rounds 30 minutes	120-125 A	38,104
Bottom half pipe	12 mm	Weld 3 rounds 30 minutes	120-125 A	38,104
Driver transition 5 (1), (2), (3), (4)	10 mm	2 hours of welding and grinding	80-84 A	14,549
Flange	15 mm	Weld 3 rounds 30 minutes	120-125 A	38,104
Dish pipe	3,5 mm	Welding and grinding took 1 hour	120-125 A	38,104
Stirling support flange	15 mm	Weld 3 rounds 30 minutes	120-125 A	38,104
Dish center piece	10 mm	Weld 3 rounds 30 minutes	120-125 A	38,104
Total		5,5 hours		281,277

Appendix T: Casting parameters

Parameter	**Value**	**Remark/reference**
$VC_{unit-metal}$	R 10,00/kg	As stipulated by the South Africa Iron and Steel Institute
W_{cast}	0,778 kg	
pc	7200 kg/m^3	Sourced from((Yoo, Kleine, Luding & Sahm, 1998:519))
V_{cast}	1,07 $\times 10^{-4}$ m^3	
f_m	1,04	
f_p	1,07	
f_f	1,04	
$C_{unit-labour}$	R 56,08/hour	
l_{act}	1	
$f_{rej-act}$	1,1	It 1,0 for other processes excluding core and mould making
t_{act} ($casting\ process$)		
melting	14,75 minutes	
core	1,5 minutes	
moulding	3 minutes	
core moulding	4 minutes	
shake out	1 minutes	
fettling	5 minutes	
$C_{unit-energy}$	1,27 R/kWh or ,528 $\times 10^{-7}$R/Joule	
f_n	2	Induction furnace
f_y	1,3	
f_r	1,05	
f_m	1,04	
f_p	1,07	

f_f	1,04	
C_{ps}	$754\frac{J}{kg\ K}$	{{321 Marukovich, EI 2006}}
t_{melt}	$1597{,}15\ K$	{{322 Pipleya, S}}
t_{room}	$298{,}15\ K$	
C_{pl}	$837\frac{J}{kg}K$	{{321 Marukovich, EI 2006}}
t_{tap}	$1775{,}15\ K$	RW, ERROR{{323 Carlson, Kent D
L	$1{,}26 \times 10^6$	{{320 Yoo, SM 1998}}
C_{index}	3	
V_{cast}	$0{,}0018\ m^3$	
C_{ac}	20	
C_s	12	
Q	1	
$C_{adminstration-rate}$	R 0,54/kg	
$C_{depreciation-rate}$	R 0,03/kg	

Appendix U: Price of casting cylinder

To:	Miss L Kayofa	***From:***	Nadeem Badat
Company:		***Reference:***	2014-09-09/02
Tel:	021 –	***Tel:***	(021) 511 8267
Fax:	021 –	***Fax:***	(021) 511 4490
E-mail:	14845431@sun.ac.za	***E-mail:***	Nadeem@ajaxmanufacturing.co.za
Date:	09 September 2014	***Page:***	1 off 1

Subject:	**Quotation : Cylinder**

Thank you for the opportunity to quote on the following item.

Item	Description	Qty	Price
1	Cylinder	1	R327.50

Quote Conditions

Prices Quoted are Excluding VAT
Prices are valid for 30 days
Price is subject to a minimum order quantity of 200 units

We trust that the above information meets your approval and await your further instruction.

