A TECHNO-ECONOMIC FEASIBILITY STUDY ON THE USE OF DISTRIBUTED CONCENTRATING SOLAR POWER GENERATION IN JOHANNESBURG

Christiaan César Bode

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2009

The financial assistance of the South African National Energy Research Institute towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to SANERI.

DECLARATION

I declare that this project report is my own unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

____

(Signature of Candidate)

On this _________day of ________________________________ 2009

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all those who provided support and assistance during the compilation of this report.

My supervisor, Professor T.J. Sheer, whose guidance is greatly appreciated.

Professor W. Cronje, of the School of Electrical and Information Engineering at the University who initiated the idea and stimulated my research.

Mr E. Brink, of the Electrical Engineering department at the University, for his assistance with Matlab code.

My parents, Lillias and Peter and my brother Sebastian, who endured my stress and provided much needed support during the research.

Finally to Mr Thomas Roos, DPSS, CSIR, whose passion for Concentrating Solar Power has been inspiring. With his optimism and zeal, these technologies will become a reality in South Africa and his input and assistance have been immeasurable.

ABSTRACT

This study provides an evaluation of Concentrating Solar Power (CSP) technologies and investigates the feasibility of distributed power generation in urban areas of Johannesburg. The University of the Witwatersrand (Wits) is used as a case study with energy security and climate change mitigation being the main motivators.

The objective of the study was to investigate the potential of CSP integration in urban areas, specifically investigating Johannesburg's solar resource. This is done by assessing the performance and financial characteristics of a variety of technologies in order to identify certain systems that may have the potential for deployment.

To aid the comparison of the technologies, CSP performance and cost data which were taken from multiple sources, were adjusted giving it local, present day assumptions. A technology screening process resulted in the conception of twelve alternative design configurations, each with a reference capacity of 120 kW(e). Hourly energy modelling was undertaken for Wits University's West Campus for each of the twelve alternatives. Three configurations were further investigated and are listed below; each with a design capacity of 480 kW(e).

1. Compound Linear Fresnel Receiver (CLFR) field with an Organic Rankine Cycle (ORC).
2. Compound Linear Fresnel Receiver field with an Organic Rankine Cycle that integrates storage for timed dispatch.
3. Compound Linear Fresnel Receiver field with an Organic Rankine Cycle that integrates hybridisation with natural gas.

Levelised electricity costs (LEC) of the systems were used as the basis for financial comparison. Real LECs, for the three configurations above, range between R4.31/kWh(e) (CLFR, ORC) and R3.18/kWh(e) (CLFR, ORC with hybridisation).

With the energy modelling of the hourly direct normal irradiation (*DNI*) input into the CSP systems, Wits University's West Campus Electricity bill was recalculated. The addition of the solar energy input resulted in certain savings and a new LEC that is Wits-specific. These LECs ranged between R3.98/kWh(e) (CLFR, ORC) and R2.77/kWh(e) (CLFR, ORC with hybridisation). A third LEC was calculated that integrates a CSP feed-in tariff (REFIT) of R2.05/kWh. At the time of writing, a CSP REFIT of R2.10/kWh was released which favours the analysis.

The analysis of the 480 kW(e) systems resulted in total plant areas of between 10350 m^2 (CLFR, ORC,) and 15270 m^2 (CLFR, ORC, with storage). With plant modulation, these plants can be placed on vacant land, above parking lots or on top of buildings which would also provide shading.

The values obtained for the average yearly insolation was 1781 kWh/m^2 based on TMY2 data. Johannesburg has a very intermittent source of *DNI* solar energy. The summer months in Johannesburg yield a higher peak *DNI*, whereas the winter months provide a more consistent average. This is due to the high amount of cloud cover experienced in summer. With this insolation, CSP electric generation is possible however, compared to the other locations, it is not ideal. Also, because of its intermittency is has been advised that certain applications such as HVAC and process heat and steam requirements be pursued.

From the results, it can be concluded that power production costs through small scale CSP systems are still higher than with conventional fossil fuel options, however several options that may favour implementation were recognised. Through the analysis it was found that if the CSP generated electricity is valued at the market price (CSP REFIT), the payback time of such systems can be decreased from 73 to 12 years (CLFR, ORC with storage). Further, due to the scale of the plants analysed, the exploitation of high efficiencies and economies-of-scale of plants with power levels above 50 MW(e), is not possible. With the introduction of these technologies at lower power levels, cost savings through the incorporation of other design options (such as waste heat utilisation) should be pursued.

It was recognised that South Africa in general has one of the greatest solar resources in the world and should therefore be technology leaders and pioneers in CSP technology. With greater emphasis being placed on the need for renewable energy systems, it is imperative that South Africa develops its skills and a knowledge base that will work at making the implementation of renewable energy, and in particular CSP generation, a reality. Technologies identified that should be pursued for distributed generation include Linear Fresnel collectors that are easy to manufacture and don't involve complicated receiver systems. There is also scope for developing thermal storage technologies in order to make generation more reliable.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Quantity	Unit
A_a	aperture area of solar field	m^2
A_{Sf}	aperture area of the solar field	m^2
BOP	balance of plant	-
CDM	Clean Development Mechanism	-
CEPCI	chemical engineering plant cost index	-
CER	Certified Emission Reduction	-
CF_{solar}	solar capacity factor	-
CLFR	compound linear Fresnel reflector	-
CSP	concentrating solar power	-
C	concentration factor	-
DNI	direct normal irradiation	$kWh/m^2/a$
E_{net}	net electricity generated	kWh
E_{solar}	net solar electricity generated	kWh
ECOSTAR	European concentrated solar thermal road mapping	-
EPW	energy plus weather	-
fcr	fixed charge rate	-
FV	future value	R/$/€
GCR	ground cover ratio	-
GEF	Global Environment Fund	-
IB	issuing body	-
IEA	International Energy Agency	-
ISCCS	integrated solar combined cycle system	-
HVAC	heating, ventilating and air conditioning	-
k_d	real debt rate	-
k_{insur}	annual insurance rate	-
K_{fuel}	annual fuel costs	R/$/€

K_{invest}	total capital investment	R/$/€
$K_{O\&M}$	annual operating and investment costs	R/$/€
LEC	Levelised Cost of Electricity	(R/$/€)/kWh
MTPP	modular trough power plant	-
n	life of plant/discount period	years
NPO	non-profit organisation	-
NREL	National Renewable Energy Laboratory (USA)	-
ORC	organic Rankine cycle	-
P_{net}	net power output	kW
PPA	power purchase agreement	-
PSA	Plataforma Solar de Almeria	-
PV	present value	R/$/€
$\dot{Q}_{Sf}$	thermal energy delivered by the solar field	kW
$\dot{Q}_{therm}$	thermal energy input to the power cycle	kW
r	interest rate	-
REFIT	renewable energy feed-in tariff	-
SANTRECT	South African National Tradable Renewable Energy Certificate Team	-
SEGS	solar energy generating systems	
S&L	Sargent and Lundy	-
T_A	mean surface temperature of the absorber tube	K
T_{amb}	ambient temperature	K
TES	thermal energy storage	-
TMY2	typical meteorological year	-
TOU	time of use	-
U	convection loss heat transfer coefficient	W/m^2K
Wits	Witwatersrand (University)	-
W_{design}	net design output of the power block	kW

Greek Symbols

Symbol	Quantity	Unit
α	coefficient of absorption of the absorber tube	-
γ	mirror quality factor	-
ε	coefficient of emission of the absorber tube	-
η_{par}	efficiency due to pumping parasitic losses	-
η_{piping}	piping efficiency	-
η_{pbnet}	net power block efficiency	-
η_{opt}	optical efficiency	-
$\eta_{rec/pip}$	receiver/piping efficiency	-
η_{s-e}	net solar to electric efficiency	-
η_{Sf}	solar field efficiency	-
η_{stor}	storage efficiency	-
ξ_{geo}	geometric Efficiency	-
ξ_{IAM}	the incident angle modifier	-
ξ_{S}	shading losses within the solar field	-
ξ_{E}	intercept factor	-
$\xi_{\cos}$	cosine losses	-
ρ	reflectivity of the mirrors	-
σ	Stefan-Boltzmann constant	$W/m^{-2}K^{-4}$
τ_1	transmission factor of the mirror glass cover	-
τ_2	transmission factor of absorber tube	-

1 INTRODUCTION

1.1 Background

The prospects of climate change and, eventually, fossil fuel depletion, trigger a growing interest in renewable energies in general. The benefits of renewable energy systems were clearly defined in a political declaration agreed upon by government representatives of 154 nations at the international "*Renewables 2004*" conference held in Bonn, June 2004 as a follow-up to the 2001 World Summit on Sustainable Development, Johannesburg. Benefits outlined included energy supply security, equity and development, improved health, overcoming peak oil price fluctuations, provision of clean water, close association with energy efficiency measures, climate change mitigation, and the common belief that *"there will be no need for war over solar energy"* (Philibert, 2005).

The use of renewable energy in the world has been implemented for many different reasons. There is a huge drive for renewable energy in Europe mainly because of the focus on reducing emissions and climate change mitigation. South Africa is well endowed with renewable energy resources that can be sustainable alternatives to fossil-fuels, so far these have remained largely untapped. South Africa released a White Paper on Renewable Energy (DME, 2003) where it identified a heavy reliance on coal to meet its energy needs mainly because it has a huge coal resource. However, at the same time South Africa recognises that the emissions of greenhouse gases, such as carbon dioxide, from the use of fossil fuels such as coal and petroleum products has led to increasing concerns worldwide, about global climate change.

The driving force for energy security can be tackled through the diversification of South Africa's supply. The South African economy, which is highly dependent on income generated from the production, processing, export and consumption of coal, is vulnerable to the possible climate change response measures implemented or to be implemented by developed countries. At the same time there are now increased opportunities for energy trade. *"Given increased opportunities for energy trade, particularly within the Southern African region, Government will pursue energy security by encouraging diversity of both supply sources and primary energy carriers. " (DME, 1998)*

For this purpose, the Government will develop the framework within which the renewable energy industry can operate, grow, and contribute positively to the South African economy and to the global environment.

1.2 Motivation

From the background of renewable energy above, three major factors motivating the use of renewable energy have arisen. These are:

- Economic reasons
- Energy security
- Climate change mitigation.

As a result of insufficient electrical power generation infrastructure investment in South Africa in the last two decades compared to economic growth, power outages have been experienced in South Africa since late 2007. This is having a detrimental effect on South Africa's economy and the need for energy security amongst businesses and institutions has arisen.

Electricity production from fossil fuels, particularly coal, is a large contributor to the CO_2 burden. In South Africa some 90% of electricity production is by coal-fired power stations and 30% of liquid fuels are derived from coal via the Fisher-Tropsch process (Roos, 2009). In fact, the Sasolburg Secunda plant is the world's largest point source of CO_2. Recognising this need for renewable energy, this study investigates options to replace electricity production from coal with a *renewable source*.

The University of the Witwatersrand, Johannesburg, (Wits) is experiencing heavy electrical usage. In parallel with an energy usage and a consumption study to understand usage patterns with a view of an energy efficiency strategy, a study was envisioned to investigate alternative energy generation. It is important to note that this study does not aim to provide a solution to financial distress but as in the case of any study, the financial feasibility cannot be ignored and will play a very important role in any implementation decisions.

For these reasons as well as the fact that Johannesburg has a high solar resource (as opposed to other renewable resources - see Section 2.2.2), researchers at Wits University have expressed interest in concentrating solar power (CSP). This study investigates potential distributed power generation solutions for urban areas, with Wits University's West Campus as a case study.

1.3 Objectives

Several studies assessing the feasibility of CSP technologies have been performed but they mainly emphasize large generating stations where land issues are unimportant and can make use of the economies of scale to drive down the Levelised Cost of Energy (LEC). The aim of this report is to review the use and the implementation of several solar-thermal electric technologies in urban environments and to carry out a technical and economic feasibility study applicable to Johannesburg.

There are many benefits regarding the use of renewable energy. Currently costs are certainly not one of these and it will also be part of this study to review these benefits to the University of the Witwatersrand (Wits) by comparing them to current sources of energy. Because of the expressed need and interest, this report could possibly lead to the implementation of some form of solar-thermal technology at Wits University.

Specific objectives identified include:

- To deliver a review of the relevant literature with regard to the development of Solar Thermal power generation.

- To draw a comparison of several of the available technologies outlining specifically what would be suitable in different applications. (e.g. off-grid, on-grid, hybridisation, scaling effects etc)

- To report on the potential for solar thermal technologies in Johannesburg, based on local conditions.

- To perform a technology screening in order to select the system that will best suit implementation at the University of the Witwatersrand.

- To identify suitable technologies and develop a model/conceptual design configurations of possible CSP generating systems for Wits University. This will explore themes which will include:

    - Technical viability - This will show which of the technologies are suitable in terms of functional criteria such as space usage, modularity, maturity of technology etc. It will also assess the suitability of Johannesburg's solar resource with respect to CSP generation.
    - Economic/financial viability - This model will explore different options, showing the financial feasibility in the implementation of the technology, from the equipment costs to the actual running and electricity costs, as well as the savings experienced in different cases.

2 LITERATURE REVIEW

2.1 Utility and Distributed Generation

Utility Scale plants are usually large centralised facilities, such as traditional coal fired plants, which can reach generation capacities of thousands of MWs. These plants have excellent economies of scale, but usually transmit electricity long distances. Most of these plants are built this way due to a number of economic, health and safety, logistical, environmental, geographical and geological factors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace; in addition such plants are often built near collieries to minimize the cost of transporting coal.

Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated near where it is used, perhaps even in the same building. Distributed energy resource systems are small-scale power generation technologies (typically in the range of 3 kW to 10000 kW) used to provide an alternative to or an enhancement of the traditional electric power system (IEEE, 2005).

A report prepared by Hoff (2000) discusses how local governments benefit from distributed resources. Such benefits include:

- Improving the environment
- Guiding economic development
- Ensuring electrical system reliability for constituents
- Providing constituents with energy security
- Providing disaster relief support.

2.2 CSP Technology: Basic concepts

2.2.1 Introduction

Concentrating solar power technologies (CSP) only use solar beam radiation as opposed to diffuse solar radiation, concentrating it several times to reach higher energy densities - and thus higher temperatures when the radiation is absorbed by some material surface. The conversion of this heat into mechanical energy is done using similar processes to conventional power cycles, for example the Rankine cycle, converting heat from burning coal into electricity.

There is a variety of technologies that are available, for example, the Californian 354 MW parabolic trough solar electric generating systems which have been operating for more than 20 years (Pitz-Paal et al., 2005). The major deterrent for solar electricity generation is the relatively high specific investment cost of the solar collector systems.

Concentrating solar power plants offer a very promising option for a sustainable electricity supply. Solar energy, as a source, fluctuates naturally, first as a result of diurnal cycles and secondly as a result of cloud passage, leading to fluctuations in generation. This has led to various technologies that have been developed to solve this intermittency. Because it uses a thermal phase, CSP technologies can easily make power production firm and even dispatchable, either by storing the heat in various forms, or by backing its production by some fossil fuel burning – in both cases using the same steam turbines and generators. Other technologies such as wind power that do not convert thermal energy into electricity can also implement storage but at a higher cost because the price of storing electricity is much higher than storing thermal energy (Pitz-Paal et al., 2005).

CSP technologies are best suited to areas with high direct solar radiation. According to Solel (ISRAEL21c, 2007), a solar thermal plant built on just one percent of the surface of the Sahara Desert could provide the entire world's electricity demands. These areas are widespread, but not universally found over the globe.

Recognising both the environmental and climatic hazards to be faced in the coming decades and the continued depletion of the world‘s most valuable fossil energy resources, concentrating solar thermal power can provide critical solutions to global energy problems within a relatively short time frame and is capable of contributing substantially to carbon dioxide reduction efforts. Among all the renewable technologies available for large-scale power production today and for the next few decades, CSP is one with the potential to make major contributions of clean energy because of its relatively conventional technology and ease of scale-up.

2.2.2 Solar Energy Resource

Before introducing the CSP technologies, the solar resource requirement is defined. Solar thermal power can only use direct sunlight, called ‘beam radiation’ or Direct Normal Irradiation (*DNI*), i.e. that fraction of sunlight which is not deviated by clouds, fumes or dust in the atmosphere and that reaches the earth’s surface in parallel beams for concentration. Hence, it must be sited in regions with high direct solar radiation. Suitable sites should receive at least 1700 kilowatt hours (kWh) of sunlight radiation per m^2 annually (Stine and Geyer, 2008), whilst best site locations receive more than 2800 $kWh/m^2/year$. Typical site regions, where the climate and vegetation do not produce high levels of atmospheric humidity, dust and fumes, include steppes, bush, savannas, semi-deserts and true deserts, ideally located within less than 40 degrees of latitude north or south. Therefore, the most promising areas of the world include the South-Western United States, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Near and Middle East, Iran and the desert plains of India, Pakistan, the former Soviet Union, China and Australia (Stine and Geyer, 2008). This is shown in Figure 2.1.

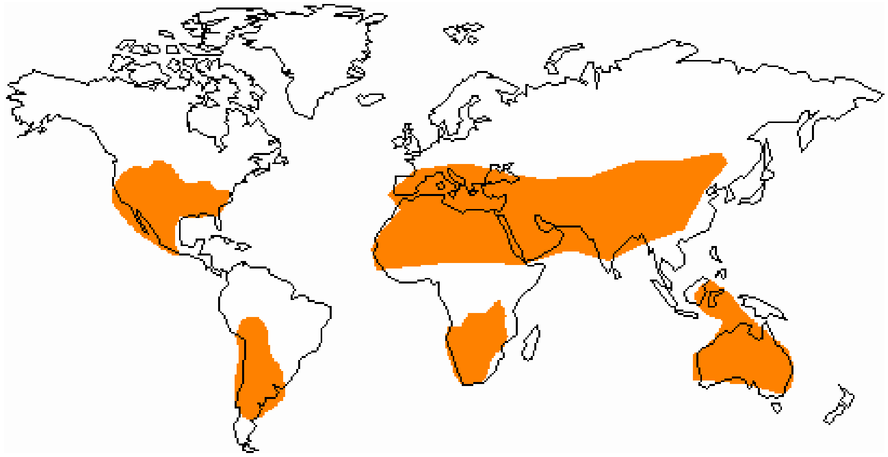


Figure 2.1: The World's Solar Resource (Stine and Geyer, 2008)

When it comes to siting in urban areas, it is important to bear in mind that there may be different design considerations such as the fact that structures found in urban areas such as buildings and towers may cast shadows onto the catchment area which may be on a field or even on top of other buildings. It will be important to consider each situation. It will be assumed that the solar data collected will be completely available at the chosen site.

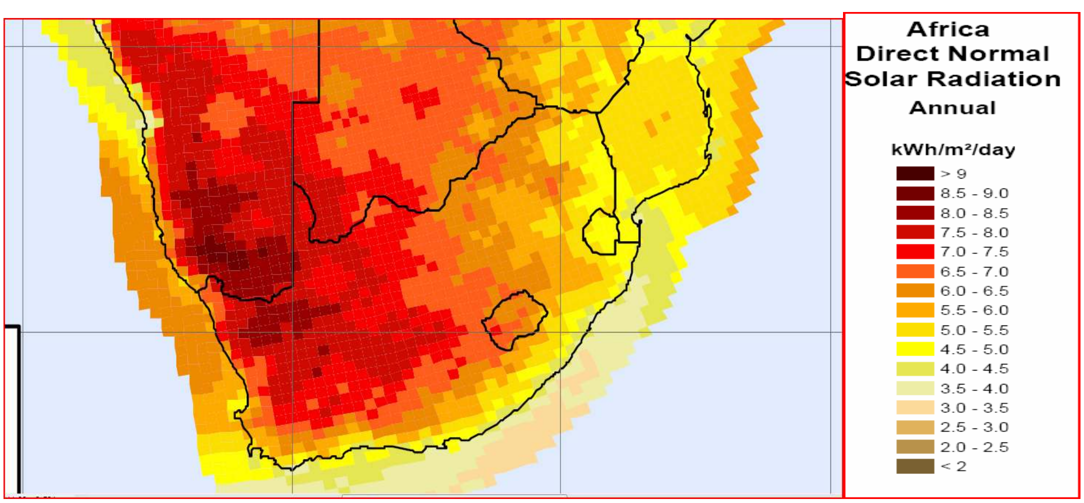


Figure 2.2: Annual *DNI* Data for South Africa (NREL, 2008)

Figure 2.2 shows the *DNI* data with 40 km^2 sensitivity. Accordingly the *DNI* for the Johannesburg region is typically between 5.0 - 6.0 $kWh/m^2/day$ which equates to 1825-2190 $kWh/m^2/year$.

2.3 Collector Types

The solar thermal technologies to be evaluated in this study vary, but most can be classified into the following broader categories:

- Line Focussing Systems
    - Trough Technology
    - Linear Fresnel Collectors.
- Point Focussing Systems
    - Central Receiver Technology
    - Dish-Stirling.
- Non-Concentrating type
    - Solar Chimney.

2.3.1 Parabolic Trough Collector System

Parabolic trough power plants are line-focusing CSP plants. Trough systems use the mirrored surface of a linear parabolic concentrator to focus direct solar radiation on an absorber pipe running along the focal line of the parabola (Figure 2.3). The heat transfer fluid inside the absorber pipe is heated and pumped to the steam generator, which, in turn, is connected to a steam turbine (STI, 2005) (Shown in Figure 2.4).

Figure 2.3: Parabolic Trough CSP Plant in the Mojave Desert (Sitenet, 2008)

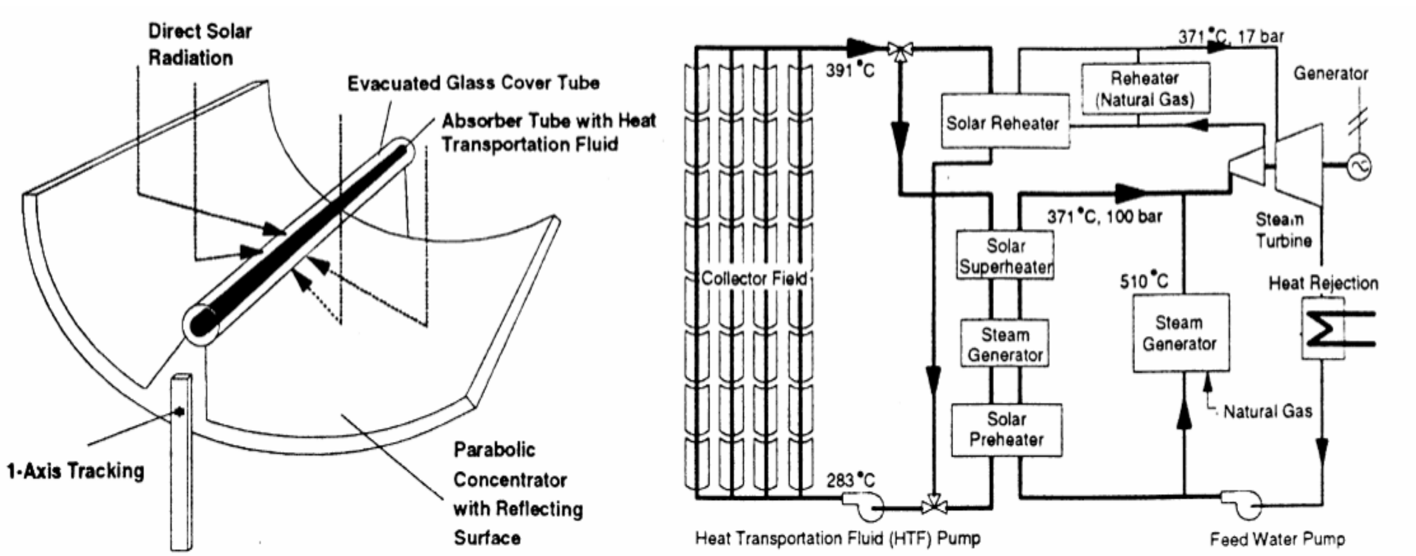


Figure 2.4: Parabolic Trough and Power Plant of SEGS Type (Beerbauma and Weinrebeb, 2000)

2.3.2 Compound Linear Fresnel Reflector (CLFR)

In the CLFR configuration, large fields of modular Fresnel reflectors concentrate beam radiation to a stationary receiver several metres high. This receiver contains a second stage reflector that directs all incoming rays to a tubular absorber (Häberle et al., 2002).

Figure 2.5: CLFR System (Power Technology, 2009)

Mills and Morrison (2000) describe an advanced CLFR technology, noting several technological aspects that need to be developed further. This concept includes a secondary reflector, installed to help direct the insolation onto the absorber. The advantage of this system is that it allows for densely packed arrays, because patterns of alternating reflector inclination can be set up such that the closely packed reflectors can be positioned without shading and blocking. The 'interleaving' of mirrors between two linear absorber lines is shown in Figure 2.6.

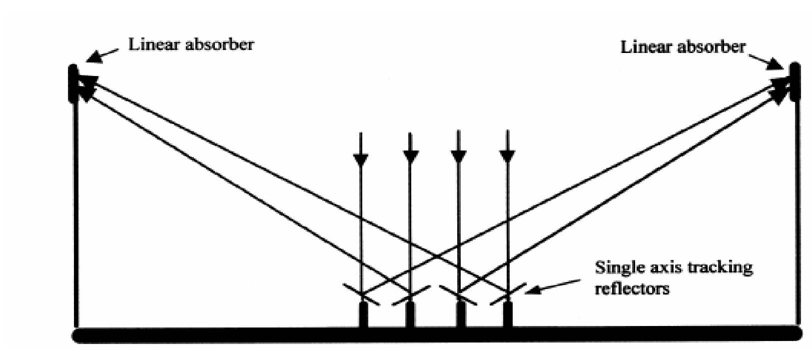


Figure 2.6: Schematic Diagram Showing Interleaving Mirrors of the CLFR Collectors (Mills and Morrison, 2000)

This arrangement minimizes beam blocking between adjacent reflectors and allows higher reflector densities and lower absorber tower heights to be used. Available area can be restricted in industrial or urban situations. Avoidance of large reflector spacing and high towers are an important cost issue when one considers the cost of ground preparation, array structure and tower structure. Using the CFLR reflectors for generation of steam, however, offers no obvious form of thermal storage (Section 2.4.1), only offering generation during sunlight hours.

The CLFR power plant, designed by Mills and Morrison (2000), includes the following additional features which enhance the system cost/performance ratio. Points a) and b) being unique to this design.

a) The array uses flat or elastically curved reflectors instead of costly sagged glass reflectors. The reflectors are mounted close to the ground, minimising structural requirements.

b) The heat transfer loop is separated from the reflector field and is fixed in space thus avoiding the high cost of flexible high pressure lines or high pressure rotating joints as required in the trough and dish concepts.

c) The heat transfer fluid is water, and passive direct boiling heat transfer could be used to avoid parasitic pumping losses and the use of expensive flow controllers. Steam supply may either be direct to the power plant steam drum, or via a heat exchanger.

d) All-glass evacuated tubes with very low radiative losses can be used as the core element of the linear absorber array.

e) Maintenance will be lower than in other types of solar concentrators because of nearly flat reflectors and ease of access for cleaning, and because the single ended evacuated tubes can be removed without breaking the heat transfer fluid circuit.

2.3.3 Central Receiver Technologies

A circular array of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and this thermal energy is be used for the subsequent generation of electricity in a Rankine or Brayton cycle turbine (Figure 2.8). To date, the heat transfer media demonstrated includes water/steam, molten salts, liquid sodium and air. If pressurised gas or air is used at very high temperatures of about 1,000°C or more as the heat transfer medium, it can even be used to directly replace natural gas burning in a gas turbine, thus making use of the excellent cycle efficiency (60% and more) of modern gas and steam combined cycles (STI, 2005). Such a system is shown below in Figure 2.7.

Figure 2.7: Central Receiver Plant (CSP, 2008)

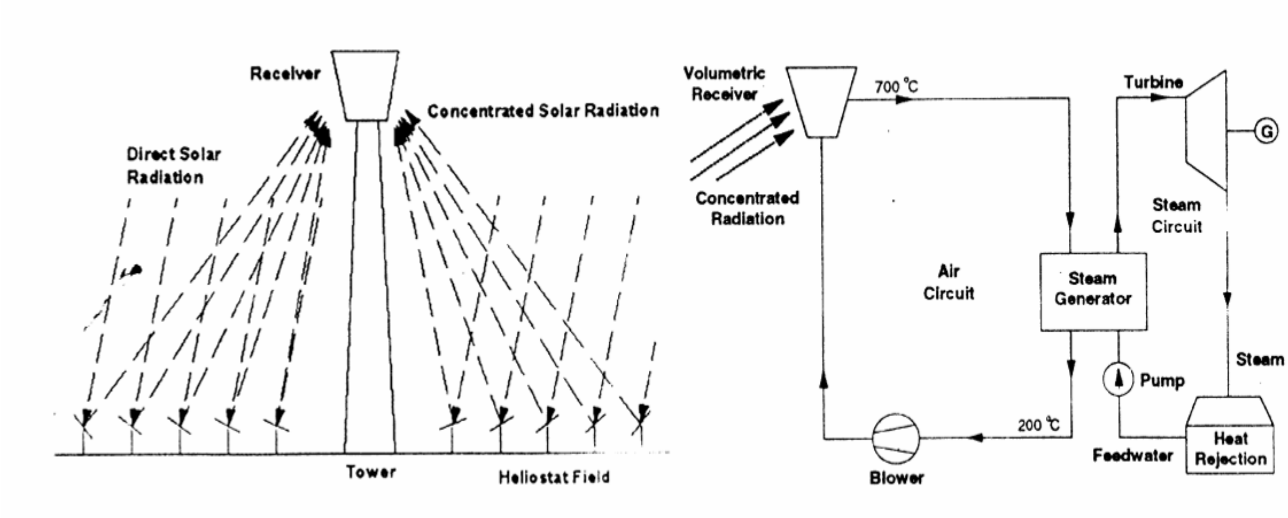


Figure 2.8: Central Receiver, PHOEBUS Schematic (Beerbauma and Weinrebeb, 2000)

2.3.4 Dish-Stirling Systems

A parabolic dish-shaped reflector is used to concentrate sunlight on to a receiver located at the focal point of the dish. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas (air) to approximately 750°C. This fluid or gas is then used to generate electricity in a small piston or Stirling engine or a micro-turbine, attached to the receiver. A photo and schematic of the Dish-Stirling system is shown below in Figure 2.9 and Figure 2.10 respectively.

Figure 2.9: Dish-Stirling System (Pitz-Paal et al., 2005)

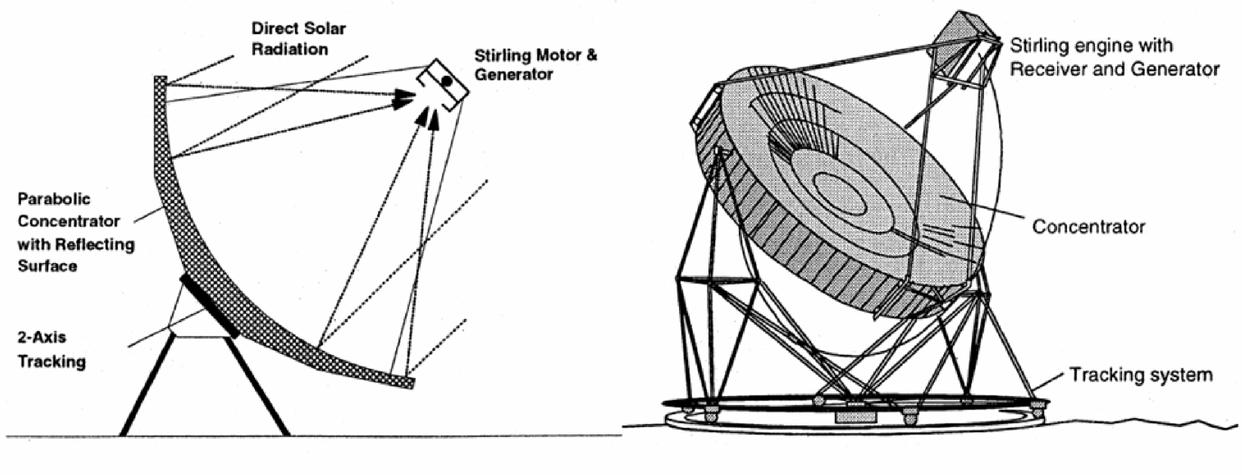


Figure 2.10: Dish Stirling System of a Schlaich Bergerman 10 kW (Beerbauma and Weinrebeb, 2000)

2.3.5 Solar Chimney Technology

The solar chimney consists of three essential elements: the solar collector, vertical chimney and wind turbine. The solar collector consists of a transparent circular roof which is open along the outside edge and situated near the ground. As the sun heats the ground, it heats the air within the roof. The rise in air temperature as well as the density decrease induces the heated air to rise through the vertical chimney in the centre. This rising air turns a wind turbine to create electrical energy through the conversion of kinetic energy. The warm rising air is constantly replaced by cool air flowing in through the sides. Based on the test results, it was estimated that a 100 MW plant would require a 1000 m tower and a greenhouse of 20 km^2 (Haaf et al., 1983). A schematic of this system is shown below in Figure 2.11.