Yours sincerely,

Nadeem Badat

Appendix V: Risk identification and risk level evaluation

Risk code	Risk Description	Linked to which of the 8 objectives	Likelihood	Impact	Risk rating	Response
	A. Financial					
A1	The risk of not acquiring venture-capital investors	1,2,6	Rare	Significant	High risk	Accept
A2	The risk of the business going bankrupt	1,2,3,6,7,8	Possible	Major	Medium risk	Mitigate
A3	Risk of business having decreasing profits	1,2,5,6	Possible	Significant	High risk	Accept & mitigate
A4	The risk of a dramatic increase in inflation	1,2,3,5,6,7	Frequent	Major	Medium risk	Accept & mitigate
A5	Risk due to theft and vandalism	1,2,6	Frequent	Significant	High risk	Avoid
	B. Marketing and sales					
B1	Risk of incorrect sales forecast	1,4,5,6	Possible	Minor	Low risk	Mitigate
B2	Risk that a new competitor	1,2,3,4,5,6,7,8	Rare	Minor	Low risk	Accept
B3	Risk in a low revenue	1,4,5,6,7	Possible	Major	Medium risk	Avoid
B4	The risk of lower demand of product	1,2,3,4,5,6,7	Possible	Significant	High risk	Mitigate
B5	Risk of increased expenses	1,2,4,5,6	Frequent	Major	Medium risk	Avoid & mitigate
B6	The risk of change in market size, geographic and demography	1,2,3,5,6	Possible	Minor	Low risk	Accept
B7	Risk of having a poor marketing strategy	1,2,3,5,6,7	Rare	Minor	Low risk	Avoid
	C. Manufacturing and operations					
C1	The risk of unreliable suppliers	1,2,6	Frequent	Significant	High risk	Mitigate
C2	The risk of power failure or unstable power supply	1,2,6	Frequent	Significant	High risk	Transfer
C3	Risk of lack of research and development	1,6,8	Possible	Minor	Low risk	Transfer
C4	Risk of business having a poor management	2,4,5,6	Possible	Minor	Low risk	Avoid
C5	Risk of low supply of raw materials	1,2	Frequent	Major	Medium risk	Mitigate
C6	Machine breakdown	1,2	Frequent	Significant	High risk	Reduce
C7	The risk of intellectual property loss and liability	1,5,6	Rare	Minor	Low risk	Avoid
C8	Changes in technology	1,2,3,4,6,8	Possible	Major	Medium risk	Accept
	D. Employees					
D1	The risk of workplace accidents/injuries	2,4	Frequent	Significant	High risk	Avoid & Mitigate
D2	Risk that employees striking	1,2,4	Frequent	Significant	High risk	Accept & Mitigate
	E. Customers					
E1	The risk that the product does not meet the customers' expectations	1,2,3,6	Frequent	Minor	Low risk	Accept & Mitigate
	F. External factors					
F1	Risks of natural disasters	1,2	Frequent	Major	Medium risk	Transfer
F2	Risk of unstable political situation	1,2,4,6,7	Possible	Minor	Low risk	Transfer
F3	Risk of global recession or country's economic downfall	1,2,4,5,6	Rare	Minor	Low risk	Transfer

F4	Cheaper competitor	1,2,6,8	Possible	Major	Medium risk	Accept & Mitigate

Appendix W: Mitigation strategy for high level risks

Risk code	Response	Mitigation strategy
A1	**Accept**	In an event were the business fails to acquire investors a bank loan or government grants can be obtained.
A3	**Accept & mitigate**	Appoint an external financial advisor to regular advise the business and audit the reports. The financial advisor would also advise business when and how to invest the profits.
A5	**Avoid & transfer**	Appoint a security company to install surveillance cameras on the premises and security guards to work 24/7.
B4	**Mitigate**	Develop an effective and continuous marketing strategy plan. Introduce a website for online purchasing and orders. Approach various governments and NGOs to purchase the product.
C1	**Mitigate**	Develop a strong relationship with suppliers. Control suppliers with contract regulations. Have alternative suppliers just in case the primary suppliers are unable to supply especially when they have gone bankrupt, run out of supplies or have suffered a catastrophic loss.
C2	**Transfer and mitigate**	Lack of electricity could lead to a standstill during production. The business would have automatic back-up generators for electricity, this allows production to continue without any delays.
C6	**Reduce**	Making sure that maintenance is regularly done on the machine.
D1	**Avoid & mitigate**	Ensure that each worker is familiar with the health and safety procedures at work. Encouraging workers to follow safe work practises. Implement procedures to prevent ergonomic hazards. Appoint someone responsible for safety .Train workers for first aid. Provide the work place with exit doors, fire extinguishers and first aid kits.
D2	**Accept & mitigate**	Pay the workers market related salaries and benefits. Have an open-door policy at work. Respect the workers and listen and address their concerns on time.