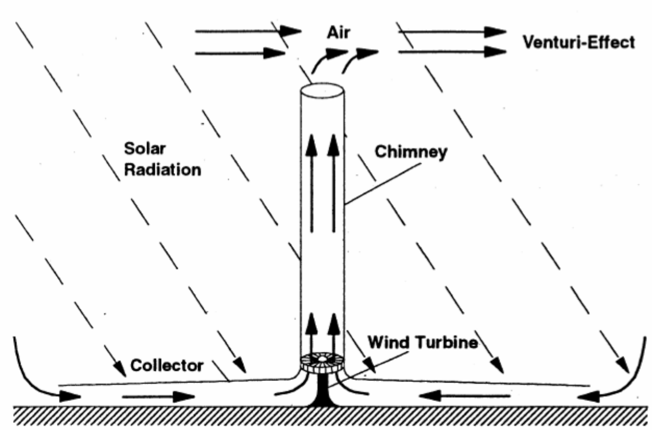


Figure 2.11: Solar Chimney Technology (Beerbauma and Weinrebeb, 2005)

2.4 Variations in Design and Common Technologies

2.4.1 Storage

Most renewable resources, including solar radiation, are intermittent in nature. A distinct advantage of CSP plants compared with other renewable energies, such as photovoltaic cells (PV) and wind, is the possibility of using relatively cheap storage systems. That is, storing the thermal energy itself, a method which is financially more feasible than storing electricity.

The principal options for using Thermal Energy Storage (TES) in a solar thermal system highly depend on the daily and yearly variation of radiation and on the electricity demand profile.

The main options, as identified by Pilkington Solar (2000), are:

- Buffering
- Delivery period displacement
- Delivery period extension.

The goal of a *buffer* is to smooth out transients in the solar input caused by passing clouds, which can significantly affect operation of solar electric generating systems.

The efficiency of electrical production will degrade with intermittent insolation. Buffer TES systems would typically require small storage capacities (maximum 1 hour full load).

Delivery period displacement requires the use of a larger storage capacity. The storage shifts some or all of the energy collected during periods with sunshine to a later period (possibly periods that have higher tariffs etc). This type of TES does not necessarily increase either the solar fraction or the required collection area. The typical size ranges from 3 to 6 hours of full load operation.

The size of a TES for *delivery period extension* will be of similar size (3 to 12 hours of full load). However, the purpose is to extend the period of power plant operation with solar energy. This TES increases the solar fraction and requires larger solar fields than a system without storage. The operating model of such a system is given in Figure 2.12 where additional thermal energy is collected during the day and is utilised for electric generation after sun-set.

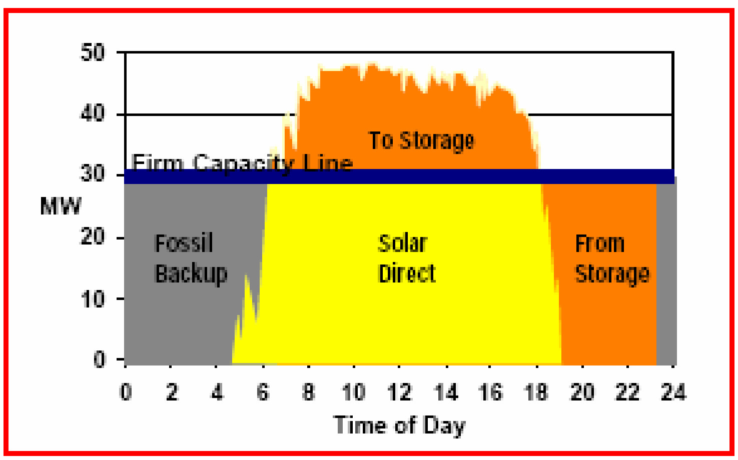


Figure 2.12: Delivery Period Extension (Geyer, 1999)

Design Criteria

A key issue in the design of a thermal energy storage system is its thermal capacity - the amount of energy that it can store and provide. However selection of the appropriate system depends on many cost-benefit considerations (Pilkington, 2000).

The cost of a TES system mainly depends on the following items:

- The storage material itself
- The heat exchanger for charging and discharging the system
- The cost for the space and/or enclosure for the TES

Pilkington outlines the most important design criteria as well as the crucial technical requirements when choosing suitable storage technologies. Different storage concepts are further discussed in Appendix A.

2.4.2 Hybrids

Hybrid systems, which make use of fossil fuels, are often used to make CSP investments bankable. Solar energy can also be used to reduce fossil fuel usage and/or boost the power output to the steam turbine (Kolb, 1998).

Typical daily power output from the hypothetical "*power boost*" hybrid power plant is depicted in Figure 2.13. From the figure it can be seen that in a power boost hybrid plant, a solar-only plant is "piggybacked" on top of a base-loaded fossil-fuelled plant. In the power boost hybrid plant, additional electricity is produced by over-sizing the steam turbine, contained within a coal-fired Rankine plant or the bottoming portion of a combined-cycle plant, so that it can operate on both full fossil and solar energy when solar is available. Studies of this concept have typically oversized the steam turbine from 25% to 50% beyond what the turbine can produce in the fossil-only mode (Kolb, 1998). Over-sizing beyond this range is not recommended because the thermal-to-electric conversion efficiency will degrade at the part loads associated with operating in the fuel-only mode. This over sizing of the steam turbine has been typically proposed for many of the World Bank and Global Environment studies where they would make use of parabolic troughs as the solar collector in the ISCCS proposals (see Section 2.4.3).

In the "*fuel saver*" plant, the fuel usage is reduced when solar energy is available and electricity output is constant. In a Rankine-cycle application, the solar steam generator can be sized to provide the entire input to the steam turbine or a fractional amount. When hybridising, it is preferred to contribute a fractional amount of heat from solar. This keeps the fossil boiler hot all the time and prevents daily start-up losses and thermal cycles. The Solgate study that uses high temperature volumetric air in the receiver of the Central receiver makes use of the "fuel saver" principle (Pitz-Paal et al., 2005).

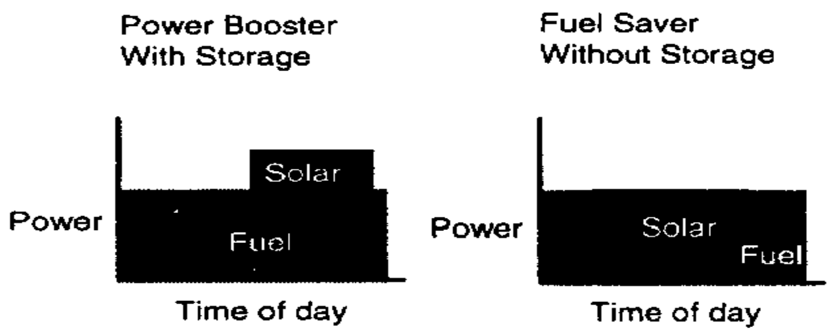


Figure 2.13: Power Booster and Fuel Saver in Hybrid Alternatives (Kolb, 1998)

2.4.3 Integrated Solar Combined Cycle System (ISCCS)

The ISCCS configuration has been considered for a number of Global Environment Fund (GEF) trough projects (World Bank, 2006). The ISCCS integrates solar steam into the Rankine steam bottoming cycle of a combined-cycle power plant (Schematic shown in Figure 2.14). The general concept is to oversize the steam turbine to handle the increased steam capacity. At the high end, steam turbine capacity can be approximately doubled, with solar heat being used for pre-heating and superheating steam. Unfortunately when solar energy is not available, the steam turbine must run at part load and thus reduced efficiency. Doubling the steam turbine capacity would result in a 25% design point solar contribution. Because solar energy is only available about 25% of the time, the annual solar contribution for trough plant without thermal storage would only be about 10% for a base-load combined –cycle plant (Price and Kearney, 2003).

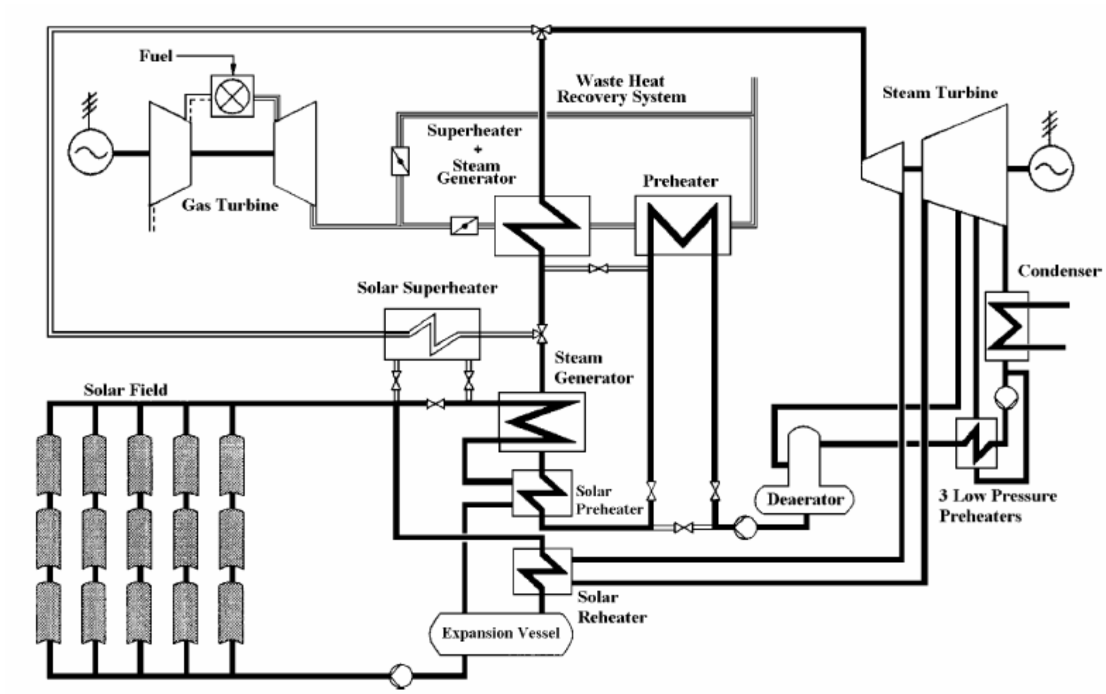


Figure 2.14: Schematic of an ISCCS System (Hosseini et al., 2005)

2.4.4 Direct Steam Generation (DSG)

In the Direct Steam Generation (DSG) concept, steam is generated directly in the parabolic-trough collectors. There is a reduction of costs found in the elimination of traditional heat transfer fluid through the use of DSG (Price and Kearney, 1999). This technology also reduces efficiency losses in the heat transfer process. DSG should also improve the solar field operating efficiency due to lower average operating temperatures and improved heat transfer in the collector receiver. The trough collectors would require some modification due to the higher operating pressure and lower fluid flow rates. Control of a DSG solar field is more complicated than traditional systems and may require a more complex design layout and a tilted collector. DSG also makes it more difficult to provide thermal storage. A pilot plant was demonstrated at the Plataforma Solar de Almería (PSA) in Spain (Price and Kearney, 1999).

2.4.5 Organic Rankine Cycles (ORC)

Traditionally, Organic Rankine Cycle Plants (ORC) are used for lower temperature heat sources such as geothermal or waste heat recovery. The low resource temperature results in low efficiency of the ORCs; however, ORCs can be designed to operate at substantially higher efficiencies with trough systems. ORCs use organic (hydrocarbon) fluids that can be selected to best match the heat source and heat sink temperatures (Prabhu, 2006).

ORCs operate at lower temperatures than steam Rankine systems and thus can reduce trough operating temperatures from 390 ˚C to 304 ˚C. This means that an inexpensive heat transfer fluid such as Caloria may be used instead of the existing fluid. Since Caloria is inexpensive, it can be used in a simple two-tank thermal storage system similar to the thermal storage system at the SEGS I plants in the Mojave Desert. Lower solar field operating temperatures are likely to translate into lower capital cost and more efficient solar field equipment (Prabhu, 2006).

If a water resource is scarce ORCs can also be designed to use air-cooling for the power cycle (as can be done for other cycles). This and the fact that the power cycle uses a hydrocarbon for a working fluid (instead of steam) means that the plant needs virtually no water to operate. Water consumption is reduced by 98%. Mirror washing is only about 1.5% of the water use at the SEGS plants, meaning that the water contribution to cleaning will be minimal (Prabhu, 2006).

These plants are capable of automatic start-up, safe shutdown, and regulation with varying solar conditions. Because of their simplicity they can generally be operated remotely. This helps to reduce operating and maintenance (O&M) costs which have been one of the key reasons for concentrated solar power (CSP) technologies to increase in size.

ORC systems have a number of disadvantages as well. ORC systems generally have lower efficiencies than steam cycles that run at higher temperatures and pressures. However, the efficient steam cycles come at the price of more capital investment and the need for higher resource temperatures. The use of air-cooling means that ORC cycles are negatively impacted by high ambient temperatures (Prabhu, 2006).

2.5 Data Sources

As already stated, several studies on the feasibility of the use of CSP generation have been performed, ranging from technology-specific to purely economic comparisons. The majority of these detailed reports have come from large organisations such as the National Renewable Energy Laboratory (NREL) in the USA. The following is a list of some of these more detailed reports, each listed with the year of respective publication.

- Solar Electric Generation – A Comparative Overview, 1997
- Eskom CSP Pre-feasability Study, 2001
- Modular Trough Power Plants (MTPP), 2001
- Solarmundo line focussing Fresnel collector, 2002
- Assessment of Parabolic Trough and Power Tower Solar Technology, 2003
- European Concentrated Solar Thermal Road-Mapping Report, 2005
- The Present And Future Use Of Solar Thermal Energy, 2005
- California studies for NREL, 2005, 2006
- Assessment of the World Bank Group/GEF Strategy, 2006.

2.5.1 Solar Electric Generation – A Comparative Overview (1997)

Trieb et al. (1997) conducted a comparative review of different technologies, costs and environmental impacts of solar electricity generation. The study shows that the different approaches cover a wide range from units producing a few Watts to utility-scale plants and from isolated to grid-connected systems.

Trieb et al. also identified two technical solutions to address the many drawbacks of solar thermal technology. The *first solution* is the hybridisation of solar power plants with fossil back-up systems. A fossil back-up system will allow for the compensation of solar input fluctuations and permits night-time operation increasing the total capacity factor. The *second solution* is the integration of energy storage systems into the solar plant. This will also allow for the compensation of solar input fluctuations with storage being possible for as long as 12 hours. This, however, does increase the solar multiple and increase the capital costs of the system quite significantly. (The solar multiple is the size of solar field relative to a field providing 100% design power at peak collection times. This means a solar multiple of 1.2 represents a field that delivers 20% more energy at solar noon than is required by the heat engine generator).

Trieb et al. identified several advantages and disadvantages of the various technologies and these have been listed below.

Table 2-1: Advantages and Disadvantages of CSP

	Advantages	Disadvantages
Dish-Stirling	• Stand-alone units • Very high concentration ratios, working temperatures and efficiencies • Long term experience with small scale power plants and single units. • Options for distributed as well as centralised electricity supply systems • Modularity of the system, benefits of mass production, no scale restriction • Simple operation and maintenance.	• Low power availability and few annual full load hours • Requires rigid support structures and perfect tracking that leads to high costs • No experience with large-scale utility scale systems • Water requirement for cleaning.
Solar Chimney	• The glass collector uses diffuse and beam radiation. • The soil under the collector acts as heat storage, avoiding sharp fluctuations and allowing power supply after sunset. • Easily available and low cost materials for construction • Simple, fully automatic operation • No water requirements.	• Very low solar to electric conversion efficiency • Hybridisation not possible • Equivalent full load hours restricted to approximately 2500h/a. • Large completely flat areas required for the collector • The high tower needed results in a large material requirement for the system.
Central Receiver	• High solar efficiencies • High steam temperatures • Simple hybridisation with fuel oil or natural gas. • Modular solar components (heliostats) with high mass production potential • Simple operation strategy • Process steam generation for eventual cogeneration.	• The solar energy and the fossil backup fuel are converted to electricity with relatively low steam cycle efficiency. • Heliostats require very stable supports for the mirrors and two axis tracking. • Water needed for mirror cleaning. • They are suited mainly for large scale electricity generation.

2.5.2 Eskom CSP Pre-feasibility Study (2001)

In 2001 Eskom performed a state-of-the-art review of CSP technologies with the goal of implementing a utility scale power plant in South Africa. Several technology options were considered, while detailed design evaluations of a Central Receiver and Parabolic Trough system were considered. A full economic study as well as an environmental assessment for the Northern Cape was performed (van Heerden, 2001). This study was co-funded by the Global Environment Fund as well as the World Bank. It is not publicly available information but has been provided by the CSIR who has been given rights to it from the World Bank.

The study comprised three tasks; these have been identified as follows:

- The identification of fourteen different CSP technologies and their design variations. Information was compiled from the published literature and demonstration and operational plants where available.
- The second task involved the compilation of Typical Meteorological Year data (TMY) for the reference site in Upington as well as a full strategic environmental assessment for the Northern Cape Province.
- The third task involved the development of a simulation model that would predict the performance of two selected technologies each at 100 MW(e). A full economic assessment and optimisation was performed on these technologies.

Eskom concluded that the central receiver technologies and parabolic trough technologies, at the time of writing, have equivalent competitiveness. The central receiver technologies, however, offered the greatest potential for cost reductions in the future. By introducing a 100 MW(e) pilot plant in Upington, Eskom would be able to produce the cheapest solar electricity in the world. CSP generated power will be more costly than coal power for the foreseeable future but still remains an attractive electricity source, primarily for peaking power production, because of its environmental benefits.

2.5.3 Modular Trough Power Plants (MTPP) (2001)

In their paper, Hassani and Price, (2001) recognized that a number of factors are creating an increased market potential for small trough power technology. They conducted research into the feasibility of Modular Trough Power Plants (MTPP). The reasons for conducting the research are as follows:

- There is a need for distributed power systems for rural communities worldwide.
- The need to generate more electricity by non-combustion renewable processes.
- The need for sustainable power for economic growth in developing countries.
- The deregulation and privatisation of the electrical generation sector worldwide.

Hassani and Price concluded that the ORC power cycles and parabolic trough solar collector technology have been successfully demonstrated separately. With the current state of these technologies, the modular trough power plant is a technologically viable concept. Their analysis indicates that cycle efficiencies in the range of 23% for a solar resource temperature of 580 ˚F (304 ˚C) are possible. Their analysis was performed using meteorological data in Barstow, California with a net electric capacity of the plant being 1 MW(e). Using cost and performance assumptions outlined in their report, a cost of power around $0.20/kWh (2001) appears to be feasible.

2.5.4 Solarmundo line focussing Fresnel collector (2003)

The Belgian company Solarmundo claim that its Fresnel collector is more cost effective than existing CSP-systems. Solarmundo operates a 2500 m^2 prototype in Liège, Belgium (Häberle et al., 2002).

In their paper Häberle et al. present optical and thermal properties of the Solarmundo collector, which were calculated using ray-tracing and computational fluid dynamics simulations. It is the basis for a simulation model to calculate the thermal output of the collector for different sites. The behaviour of Fresnel collectors compared to parabolic troughs is also discussed. An outlook on the achievable costs of electricity is given.

2.5.5 Assessment of Parabolic Trough and Power Tower Technology (2003)

NREL has produced an assessment of parabolic trough and central receiver costs and performance forecasts. The assessment was performed by the consulting group Sargent and Lundy LLC (S&L, 2003).

The following are specific themes that Sargent and Lundy investigated:

- The examination of the current trough and tower baseline technologies that are examples of the next plants to be built, including a detailed assessment of the cost and performance basis for these plants.
- Analysis of the industry projections for technology improvement and plant scale-up to 2020, including a detailed assessment of the cost and performance projections for future trough and tower plants based on factors such as technology R&D progress, economies of scale, economies of learning resulting from increased deployment, and experience-related O&M cost reductions resulting from deployments.
- Assessment of the level of cost reductions and performance improvements that, based on Sargent and Lundy experience, are most likely to be achieved, and a financial analysis of the cost of electricity from such future solar trough and tower plants.

Sargent and Lundy concluded that CSP is a proven technology for energy production, and that significant cost reductions are achievable assuming that reasonable deployment of CSP technologies occurs. Sargent and Lundy independently projected capital and operating and maintenance costs, from which the levelised energy costs were derived, based on a conservative approach whereby the technology improvements are limited to current demonstrated or tested improvements.

In their report Sargent and Lundy identified several market barriers that need to be overcome to aid the implementation of CSP technologies in bulk scale generation facilities. For CSP technologies to reach market acceptance the following market entry barriers need to be overcome:

- Market expansion of trough and tower technology will require incentives to reach market acceptance (competitiveness). Both tower and trough technology currently produce electricity that is more expensive than conventional fossil-fuelled technology. Analysis of incentives required to reach market acceptance was not within the scope of the report.
- Significant cost reductions will be required to reach market acceptance (competitiveness). Sargent and Lundy focused on the potential of cost reductions with the assumption that incentives will occur to support deployment through market expansion.

They also concluded that cost reductions are achievable for CSP systems, assuming reasonable deployment occurs. They predicted projected energy costs, reductions and performance improvements for the long term (2020). These are summarised in Figure 2.15. This figure describes cost reductions with time. This is based in turn on cost reductions with numbers of units in the field. The Sunlab study referred to in Figure 2.15 forms the basis for comparison.

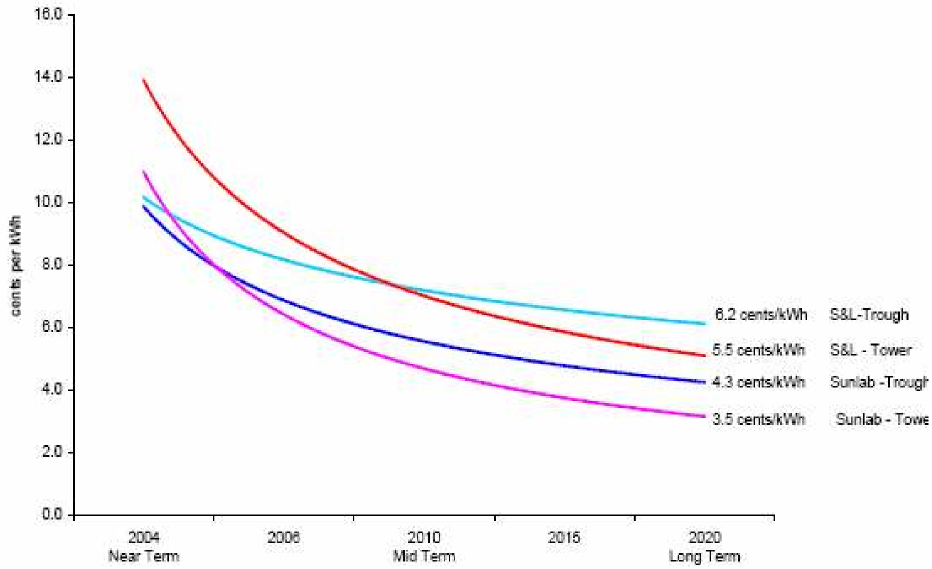


Figure 2.15: S&L Cost Reduction Potential of CSP (S&L, 2003)

To arrive at a credible prediction, Sargent and Lundy went into great detail outlining all the technologies involved in each system, comparing them as well as costs to various existing systems and predictions made by other organisations, for example the SunLab cost model, outlining the differences in methodologies as well as results.

No marketing analysis was performed in terms of the power generation market and its associated issues. Included in such an analysis would be the required incentives needed for effective deployment.

The Sargent and Lundy report did not include a bottom-up cost estimate. Instead, Sargent and Lundy drew heavily from industry experience, vendor quotes, and other sources rather than recreate all this analysis on its own. The methodology used by Sargent and Lundy stands on its own as a credible assessment of the status and potential of parabolic trough and central receiver technologies. The results obtained in the Sargent and Lundy study are insufficient for the current study because of the scaling differences and other assumptions used.

The appendices in the Sargent and Lundy report are quite extensive and detail methods of calculation for different aspects of the feasibility. These have been used in this report, for example the same scaling methods were followed. Also the equations used in the calculation of the solar capacity factor, field area, LEC and availability were used in this report.

2.5.6 European Concentrated Solar Thermal Road-Mapping Report (2005)

The European Concentrated Solar Thermal Road-Mapping Report (ECOSTAR) is a document prepared for the EU which compares major CSP technologies under the following objectives (Pitz-Paal et al., 2005):

- To identify the potential European technical innovations with the highest impact on CSP cost reduction.
- To focus the European research activities and the national research programs of the partners involved on common goals and priorities.
- To broaden the basis of industrial and research excellence and to solve multidisciplinary, CSP specific, problems.

The approach of the document was to analyse the impact on cost of different innovations applied to a reference system in order to identify those with the highest impacts. Cost and performance information of the reference systems used were at different levels of maturity. The evaluation therefore focused on the identification of the major cost reduction drivers for each of the considered reference systems and identified the impact of technical innovation approaches. This led to recommendation on R&D priorities as well as to recommendation on changes in the political framework needed to achieve a successful deployment. The methodology for the cost study is depicted in Figure 2.16.

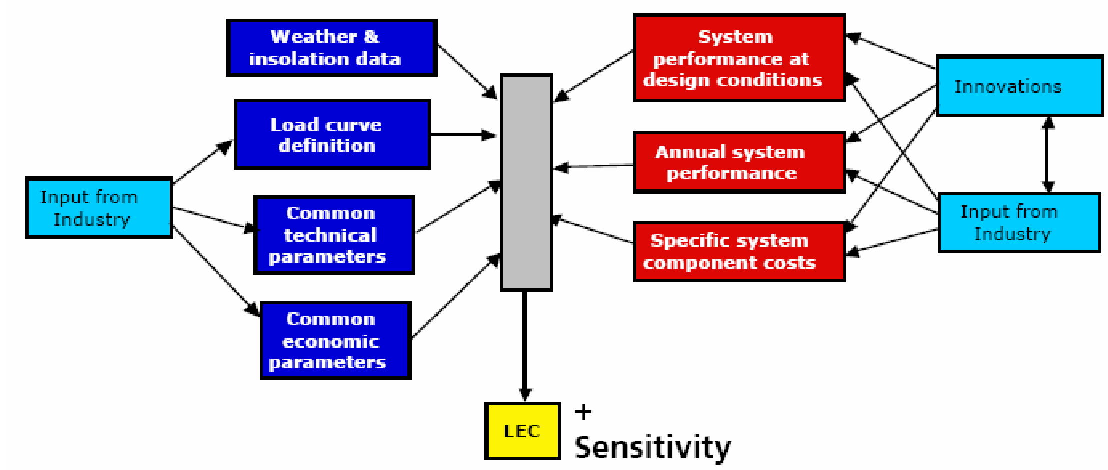


Figure 2.16: Methodology for the Ecostar Cost Study (Pitz-Paal et al., 2005)

In their conclusion they identified different classes of innovation whereby uncertainty is addressed by providing optimistic and pessimistic bounds on the input data for the performance and cost model, resulting in appropriate bounds for the LEC values and cost reduction percentages.

Many of the systems considered are planned for commercial deployment in Spain, which at the time of reporting recently enacted an incentive of around 21 cents€/kWh for solar thermal electricity (Technologies found in Appendix B). The present ECOSTAR evaluation estimates levelised electricity cost of 17-18 cents€/kWh for initial systems currently being built and some completed systems in Spain. These cost estimates will probably deviate from electricity revenues needed for the first commercial plants in Spain because they were evaluated using a simplified methodology including the financing assumptions recommended by the IEA (1991) for comparative studies like this.

The other technologies analyzed are currently planned in significantly smaller pilot scales of up to 15 MW(e). The LEC is significantly higher for these small systems ranging from 19 to 28 cents€/kWh. Assuming that several of the smaller systems are built at the same site to achieve a power level of 50 MW and take benefit of a similar O&M effort as the larger plants, LEC estimates of all of the systems also range between 15 and 20 cents€/kWh. The systems achieve a solar capacity factor of up to 30% under these conditions (depending on the availability of storage).

Figure 2.17 shows the cost reduction potential as predicted by the ECOSTAR roadmap for the 7 CSP technologies investigated in the study based on the LEC for the 50 MW(e) reference systems and assuming a combination of selected innovations for each system.

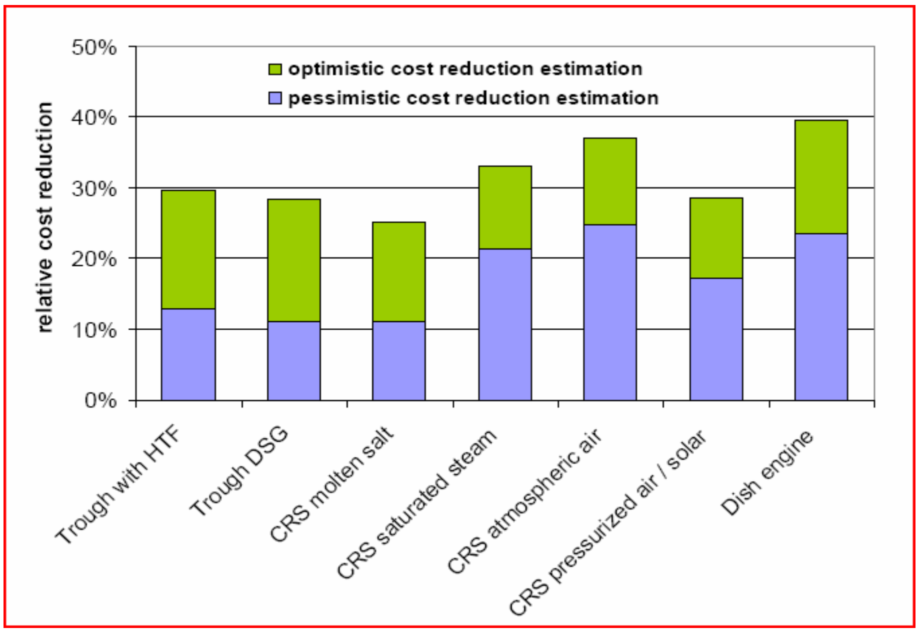


Figure 2.17: Ecostar Cost Reduction Potential (Pitz-Paal et al., 2005)

Method used in Ecostar

Ecostar performed a major comparison between several of the existing CSP systems. The goal of the Ecostar study is the comparison of different technical innovations, therefore any project specific data (e.g. tax influences, or financing conditions) are neglected. The approach is kept simple, but it is appropriate to perform the relative comparison necessary to quantify the impact of different innovations.

The model uses common assumptions for the site, meteorological data and load curve. The common assumptions used in the ECOSTAR model are as follows:

The site under analysis is Seville, Spain 5.9 ° W, 37.2° N, 20 m above sea level, land costs 2,000,000 €/km^2. Meteorological data and Direct Normal Irradiance for Seville are used. (*DNI* 2014 kWh/m^{2}a; average Temp 19,5C°, Min = 4,1°C, Max = 41,4°C). It is analysed in free-load operation or in hybrid operation with 100% load between 9:00 a.m. and 11:00 p.m. every day. An average availability of 96% to account for forced and scheduled outages results in a capacity factor of 55%.

The Ecostar model calculates the annual electricity production hour by hour, taking into account the instant solar radiation, load curve, part load performance of all components (depending on load fraction and ambient temperature), operation of thermal energy storage, and parasitic energy requirements.
The reference size of all systems is assumed to be 50 MW(e) net.

2.5.7 The Present and Future Use of Solar Thermal Energy (2005)

Philibert (2005) produced a report for the International Energy Agency (IEA) on the present and future use of solar thermal energy. His review not only included the use of CSP technologies but other solar thermal technologies such as the use of passive solar architecture and the production of fuels which provides an interesting discussion on the extent and possibilities of solar thermal applications.

2.5.8 California Studies for NREL (2005, 2006)

NREL also commissioned a project with the goal to evaluate the feasibility of developing up to 1000 MW(e) of parabolic trough solar thermal power plants to serve municipal utility electricity demand in the State of California. This was presented to NREL by Solargenix Energy (Solargenix Energy, 2005).

The objectives as laid out in the document were to:

- Estimate the relative performance and cost in different regions of the state
- Examine siting issues for solar parabolic trough power plants.
- Identify specific permitting requirements, with an emphasis on unique issues associated with this technology.
- Discuss technology options that include a reduction of cooling water consumption and add a thermal storage capability to the plants.
- Explore financial and business models, and associated incentives, that might lead to accelerated development and deployment in California.
- Formulate a draft power purchase agreement for use between an IPP developer and a municipal utility.

The direct normal solar radiation in specific areas in southern California is large enough to generate thousands of GW using CSP technology. Although currently limited by transmission availability, this still represents a very large and attractive resource for the California Municipalities. Trough technology is proven and commercial, but its current cost makes selection difficult for the cost-conscious Municipalities. When the added costs of future fuel price volatility and environmental regulations are considered, the near-term costs of CSP appear close to fossil-fuelled alternatives. Furthermore, the long-term trend suggests a crossover between CSP and fossil-fuelled generation costs within about 5 to 10 years.

Another document that was prepared for NREL details the economic, energy, and environmental benefits of concentrating solar power in California (Stoddard et al., 2006). Emphasis was placed on in-state economic impact in terms of direct and indirect employment created by the manufacture, installation, and operation of CSP plants. The environmental impact of CSP relative to natural gas fuelled counterparts, as well as the value of CSP as a hedge against natural gas price increases and volatility, was studied.

2.5.9 Assessment of the World Bank Group/GEF Strategy (2006)

The World Bank (2006) produced a strategy report detailing the market development of CSP technologies. This study presents an independent review of the implementation progress for several World Bank/Global Environment Fund (GEF) funded projects in the context of the long-term strategy for solar thermal development. The study team undertook extensive consultations with stakeholders and made some specific recommendations with regard to project implementation. In particular, they emphasised the need for flexibility in technology choice and implementation approach.

The World Bank and GEF undertook the development of four ISCCS solar thermal projects in Mexico, Morocco, Egypt, and India. All four have experienced implementation problems. These implementation problems arose mainly from three specific issues, these being:

1) The contradiction between the drivers of economic development in developing countries, i.e. poverty alleviation, and those of the developed world, i.e. environmental concerns, generates a mismatch of global expectations and local willingness to support these projects.
2) There has been insufficient dialogue between GEF and the CSP industry during project design, adoption of the CSP strategy, and project implementation.
3) GEF has remained the only significant funding source for these CSP plants.

The main objective of the assignment was to assess the strategy being followed by the World Bank/GEF for solar thermal power technology in light of:

1. The current state of technology, costs, and market development.
2. The difficulties experienced by the GEF co-financed projects, assessing the three primary risks facing the Bank/GEF portfolio.

a. Limited industry response.

b. Uncertainty of meeting the cost and performance targets.

c. Uncertainty of sustainability and replicability arising from the absence of long-term country or international commitments.

According to the aims of the investigation, the following three tasks were carried out:

Task 1—Summary of Solar Thermal Technology Growth.

Task 2—Risk Assessment and Mitigation: This assessment included technological performance risk, financial/commercial risks, regulatory/institutional risks, and strategy risks.

Task 3—Market Development Strategy: Following on Tasks 1 and 2, the report considers the chances of realisation and the bottlenecks of each of the four projects in the WB/GEF portfolio, including projected market impacts of partial or full implementation of the portfolio.

As well as completing these tasks, the World Bank also summarised all the CSP projects currently being considered and developed as well as several institutional, economic and technical factors that each project faces in its implementation.

3 METHODOLOGY

3.1 Outline

To identify systems which are applicable for distributed power generation, energy and financial modelling was performed to gain an overview of what is available and how these system configurations can be integrated into urban areas, and more specifically Wits University. To arrive at a nominal cost of electricity generation, the affects that these systems would have on Wits University's electricity usage is also investigated. The methodology followed is now outlined.

Data Synthesis - Technologies Analysed

Different system configurations and operating performance of the plants in operation are expected because of the radically different operating conditions. In order to specify such systems that would be suitable for Wits University, an extensive comparison of the existing plants was performed.

Data Comparison and Verification

As discussed in the literature review, the Ecostar as well as the Eskom study provide a very convenient means of comparison between a number of technologies already in operation. Absolute cost data for each of the reference systems in the studies are hard to estimate because the systems are all on different levels of maturity. However the relative distribution of the different cost items is considered to be well estimated by the approach.

Of the different studies available, the Ecostar study is the most transparent, most of the cost and performance assumptions are stated explicitly which allows for a very convenient reference. Methods from the various sources (Section 2.5) are used as well but it is the Ecostar study that is used throughout this study as a basis for comparison. The Eskom study is also used but not as extensively because it lacks the same transparency and is mainly used as a comparison to the Ecostar study.

The examination and analysis of the data described above led to the development of a model comparing the technologies used in the Ecostar Study to that of the Eskom study. This allowed for rigorous verification of data. The assumptions used in the various models were also identified, and where applicable criticised or substantiated. Technical aspects such as plant performance, energy flow and conversion were also verified. The costing involved in the technologies however was not verified on an absolute level but just compared to cost data used in other studies.

Technology Screening and Design Configurations

This model described above was then updated to compare the technologies under common conditions in South Africa. These conditions are described in Section 3.2.4. The conclusions from this comparison aided in the technology screening in order to select systems that will be applicable to urban electric generation. This procedure is described below.

- Identify several technologies to be used in the comparison.
- Identify functional criteria relevant to distributed urban generation.
- Perform a numerical analysis ranking these criteria.
- Provide a perspective model (tool which ranks the different technologies according to the desired functions) comparing the chosen technologies.
- Select appropriate alternatives that qualify for distributed urban generation.

A full analysis of these chosen technologies with respect to their installation at Wits University was then performed, described below.

- Identify appropriate installation sites within the University.
- Analyse the appropriate climate data and its appropriateness for CSP generation.

- Adjust the comparison model for Wits University local data as well as an appropriate capacity (MW(e)).
- Identify the needs specific to Wits University by analysing its electricity profiles and usage trends.

Modelling

The conclusions from the above analysis resulted in separate design configurations being chosen for Wits University. The technical performance of these systems was then analysed, which included thermal energy flow modelling in Matlab. A model was then developed that analyses the impact that these technologies will have on Wits University's power usage on an hourly basis and how this affects Wits University's total bill in order to find a nominal cost of generation.

3.2 Data Synthesis

In order to verify the results obtained by different studies, their methodology needed to be analysed. The methodology that was followed in the Ecostar study was briefly touched on in Section 2.5, but the analysis is also common to other studies and the inputs to these models are explored below.

3.2.1 CSP Technical Performance

Net Annual Solar Electricity

To calculate the net annual electricity generated [kWh] by each of the alternatives analysed two equations were used, these are detailed below.

$$E_{solar} = A_a \cdot DNI_a \cdot \eta_{s-e} \quad \textbf{(1)}$$ (Pitz-Paal et al., 2005)

where

E_{solar} = net annual solar electricity produced

A_a = aperture area of solar field

η_{s-e} = net solar to electric efficiency

DNI_a = annual direct normal irradiation

$$\eta_{s-e} = \eta_{Sf} \cdot \eta_{para} \cdot \eta_{pbnet} \cdot \eta_{rec/pip} \cdot \eta_{stor}$$ **(2)** ({Pitz-Paal et al., 2005})

where

η_{Sf} = solar field efficiency

η_{para} = efficiency due to parasitics

η_{pbnet} = net power block efficiency

$\eta_{rec/pip}$ = receiver/piping efficiency

η_{stor} = storage efficiency

Capacity Factor

The capacity factor is the amount of electricity generated by the plant [kWh] compared to the rated design capacity.

Solar Capacity factor (S&L, 2003)

$$CF_{solar} = \frac{E_{solar}}{W_{design}} \cdot \frac{1}{8760}$$ **(3)** ({S&L, 2003})

where

W_{design} = net design output of the power block [kW]

8760 = total amount of hours in a normal year

E_{solar} = net annual solar electricity produced

Net Capacity factor (including hybridisation)

$$CF_{net} = \frac{E_{net}}{W_{design}} \cdot \frac{1}{8760}$$ **(4)** ({S&L, 2003})

where

E_{net} = net annual total electricity produced

Solar field Area

Aperture Area

To calculate the total aperture area, Equation (1) above is modified to Equation (5) provided by Sargent and Lundy which now takes into account the capacity factor. The goal here is to deliver a certain amount of energy per year according to the design capacity factor. Another method of calculating the plant area is by designing a plant according to the peak *DNI*, but if a plant is designed to give a certain amount of power at certain times reliability issues result because of the unpredictable solar resource found in Johannesburg.

$$A_a = \frac{W_{design} \cdot CF \cdot 8760}{\eta_{s-e} \cdot DNI_a}$$ **(5)** ({S&L, 2003})

Total Plant Area

According to the results from the Ecostar Study, the cover ratio (GCR), which is the ratio of solar field area to land area, of all the plants, are found to be between 24-26% of the total plant area, with the exception of the CLFR plant which makes up 65% of the total plant area. This ratio is dependent on a number of factors such as the use of storage, where storage tanks, depending on the capacity, can be quite space demanding. These ratios are used to calculate the total land area. Other studies suggest similar ratios. Black and Veatch Corporation (2007) suggest that parabolic trough systems have a GCR of 30% compared to 70% for CLFR technologies. To remain consistent, the Ecostar ratios are used in this study.

Hybrid Systems

For the purposes of this study, when choosing design alternatives, the added size of the boiler room, in the hybrid systems, will be ignored. According to the Engineering Toolbox (2009), a recommended size of a boiler room with a 500kW capacity is 40 m^2 which, for the purposes of this study, is considered negligible.

3.2.2 Financial Calculations

Levelised Electricity Cost

"Levelisation" involves calculating a stream of equal cash flows whose Net Present Value (NPV) is equal to that of a given stream of variable flows. If a project's levelised annual cash flow is divided by the annual amount of energy produced, the result is called the levelised cost of energy. Using a levelised evaluation provides a simple way to compare alternative projects to each other and is broadly used in the utility industry.

The levelised electricity cost (LEC) is an indicator of the cost of electricity produced. This method has been suggested by Sargent and Lundy (2003) as well as the IEA (1991). CSP plants need to be evaluated on a life-cycle cost basis to determine their true economic value. This is particularly important for a solar plant since they are characterised by high initial investment costs that are recovered over a long period through low operating costs (by virtue of having no fuel expenses).

The total E_{net} electricity in Equation (6) can be used to verify the electric production in the Ecostar and Eskom study by using given costs.

$$LEC = \frac{fcr \cdot K_{invest} + K_{O\&M} + K_{fuel}}{E_{net}} \qquad \textbf{(6)} \text{ (\{IEA, 1991\})}$$

where

fcr = fixed charge rate

K_{invest} = total capital investment

$K_{O\&M}$ = annual operating and investment costs

K_{fuel} = annual fuel costs

E_{net} = annual net electricity.

$$fcr = \frac{k_d\left(1+k_d\right)^n}{\left(1+k_d\right)^n - 1} + k_{insur} \qquad \textbf{(7)} \text{ (\{IEA, 1991\})}$$

where

k_d = real debt rate

k_{insur} = annual insurance rate

n = life of plant in years.

Specific Investment

The specific investment is the total cost of the installation (including indirect costs and contingencies) per installed kW. The total costs of the installation include the sum of the following components:

- Investment, Solar Field
- Investment, Power Block, Balance of Plant (BOP)
- Investment, Receiver
- Investment, Tower
- Investment, Storage
- Investment, Land.

Investment in the receiver and tower refer to the central receiver systems. And the investment costs for storage are only applied to the relevant systems which encompass storage.

3.2.3 Model Development and Verification

A Microsoft Excel model has been produced to verify the Eskom and Ecostar data. The intention of this model is to replicate the models used in the two studies using the process described in Section 3.2. The model is given in Appendix L. Inputs to this model include the technical and financial aspects of the plants using the methodologies followed in Sections 3.2.1 and 3.2.2

The financial assumptions, such as the *fcr* used in the Ecostar study, have been used. The intention of this model is to make it fully adjustable so that local conditions such as insolation, land areas, local currencies etc can be used to reflect results that can be expected anywhere in the world. The model is later used to compare the technologies for an initial technology screening.

From this model, it can be concluded that the Ecostar data was verified with the average error obtained being less than 2 % and this is due to rounding errors from the data provided in their report. The Eskom data provided was not as detailed as that given by the Ecostar study. The data verification was therefore not as successful with errors being between 3-6%.

One major error for the central receiver that uses molten salt in the Ecostar study was found. For technologies that use only solar energy, these systems will have a total capacity factor equal to its solar capacity factor. It is only the hybrid technologies that will have differing capacity factors. When calculating the E_{net} using Equation (6) and comparing this to the E_{solar} calculated using Equation (1), a difference in the solar and net capacity factors of 15% is found. This implies hybridisation. Ecostar did not intend their design to include hybrid mode, and fuel costs were hence not accounted for. It was mentioned that the design was adapted from a plant that includes hybrid operation. The LEC has therefore been adjusted to take into account the E_{solar} produced, which will effectively increase the LEC of the central receiver using molten salt. It is uncertain whether the balance of plant takes into account the costing of the hybrid components of the plant in the power block/BOP value. It will be assumed that because the fuel costs were not accounted for, this value is also neglected.

3.2.4 Model Adjustment

To compare the technologies for use under local conditions the model is adjusted according to the following criteria, in order to obtain a relevant model. The intention of these adjustments is to derive a model that will be able to compare the known technologies under a common local and present day situation. This will assist in the technology screening.

- **Present value:** The costing of the technologies analysed in the studies - fuel prices, maintenance, and hence the LEC - was calculated in foreign currencies and performed a number of years ago. This value needs to be brought to an equivalent present day value in South African Rands.
- **Local radiation data:** The *DNI* received at different sites will affect the performance of the plant. If the design capacity factor is to be maintained, the size of the collector area will change if the *DNI* changes. Local *DNI* data therefore need to be obtained.
- **Scaling methods:** The data used in the comparison are data for plants that are usually of quite large scale. An appropriate scaling method is needed in order to bring these plants to small scale size. This will have an effect on the costs involved and hence the LEC.

Present Value of the Past

The Eskom data provided is based on U.S. dollar prices at the time of writing (2001), and the Ecostar data is based on Euro prices in 2005. These both need to be adjusted to find present day values. The future value equation is defined below.

$$FV = PV(1+r)^n \qquad \textbf{(8)} \text{ (\{Wolf, 1969\})}$$

where

FV = the future value of the of the investment

PV = the present value of the investment, often referred to as the principal

r = the interest rate

n = the number of periods for which the investment will be discounted.

The definition of this formula assumes that the present value is the value of today's investment and the future value will be the value of the investment n years in the future compounded at an interest rate r.

For the purposes of this study, the future value FV referred to in Equation (8) is today's present value. PV is the actual costs and pricing of the various technologies in the year of writing. This value needs to be brought forward using the interest rate r, sometimes called the 'decay rate' when finding the 'present value of the past' (Wolf, 1969).

Decay Rate

Westney (1997) shows that cost escalations or the variation in prices can be the result of several factors. General increases in prices can be a result of overall inflation in the currency; or there can be spot price changes in certain commodities caused by shortages, built in price changes, or monopolies. These two inflation rates can be defined as the price inflation and cost inflation respectively. These inflation rates will have an influence on material costs, labour costs, equipment costs, and other costs such as financing costs.

Chemical Engineering Plant Cost Index

To calculate a suitable decay rate certain indices are available which account for the price inflation of certain process-equipments. Two indexes, the Marshall and Swift equipment cost index and the Chemical Engineering Plant cost index are both recommended (Peters and Timmerhaus, 1991). These two indexes give very similar results but it is the Chemical Engineering Plant Cost Index (CEPCI) that is used here.

Construction costs for chemical plants form the basis of the CEPCI. This index is viewed as a better reflection of cost inflation than traditional inflation measures such as the common consumer price index (CPI). The four major components of the index are weighted by percentage in the following manner:

- Equipment, machinery and supports 61%
- Erection and installation labour 22%
- Buildings, materials and labour 7%
- Engineering and supervision 10%

The index in based in U.S dollars and even though the Ecostar cost data is published in Euros, much of their data was sourced in dollars, which allows for an acceptable adjustment.

Table 3-1: Chemical Engineering Plant Cost Index

Year	Index	Year on year increase %
2000	394.1	
2001	394.3	0.05%
2002	395.6	0.33%
2003	402	1.62%
2004	444.2	10.50%

2005	468.2	5.40%
2006	499.6	6.71%
2007	525.4	5.16%
2008	609.1	15.93%

Table 3-2: CEPCI Average

Average	
2005-2008	8.30%
2001-2008	5.71%

Because the results published by Ecostar were in 2005 Euro, the decay rate to be used is 8.3%. The rate the Eskom data is adjusted by is 5.71%.

Sargent and Lundy (2003) state the costs decline by a certain percentage with each doubling of the total number of units produced. These adjusted rates as discussed do not reflect the effects of the volume of production and learning curve.

Solar Radiation

The effects of a changing input solar radiation will have an effect on the capacity factor experienced by the plant if the solar field is not scaled correctly. To determine the size of the adjusted solar field for a change in the direct normal irradiation (*DNI*), Equation (1) has been adjusted to form Equation (9). This assumes that the annual solar-electric efficiency remains unchanged. The resulting solar field size will be equal to the existing field, multiplied by the ratio of the annual *DNI* at the existing site to the annual *DNI* at the new location.

$$A_{a-new} = A_a \cdot \frac{DNI}{DNI_{new}} \quad \textbf{(9)}$$

The Ecostar study assumes an average annual direct solar radiation value of 2014 kWh/m^{2}a, found in Seville, Spain. The Eskom study uses an annual *DNI* value of 2900 kWh/m^{2}a. According to the Typical Meteorological Year (TMY2) data obtained from the NREL (1995) for Johannesburg, the average insolation received over the period of a year is 1780 kWh/m^{2}a which is the value used in the in the analysis. The details of this data are further described in Section 5.3.

Scaling methods

Sargent and Lundy (2003) state that the economies-of-scale method, for estimating and evaluating costs of various scaled components, is appropriate. Scaling factors were used to estimate the cost of a new size or capacity from the known cost for a different size or capacity. The relationship is based on the following formula:

$$C_2 = C_1 (\frac{S_2}{S_1})^{Sf} \qquad \textbf{(10)} \text{ (\{S\&L, 2003\})}$$

where

C_2 = desired cost of equipment at size (or capacity) of S_2

C_1 = given cost of equipment at size (or capacity) of S_1

Sf = scaling factor

Several of the technologies in the Ecostar study have been scaled up from existing technologies for comparison reasons. By using Equation (10) it is possible to extract a scaling factor from the scaling of the technologies. This factor can then be used in estimating the costs involved with other scaled plants. Where some technologies were not originally scaled, the average scaling factor was used. This was deemed appropriate because the scaling factors across the technologies were relatively constant.

3.3 Technology Screening

In order to select appropriate technologies suitable for urban application, candidate technologies were identified and by ranking them according to identified functional criteria, full perspective of practices and operational systems was identified. The methodology followed in the screening of the technologies is further elaborated in Section 4. The criteria that should be considered for site selection are however given below.

Site Screening

The selection of an appropriate site for the implementation of a distributed CSP system in urban areas will be based on certain criteria that will often differ from that of normal utility plants.

The Bureau of Land Management (BLM) in the USA detailed a report for the National Energy Policy Implementation Plan, which was to identify and evaluate renewable energy resources on public lands and any limitations on access to them. The following is a summary of the criteria identified for CSP systems (BLM, 2003).

Central Generation Technology Criteria:

1. Solar resource is 1700 $kWh/m^2/a$ of direct normal radiation (at least) (Stine and Geyer, 2008)
2. Slope of land area at the site must be less than 5 %, and ideally less than 1 %.
3. Transmission access is within 80 km, and transmission capacity is available.
4. Forty acres is the minimum parcel size.
5. Site must have access to roads or rail within 80 km.

Distributed Generation Technology Criteria:

1. Solar resource is 1700 $kWh/m^2/a$ of direct normal radiation.
2. Slope of land area at the site must be less than 10 %.
3. Site must have access to roads.

The following items were also identified but not as the most important screening criteria.

Central Generation Technology Criteria:

• The site must have a low average wind speed (average wind speed < 16 km/hour).

• Water resources must be available.

• The site should be within 40 km of a main natural gas pipeline for some configurations.

• All vegetation at the site must be removed.

• Federal, state, and local policies are supportive.

• The site must allow structures 5-15 m high. Some technologies could require structures hundreds of feet high.

• Livestock protection is possible.

• Light reflection at sites near major roads not issues for some technologies

• A population centre should be within 160 km.

Distributed Generation Criteria:

• The site is within 160 km of a population centre.

• Transmission access, water availability, and minimum parcel size are not an issue.

3.4 Application

After analysing Wits University's load profiles and siting options described in Sections 5.1 and 5.2, certain design configurations can then be selected which would include plant capacity, storage integration etc.

To analyse the energy output from the hourly *DNI* collected over a certain area a solar field aperture is sized using the average total *DNI* received over the span of a year. This aperture area is designed using the method described in Section 3.2. Using this designed aperture area, the net power output and plant performance are calculated on an hourly basis. This method is further described below.

3.4.1 CSP Plant Performance

Many of the studies performed did not provide full details of their solar-electric modelling (the conversion of solar energy into electrical energy). In order to verify their data, the model suggested by Broesamle et al. (2000) has been followed.

The model is made up of two parts, one that simulates the energy balance of the solar field, being the conversion of solar energy into usable thermal energy. The second part represents the conversion efficiency of the power cycle.

Figure 3.1 represents the outline of the inputs to the model. It calculates the hourly thermal power output of the solar field and the electricity yield from the solar direct normal radiation generated in the meteorology module at a certain location. For the simulation of the collector field energy output, a simplified stationary model of the physical properties and behaviour of the collector is applied, as described below.

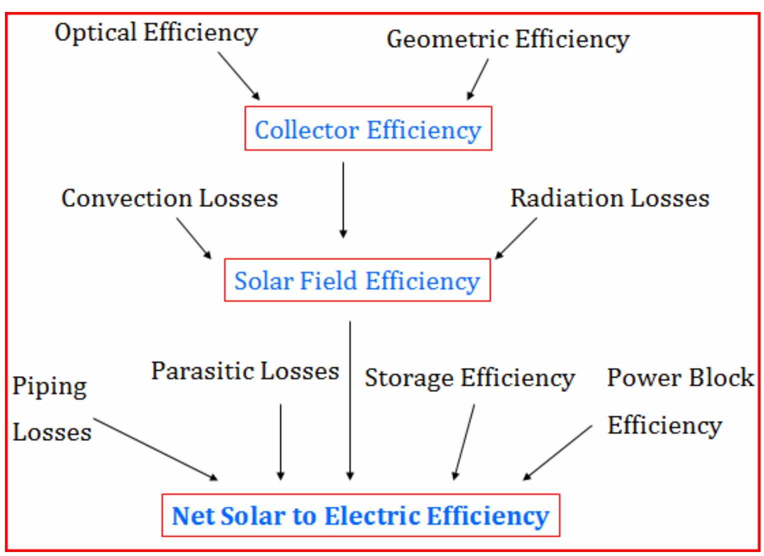


Figure 3.1: Solar to Electric Efficiency

Collector Efficiency

The efficiency of the solar collectors is a function of the geometric efficiency and the optical efficiency of the mirrors.

$$\eta_{col} = \xi_{geo} \cdot \eta_{opt} \quad \textbf{(11)}$$

where

η_{col} = collector efficiency

ξ_{geo} = geometric efficiency

η_{opt} = optical efficiency.

Geometric Efficiency

A one-axis tracked parabolic trough collector shows certain losses that depend only on its geometrical structure. The following geometric losses are considered in the model:

$$\xi_{geo} = \xi_{IAM} \cdot \xi_S \cdot \xi_E \cdot \xi_{\cos} \quad \textbf{(12)}$$ ({Broesamle et al., 2000})

where

ξ_{geo} = Geometric efficiency

ξ_{IAM} = The incident angle modifier (considers the distortion of the reflected image of the sun at non-perpendicular incident angles)

ξ_S = Shading losses within the solar field

ξ_E= Intercept factor - Collector end-losses (the portion of the sunlight that is reflected outside of the range of the absorber tubes at the end of each collector row)

$\xi_{\cos}$ = Cosine losses (considers the smaller active area of projection of the collector due to non-perpendicular irradiation and on the angle of incidence).

Optical Efficiency

$$\eta_{opt} = \alpha \cdot \rho \cdot \gamma \cdot \tau_1 \cdot \tau_2 \qquad \textbf{(13)}$$ ({Broesamle et al., 2000})

where

η_{opt} = optical efficiency

α = coefficient of absorption of the absorber tube

ρ = reflectivity of the mirrors

γ = optical precision of the mirror surface (quality factor)

τ_1 = transmission factor of the mirror glass cover

τ_2 = transmission factor of the glass tube that surrounds the absorber tube

For compound linear Fresnel reflectors this equation is modified to take into account the effects of the secondary reflector ρ_2. Equation (13) becomes:

$$\eta_{opt} = \alpha \cdot \rho_1 \cdot \gamma \cdot \tau_1 \cdot \tau_2 \cdot \rho_2 \qquad \textbf{(14)}$$ ({Broesamle et al., 2000})

Thermal Energy conversion

The conversion of the Direct Normal Irradiation into useable thermal energy is modelled using Equation (15) and Equation (16). The efficiency of the solar field takes into account the collector efficiency (Equation 11) as well as losses. The second term in Equation (15) refers to the convection losses in the solar field and the last term accounts for radiation losses.

$$\eta_{Sf} = \left[\eta_{col} - \frac{\pi \cdot U}{C \cdot DNI}\left(T_A - T_{amb}\right) - \frac{\pi \cdot \varepsilon \cdot \sigma}{C \cdot DNI}\left(T_A{}^4 - T_{amb}{}^4\right) \right] \qquad \textbf{(15)}$$ ({Broesamle et al., 2000})

where

η_{Sf} = solar field efficiency

U = convection loss heat transfer coefficient [W/m^{2}K].

C = the factor of concentration of the parabolic trough

T_A = mean surface temperature of the absorber tube

T_{amb} = ambient temperature perceived by the absorber tube exposed to the sunlight

ε = coefficient of emission of the absorber tube surface

σ = Stefan-Boltzmann constant [W/m^{-2}K^{-4}]

DNI = Direct Normal Radiation

Equation (16) takes the total *DNI* in a certain period and finds the thermal energy delivered by the solar field.

$$\dot{Q}_{Sf} = A_{Sf} \cdot DNI \cdot \eta_{Sf}$$ **(16)** ({Broesamle et al., 2000})

where

$\dot{Q}_{Sf}$ = thermal energy delivered by the solar field [kW]

A_{Sf} = solar field area

η_{Sf} = solar field efficiency

DNI = Direct Normal Radiation

Certain losses in delivering the thermal energy from the solar field to the power block, Equation (17), result in the net power output (Equation (18)).

$$\dot{Q}_{therm} = \eta_{piping} \cdot \eta_{stor} \cdot \eta_{par} \cdot \dot{Q}_{Sf}$$ **(17)** ({Broesamle et al., 2000})

where

$\dot{Q}_{therm}$ = rate of thermal energy input to the power cycle [kW]

η_{stor} = storage efficiency

η_{piping} = piping efficiency

η_{par} = efficiency due to pumping parasitic losses

$\dot{Q}_{Sf}$ = thermal energy delivered by the solar field

The power generated from the thermal energy generated from the solar field is calculated using Equation (18).

$$P_{net} = \dot{Q}_{therm} \cdot \eta_{pbnet}$$ **(18)** ({Broesamle et al., 2000})

where

P_{net} =net power output [kW]

$\dot{Q}_{therm}$ = thermal energy input to the power cycle

η_{pbnet} =net efficiency of the power block (including dumping and availability)

Costing

The costing of the design configurations chosen were analysed using average economic data from multiple sources. The details of this are described in Section 3.2.2.

3.4.2 Energy Modelling

In order to analyse the performance of the chosen design configurations, energy modelling on an hourly basis was performed using Matlab. The hourly analysis of the design configurations, when integrated with Wits University's usage, will result in certain cost savings that translates into a reduced LEC. The details of the modelling are further described in Section 6.

4 TECHNOLOGY SCREENING

In order to select different technologies considered for application at Wits University a full screening of the available technologies had to be performed. The following analysis covers the comparative evaluation of these technologies. Different selection criteria are identified and the various technologies are evaluated accordingly.

4.1 Economic Comparison of Existing Technologies

Two major economic comparisons have been performed in the last decade. These, as previously discussed, are the study performed by Ecostar and one performed by South Africa's utility Eskom. Each performed a technology review of similar operational systems, each with different assumptions.

An Excel spreadsheet model that can be adjusted according to *DNI* radiation, capacity and site area has been developed in order to compare the technologies from the Ecostar and the Eskom study, giving them common assumptions. Although the results cannot be used as an absolute reference, they are a reasonable base for the comparison of different reference systems.

To compare the technologies from the two studies, the financial data has been adjusted to assume the following baseline *DNI* and plant capacity:

- *DNI* radiation 2900 kWh/m^2a (Upington)
- Plant Capacity 100 MW(e)

These assumptions form the basis for the Eskom comparison and are used in this model.

The economic data in both cases is brought to present value Rands. The plants are also scaled using the common *DNI* values as well as the same plant capacity using the method described in Section 3.2.4.

A summary of the results obtained is provided in Figure 4.1. The solid points in the figure are technologies represented in the Ecostar study and the hollow data points represent those adjusted from the Eskom study. For each case, the squares represent technologies that utilise parabolic troughs as the collector technology; the circles represent central receiver systems and the triangles represent Dish-Stirling collectors. The source for the data in Figure 4.1 is shown in the spreadsheet found in Appendix L.

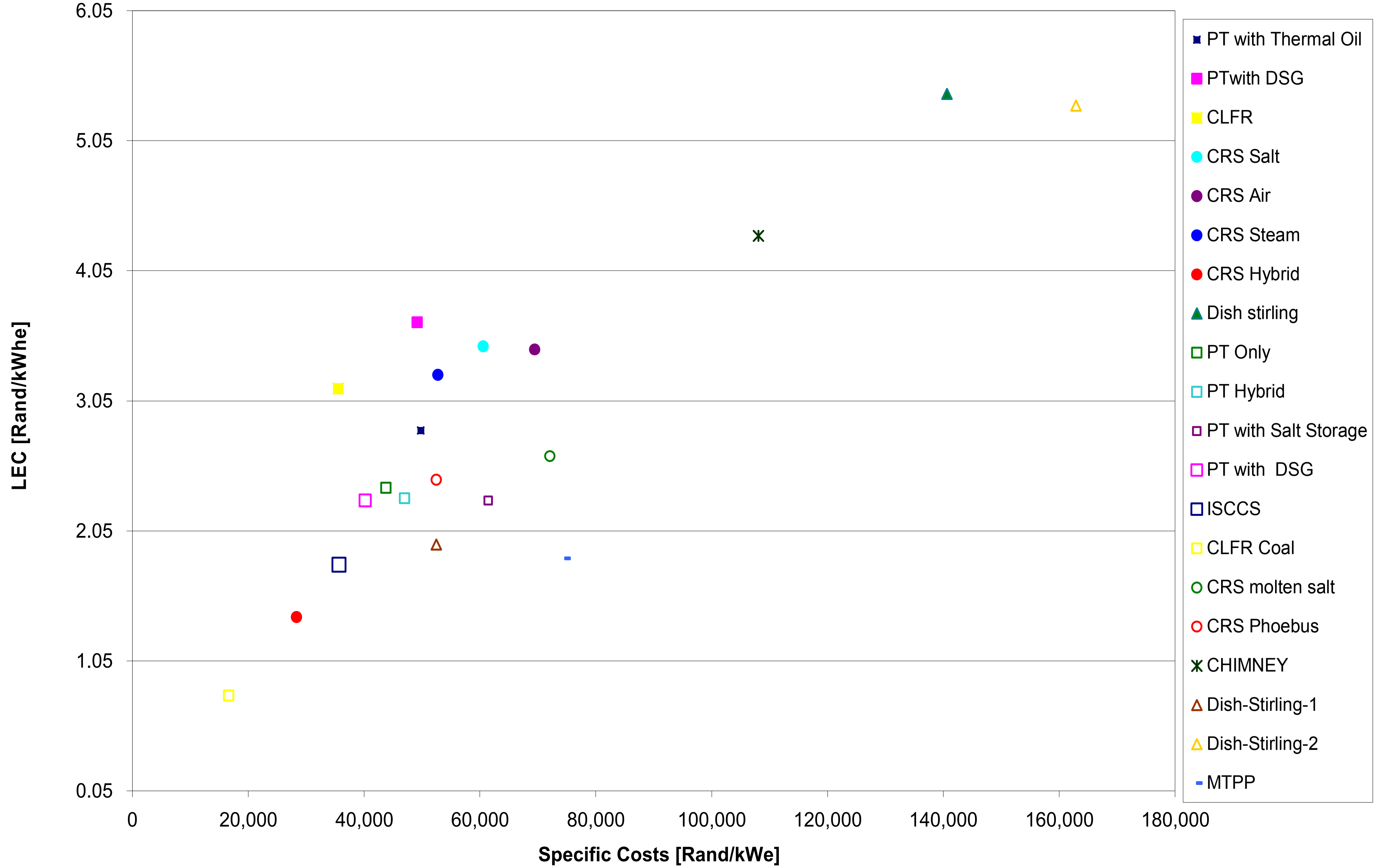


Figure 4.1: Financial Results

It can be seen from the graph that the Dish-Stirling concept is by far the most costly option, both it's levelised electricity cost (LEC) as well as the specific costs related to installation are the highest. The details of two separate Dish-Stirling options from Eskom are provided. The first option (Dish-Stirling-1 in the graph) represents the cost assumptions used in Eskom's analysis. These cost estimates are actually representative of a near term estimate and are not representative of current installation costs (at the time of writing – Eskom 2001). The second option (Dish-Stirling-2) shows the current installation costs for 2001, which is viewed as a more realistic basis for comparison. The Dish-Stirling-2 point also compares closely with the Ecostar estimate. From this it can be concluded that the Dish-Stirling systems are the most expensive alternative. Only the Eskom study looked at ISCCS and the Chimney technologies. The chimney initially appears unfeasible because of the high costs involved.

These adjusted results are in line with the comparison performed by Eskom and Ecostar. It is interesting to note that the Eskom data results in a lower LEC calculation than that calculated by Ecostar. Reasons for this include the fact that South Africa has specific land costs as well as O&M costs that are lower than those estimated in Europe.

4.2 Candidate Technologies

The following technologies have been identified because they have either been tested or put into commercial operation, allowing for performance and financial data to be collected. It is important to note that these alternatives were chosen because of the availability of performance data. In most cases they would not be suitable for small scale distributed power applications. The ranking of these alternatives is discussed in detail.

The majority of the data used here has been taken from the Ecostar study. ISCCS and the solar chimney technology have been taken from the Eskom study. The MTPP data has been taken from a study performed by Hassani and Price (2001). A brief description of these technologies can be found in Appendix B.

1. Standard parabolic trough (SEGS)
2. Parabolic trough with storage (SEGS with storage)
3. Parabolic trough with direct steam generation (SEGS DSG)
4. Compound Linear Fresnel (CLFR)
5. Central receiver with heliostat field and Salt as HTF (CRS - Molten Salt)
6. Central receiver with heliostat field with atmospheric receiver – air as heat transfer fluid (CRS - atmospheric air)
7. Central receiver with heliostat field with pressurized volumetric receiver (CRS - Brayton)
8. Integrated Solar Combined Cycle - (Fossil-fired Brayton topping cycle and solar-assisted Rankine bottoming cycle) (ISCCS)
9. Dish-Stirling engines (Stirling Cycle)
10. Solar Chimney
11. Modular Thermal Power Plant (MTPP)

4.3 Functional Criteria

All functions defined here are intended to be a clear and concise description of what must be achieved. They have been defined by a verb and a noun, a value engineering method prescribed by Huber (2008).

Each technology is best suited for different applications. The functions that are most significant in terms of urban use, and those which can be addressed by different features from each of the existing technologies, have been identified below.

Produce electricity

This is the primary function of the power plant and because all plants (including fossil fired plants) produce electricity it is important to define this function more specifically in terms of the capacity factor. The capacity factor is the amount of electricity produced by the plant [kWh] compared to the rated design capacity.

Capacity Factor

The capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time and its output if it had operated at full rated capacity the entire time. The power outages South Africa faces are creating a drop in productivity and in many cases large economic losses. Energy independence from Eskom is also a driver of independent power generation. All technologies under consideration can provide some form of independence from Eskom. This capacity factor will include technologies under hybrid operation.

Another form of independence, which is not considered here, is the shift from the reliance on fossil fuels such as oil, gas and coal. As these fuels are depleted, their demand keeps on rising. Reducing the dependence on these fossil fuels is of high priority; by emphasizing the reduction of emissions, which is a factor discussed later, we imply independence from fossil fuels that produce greenhouse gases in their combustion.

Minimise costs

Cost referred to here is solely the cost of producing electricity. The Levelised Cost of Electricity (LEC) takes into account initial capital costs, maintenance and operation and fuel costs. These were therefore not evaluated individually.

Simplify integration

Because urban areas are usually space-constrained, this will be one of the most important evaluation criteria. The first criterion evaluated is the required floor size of the solar field and power plant (Power/Area ratio [kW/m^2]). The second is the vertical height of the structures. For example building a central receiver on the roof of an existing building may oppose the aesthetic appeal of the building.

The disjointed nature of the space found in urban areas was also taken into consideration. One often finds small pieces of land or convenient roof tops that are too small for the installation of a large scale CSP plant. Hence the modular nature of some technologies such as micro-steam turbines or the use of organic Rankine cycles also using smaller turbines could prove to be successful.

Reduce Emissions

This function refers to the reduction of greenhouse gas emissions typically produced by fossil-fuel power generation facilities. It was deemed less important because all of the solar technologies reduce emissions to some extent. This criterion is usually used in evaluating renewable energy in general, as compared to fossil-fuels.

Different countries and organisations pursue the use of CSP generation for different reasons. South Africa, as a developing country, even though there is significant pressure placed on it, is still more concerned with energy security and economic growth than it is with emission reduction. In some cases the plants' capacity to produce electricity, as a function, is a contradiction to this emission reduction function because a hybrid plant, for example, will score higher in its capacity and at the same time be penalised with the reduction of emissions.

This function would receive a greater weighting if, for example, the technologies in comparison included fossil-fuel power plants. A more quantitative judge on the securing of energy independence from fossil-fuels is the measure of the solar fraction. The solar fraction is a crude indicator of the different technologies' ability to prevent greenhouse gas emissions.

Maturity of technology

Here the maturity of the technology refers to its reliability through a record of demonstrated performance. The reliability of the technology actually refers to technical risk. Low technical risk is preferred in a project, all else equal. Points were allocated based on the judgement of the degree of demonstration to date, industry backing of technology as well as judgement of scaling issues.

Promote Local Industry

Technologies that can be produced using local industries are preferred to those that need to be imported.

System Safety

Because the technologies will be placed in an urban area, which experiences a lot of human traffic and thoroughfare, solutions which are least vulnerable to this as well as to vandalism are credited accordingly. At the same time, the systems cannot pose a threat to the health and the security of bystanders and maintenance personnel.

4.4 Numerical Analysis

The following numerical analysis is a Value Engineering approach to identify the most significant functional criteria when evaluating the implementation of CSP technology in urban environments in Johannesburg. This method has been recommended by Huber (2008).

In order to prioritize the functions, a numerical analysis is performed using a 'function numerical evaluation matrix'. This matrix compares functions against one another to rank their relative importance. The functions are ranked using a score from 1 to 3, where 1 indicates a minor difference and 3 indicates a major difference. The scores are then tabulated and from this, the most important functions may be determined. The aim is to create an objective and un-biased method of evaluating the priority of the functions.

The final outcome of the numerical analysis is to create a *cause and effect graph*. This graph separates the most important functions from the less important functions. The rationale is that addressing the 'cause' of the issue will implicitly address the minor 'effects' of the issues, thus focussing on the fewer, critical functions. The numerical analysis is given below, followed by the cause and effect results graph.

Scoring Rules: Minor/Medium/Minor Difference — 1 Minor, 2 Med, 3 Major

Numerical Evaluation									Function	Score	Rank
A	A3	A1	A3	A2	A1	A1	A2	A	Produce Electricity	13	1
	B	C2	B2	E1	F2	G3	B1	B	Promote Local Industry	3	6
		C	C3	C2	F1	G1	C2	C	Reduce Emissions	9	4
			D	E3	F3	G3	H2	D	System Safety	0	7
				E	F1	G2	E2	E	Maturity of Technology	6	5
					F	G1	F2	F	Simplify integration	9	3
						G	G1	G	Minimise costs	11	2
							H				

Figure 4.2: Numerical Evaluation Matrix

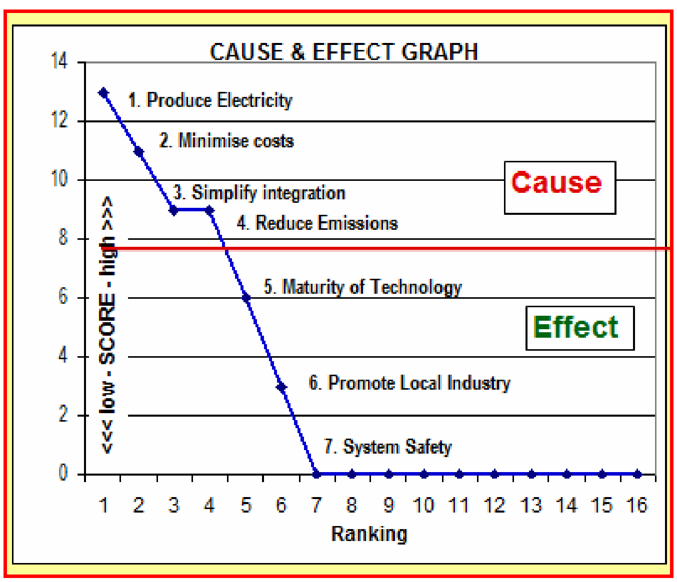


Figure 4.3: Cause and Effect Graph

As can be noted from Figure 4.2 and Figure 4.3, the four functions that the technologies will be rated against are:

- Produce Electricity
- Minimise Costs
- Simplify Integration
- Reduce Emissions.

4.5 Perspective Model

Because the performance and costs of small scale power generation modules have not been well documented, the only resources available are those from technologies that have been well demonstrated in the past. These technologies range in size from 1 MW for the Dish Stirling concentrators to 80 MW plants for the original SEGS plants in the Mojave Desert in California. Due to the requirements that distributed urban generation demands, the selection of the technology that would best be suited, would therefore not necessarily have the same specifications or capacity as the existing technologies on the market.

The technique used in the analysis of the alternatives is called perspective modelling (Huber, 2008). For each of the functional criteria as defined in the first row of Table 4-1 below, each of the alternative technologies is given a score out of ten. The alternatives score is then multiplied by the functions score (from the numerical evaluation in Section 4.4), for a weighted score. This process is continued across the matrix, until alternative one has been evaluated against all the functions. This is then repeated for all the alternatives. The highest total is the solution that is most likely to meet al.l the requirements of the evaluation.

Accordingly, each of the alternative technologies is ranked from best case scenario to worst. This is given in the last column in Table 4-1. The results are further discussed.

Table 4-1: Perspective Model

		Functions									
	Alternatives	**1. Produce Electricity**		**2. Minimise costs**		**3. Simplify integration**		**4. Reduce Emissions**		**Total**	**Rank**
	Score	13		11		9		9			
1	**SEGS**	6	78	2	22	4	36	5	45	181	10
2	**SEGS with Storage**	7	91	5	55	4	36	8	72	254	4
3	**SEGS DSG**	6	78	3	33	4	36	8	72	219	9
4	**CLFR**	5	65	6	66	9	81	8	72	284	2
5	**CRS Molten Salt**	8	104	8	88	2	18	8	72	282	3
6	**CRS Atmospheric Air**	7	91	4	44	2	18	8	72	225	8
7	**CRS Brayton**	8	104	9	99	2	18	2	18	239	6
8	**ISCC**	8	104	10	110	0	0	*2*	18	232	7
9	**Solar Chimney**	8	104	0	0	0	0	8	72	176	11
10	**Dish Stirling**	6	78	1	11	10	90	7	63	242	5
11	**MTPP**	10	130	7	77	9	81	8	72	360	1

4.6 Alternative Technology Evaluation

Each technology is suited for different applications. These technologies that have been ranked according to the functions defined in Section 4.3 above will now be discussed. The ranking of these technologies is by no means ”fair”, for example, some technologies make use of storage which will increase the capacity factor. By examining the different features from each of the existing systems, design decisions and conclusions can be drawn.

Produce Electricity

The technologies with the highest capacity factor scored the highest. Even though it is possible for some of the hybrid technologies to reach the capacity factors of normal fossil fired power plants, their demonstrated operation is assumed to hold. With the successful demonstrated operation of a large-scale thermal storage system at Solar Two (Pitz-Paal et al., 2005), the central receiver with molten salt also scored high. These systems are expected to be able to be designed for reliable operation that could extend well beyond early evening peak hours or cloud transients. The same score was given to the parabolic trough plant with storage which also has proven dispatchability. Because the atmospheric air central receiver has lower thermal storage capacity, it scored lower.

The solar chimney does not require direct solar radiation to sustain operation and can sustain power generation through minor cloud transients. Additionally it doesn't require as rigorous start-up procedures. The CLFR technology evaluated uses direct steam generation which does not have a form of thermal storage and therefore scored less.

Minimise Costs

The major problem with the integration of renewable energy systems is the price of electricity produced. The actual cost of the solar field technology is currently too expensive to compete with utility scale plants. There is significant room for cost reductions with a reasonable deployment of the technologies in the future. The technologies were ranked according to their levelised energy cost (LEC). The LEC is the cost of electricity per kWh and takes into account capital costs, maintenance and fuel and assumes standard financing costs.

Simplify Integration

Solar Field

When judging the sizing, it is only the size of the solar field that was taken into consideration. All sets of technologies, for example parabolic troughs, scored the same as they all use the same sized solar fields. The solar chimney scored the least because of the immense size the solar field demands. The power towers also scored poorly in terms of space utilisation because they make use of the largest solar field which in desert areas is not a problem but when it comes to urban areas, the cost of land or its utility/opportunity cost is significantly higher. CLFR uses the least amount of land area for the solar field and therefore scored the highest.

Flexibility, Modularity and Practicality

Dish-Stirling and MTPP scored equally high because modularity in urban areas is critical. In general there is a lack of space and therefore the option of modulating the technologies is a very attractive option, especially if the plants will be situated on multiple roof tops. CLFR technologies, even though are not modular, are quite flexible because they make use of flat, closely spaced mirrors and there is an opportunity for them to be built on rooftops or used as shading mechanisms such as above parking lots. Central receivers and the solar chimney scored the least in this criterion merely because the tower is such a permanent structure and has high vertical space requirements.

The CLFR technology, because of its compact nature will also be easier to clean. Also because of its horizontal profile, CLFR technology experiences the least amount of wind loading and during high wind conditions the mirrors can be adjusted to sit horizontally and during high hail conditions the mirrors can easily be set to the vertical. This flexibility allows the CLFR technology to be placed in extreme weather conditions, often found on the top of high buildings.

4.7 Chosen Alternatives and Discussion

It is noted again that the technologies analysed here, merely serve as the groundwork for the specific design decisions to be made for distributed urban generation. This is a general analysis of systems in operation put under comparison in order to gain perspective of what is available. Most of these technologies were originally designed with different outcomes in mind, for example, to meet peak loads or evening loads. What is required are distributed generation systems and what is to be discussed now, is the reasoning behind the scoring, which will lead to further investigations and initial design decisions.

From the screening analysis performed, it is clear that the Modular Trough Power Plant (MTPP) scored the highest in the analysis. It is however important to analyse the reasons for its first place ranking. The MTPP technology scored the highest points in its ability to produce electricity. The criterion for this function is a high capacity factor. Here, storage is a design choice. The conceptual design of this plant, for NREL (Hassani and Price, 2001), assumed 9 hours of storage which contributed to its high capacity factor. The longest storage for the other technologies in the comparison was three hours and therefore they did not score as high. It is important to note here that it is of course possible to design any of the other technologies with 9 hours of storage which would rank them equal to the MTPP system. This is however a general comparison of existing systems and what is concluded here is that a system that gives the highest capacity factor is favoured.

Because of the nature and flexibility of the technology, it is possible to select components from different systems to make up a new concept. The LEC costs will have to be re-calculated and the accuracy of these calculations (first order) may not be as credible and hence non-comparable. A detailed life-cycle cost analysis would need to be performed to find the predicted LEC for the new system.

Purely because of the billing system where the peak demand is billed differently to the actual usage, hybrid operation or storage will intuitively be the best option at tackling the need for continued usage during cloud transients. Johannesburg, especially during the summer, can experience days of cloud cover and in these cases storage will not solve the problem. Only hybrid operation will work in these cases. But then the cost of fuel comes into play and whether it will be cost effective operating in this mode through extended periods. If it will be more expensive to operate in such conditions then the cost of electricity produced through hybrid operation will need to be compared to the benefits of obtaining energy independence. It may be the case that the financial disadvantage is too great to actually install such technology and the primary function will hence remain unfulfilled. The purpose of installing the technology may then need to be re-assessed.

In terms of the solar field and collectors, CLFR definitely looks the most promising. It is by far the cheapest because it doesn't use parabolic shaped mirrors and operates with one-axis tracking. This, however, does decrease the efficiency of the plant.

The use of an ORC is also very advantageous because of its low operating temperatures. Again the efficiency of these cycles is low and if used in conjunction with CLFR collectors, the efficiency of the entire cycle will be very low and hence may demand greater space requirements and perhaps nullify the space advantages of the CLFR collectors. These differences are investigated further.

Technologies that are clearly not feasible for small scale generation are listed below, with reasons.

Central receivers: The central receiver with molten salt ranked second mainly because of its ability to produce electricity at very low costs. They have the potential for large scale integration but require the amount of land space for the solar field, as well as vertical space for the tower. They are therefore not suited for modular production. Because the Brayton cycle plant requires high inlet temperatures (only reachable in CRS plants), it is also eliminated.

Solar Chimney: For the same reasons that central receivers are unsuitable for small scale distributed generation, solar chimneys are also unsuitable. They require vast amounts of space and also produce electricity at high costs.

Dish Stirling: The dish Stirling concept, on all other accounts, may seem perfect for modular integration but they currently produce electricity at very high costs and are therefore eliminated.

DSG: Direct Steam generation is an advanced technology and also has safety concerns and will thus not be further investigated.

The technologies best suited are the MTPP and CLFR concepts. These concepts are investigated further, with and without storage and hybridisation. These are also evaluated with two different power cycles; normal steam Rankine Cycle and an Organic Rankine cycle.

5 APPLICATION

As noted, the University of the Witwatersrand is used as a case study for the possible installation of a pilot scale CSP generation system. The following section analyses the feasibility of such CSP systems.

5.1 Wits Electricity Profiles

Wits University is separated into six separate campuses which are all billed separately. These campuses include: Gate House (East Campus), Raikes Road (West Campus), Wits Business School, Wits Education Campus, Wits Medical School, University Corner. Wits East and West Campus consume the most electricity. West Campus' electricity profiles are examined here. All data is taken from the Metoring Online site that controls bills for City Power customers in Johannesburg (MOL, 2008).

The monthly bills are calculated on a per kWh basis as well as charging for the peak kVA utilised. This peak kVA charge is quite significant, as shown in a typical monthly bill, in Appendix G.

The CSP systems will be used to try to decrease the daily peak load because it is this that is responsible for the Maximum Demand charge. The Maximum Demand experienced is different on all campuses and occurs between the hours of 7 am to 8 pm, with the maximum peak experienced at mid-day. Solar technology is therefore an obvious solution because the sun shines during the day. On an annual basis, this full load scheme represents a 54.1% (=13/24) capacity factor.

Also seen in Appendix G are two electricity profiles, the first being that for the month of November 2007 and the second for June 2008. Each profile indicates the distribution of usage in a twenty four hour period, for a typical summer and winter month during University term. Both show a common peak at 12h00 and again at 19h00. Because the peak kVA contributes a significant amount to the monthly bill (approximately 1/3), it would be ideal to decrease these two peak levels. For summer usage, this means bringing the usage down from a peak of 2100 kW to 1600 kW and in winter from 2700 kW to 2200 kW (production from 07h00 to 20h00). This is the equivalent generation capacity of 500 kW.

5.2 Site

Actual site selection for the installation of the CSP system is beyond the scope of this study. However general application and sizing of the system is important in determining the feasibility. The site plans for Wits University Main Campus were obtained and some of the building areas were simply measured. A list of potential sites is given in Table 5-1. These figures represent the roof areas of the various buildings or open areas and serve merely as a guide to conceptualise the possibility of system integration.

Table 5-1: Potential Site Areas

West Campus	**[m2]**
Parking Lot Outside Hall 29	6365
DJ du Plessis Building	9900
New Commerce	2220
Commerce Library	2400
West Campus South Side Parking	8000
Genmin Laboratory	1750
East Campus	**[m2]**
Old Mutual Sports Hall	2400
Senate House	7600
Hillman Block	1820
NWE Building	2625

SWE Building	2450

Only larger buildings with symmetrical rectangular shapes are given here. These sizes are not entirely accurate because only the main rectangular sections were measured. The suitability of the roofs, in terms of structural, practical and aesthetic factors is beyond the scope of this report.

5.3 *DNI* Data

The weather data used in the analysis is Energy Plus Weather (EPW) format in SI units. The format is simple text based data based on the TMY2 (typical meteorological year) format but rearranged to facilitate visual inspection of the data (NREL, 1995).

A TMY provides a standard for hourly data for solar radiation and other meteorological elements that permit performance comparisons of system types and configurations for one or more locations. It represents conditions judged to be typical over a long period of time. Specifically, for Johannesburg, the data represents a typical meteorological year from data collected over 30 years from 1961 to 1990.

The generic site chosen in this case is Wits University. Due to the lack of solar data specific to Wits, generic data for Johannesburg (Latitude -26.13, Longtitude 28.23 and elevation of 1700m) which is available from the NREL website (NREL, 1995), is used in the analysis.

Seville, Spain, has a typical *DNI* of 2014 kWh/m^{2}a (Pitz-Paal et al., 2005) and has been the site for many CSP applications. Johannesburg's *DNI* is typically 1781 kWh/m^{2}a (shown in Appendix C), a value lower than that of Seville but above the recommended 1700 kWh/m^{2}a (Stine and Geyer, 2008).

The TMY2 data of 1781 kWh/m^{2}a is typically less than that found using Figure 2.2 (1825-2190 kWh/m^2/year), but resolution of the data obtained from this *DNI* map is lower than the TMY2 data which is why the TMY2 data is used. Appendix C provides details of this data. Even though the summer months in Johannesburg yield a higher peak *DNI*, it is actually the winter months that provide a more consistent average. This is due to the high amount of cloud cover experienced in summer.

5.4 Design Configurations

In order to assess the potential of CSP generating facilities at Wits University, the following combination of technologies have been chosen for the assessment. These alternatives have been chosen following from the technology selection criteria discussed and selection detailed in Section 4.7.

1. Parabolic Trough with normal Steam Cycle, no storage, no hybridisation
2. Parabolic Trough with normal Steam Cycle, with storage
3. Parabolic Trough with normal Steam Cycle, with hybridisation

4. Parabolic Trough with Organic Rankine Cycle, no storage, no hybridisation
5. Parabolic Trough with Organic Rankine Cycle, with storage
6. Parabolic Trough with Organic Rankine Cycle, with hybridisation

7. CLFR with normal Steam Cycle, no storage, no hybridisation
8. CLFR with normal Steam Cycle, with storage
9. CLFR with normal Steam Cycle, with hybridisation

10. CLFR with Organic Rankine Cycle, no storage, no hybridisation
11. CLFR with Organic Rankine Cycle, with storage
12. CLFR with Organic Rankine Cycle, with hybridisation

5.4.1 Output Capacity

In order to compare the different options a standard electric output of 120 kW(e) has been chosen. This size was determined by considering different applications currently in operation. As an example, Freepower, being one of the many ORC technology suppliers, provides 120 kW(e) Organic Rankine Cycle Turbine Generators which are closed cycle electrical power generation systems driven by an external heat source with no internal combustion being needed. This or a similar generator would be used in the implementation. Technical aspects of the Freepower generator can be found on their website (Freepower, 2008).

The initial site sizing which would integrate a parabolic trough system to provide the required thermal energy input to such a steam turbine generator is approximately 4000 m^2 and 1400 m^2 for a CLFR collector field. (This was calculated using the initial model developed in Section 4.1 using the Ecostar specifications).

Because of the need for modularity, this 120 kW(e) system is used as the reference size. In order to make the required impact on Wits University's electric bill, and to create a system that will provide better energy security, a bigger capacity will need to be installed. The plants are to be modularly integrated and will hence be installed in multiples of the 120 kW(e) reference plant. By examining Wits University's usage profile for West Campus in Section 5.1, it is concluded that 500kW of production will satisfactorily decrease the peak day time usage without demanding high production in hours with no sunlight. Therefore, 480 kW(e) is chosen because this is a multiple of the 120 kW(e) reference plant. These systems, depending on space availability, may be located at the same site or, with modularity in mind, at separate sites.

5.4.2 Reference Plant

The alternative selections with no storage or hybridisation will be designed to have an average capacity factor of 20%. Assuming constant solar load, this represents solar electric production for 5 hours per day which will be sufficient to meet mid-day peak loads. Because of weather effects, some days will experience no sunshine and therefore is compensated by days with considerable sunshine, generating electricity for more than the 5 hour peak period.

5.4.3 Storage

The storage alternatives will be designed to give an average capacity factor of 30% which make will provide approximately 3 hours of storage at the design input. The solar multiple for a plant will be 1.5 (=0.3/0.2). The actual size of the plant will be greater than 1.5 times the size of the reference plant because of the effect of the storage efficiency of these alternatives.

The design choice for solar storage is a one tank system because of the space constraints at Wits. It is suggested that the storage system, if implemented, is an active storage system based on the thermocline design (see Appendix A). The storage efficiency for such a system is unknown and beyond the scope of this report. For the purposes of this study, the efficiency of the storage system is assumed to be 94.7% which is the same storage efficiency found in the Ecostar study. This efficiency is applied to the entire system, which in effect will tend to under-estimate the net solar to electric efficiency. This is satisfactory in this case but when a full analysis is performed using Matlab, this efficiency is only applied to the thermal energy that enters the storage system.

5.4.4 Hybridisation

As discussed, the electricity usage at Wits University is significantly higher than the base load between 7am and 8pm giving a capacity factor of 54.1%. By making use of hybridisation significant LEC production savings can be achieved. This will also have a significant effect on bringing down the peak demand experienced by Wits University, in turn bringing down the peak price paid for electricity.

5.5 CSP Plant Performance

The model provided by the Ecostar study does not provide full details of its energy modelling; the model suggested by Broesamle et al. (2000) has therefore been followed. Only the data relevant to the chosen alternatives will be analysed.

5.5.1 Parabolic Trough

Collector Efficiency

The Collector efficiency of the parabolic troughs is 67%. This is calculated using Equation (11) with a geometric efficiency of 89% (Broesamle et al., 2000) and an optical efficiency of 76%. This is based on the design data of the LUZ-2 reflectors. The physical parameters representing the LS-2 parabolic trough collectors which were used in the SEGS plants in California are listed below.

Table 5-2: Optical Characteristics of the Parabolic Trough System

ρ_1 =0.93
τ_1 =0.98
τ_2 =0.95
α =0.94
γ =0.93

Solar field efficiency

The efficiency of the solar field (η_{Sf}) given by Equation (15), is a function of the convection and radiation losses and is equal to 51.23%. The details of the convection and radiation losses are described below.

Convection losses described by the second term in Equation (15) [$\frac{\pi \cdot U}{C \cdot DNI}(T_A - T_{amb})$] are equal to 3.5%. Data used in this calculation are provided in

Table 5-3. This data is provided by Broesamle et al. (2000) and as stated represents the LUZ-2 type reflectors. The *DNI* data is taken locally for Johannesburg and is not the design point radiation value (this value will be taken as the peak value experienced in the year). It is hard to say to what extent the use of local radiation data will affect the temperatures experienced by the absorber. For ease of calculation it is assumed here that this effect is minimal and is not accounted for.

Table 5-3: Convection Losses for Parabolic Trough Collectors

DNI	Direct Normal Radiation	800	W/m^2
U	Convection Loss Factor	2	W/m^2K
C	Factor of Concentration	72	
T_a	Mean Surface Temp of Absorber Tube	653	K
T_{amb}	Ambient Temp	330	K
Convection losses	0.035		

Radiation Losses are accounted for in Table 5-4 and are equal to 12.6%, using Equation (15). Again the data used is taken from Broesamle et al. (2000).

Table 5-4: Radiation losses for Parabolic Trough Collectors

sigma	Stefan-Boltzmann constant	5.6704E-08	$W.m^{-2}K^{-4}$
e	coefficient of emission	0.24	
DNI	Direct Normal Radiation	800	W/m^2
U	Convection Loss Factor	2	W/m^2K
C	Factor of Concentration	72	
T_a	Mean Surface Temp of Absorber Tube	653	K
T_{amb}	Ambient Temp	330	K
Radiation losses	0.126		

5.5.2 CLFR

Collector Efficiency

The optical efficiency of the CLFR system will be slightly different from that of the parabolic trough because the Fresnel receivers make use of a secondary reflector which in turn decreases the efficiency of the system. The data used to calculate the optical efficiency has been taken from the Solarmundo study (see Table 5-5) where a 2500 m^2 prototype collector system was built and tested (Häberle et al., 2002). The extra variable listed is the secondary receiver efficiency ρ_2. The optical efficiency is therefore 68% which is a significant drop from that found in the parabolic trough collectors. (This efficiency takes into account the surface quality factor of 93%). This efficiency has a high correlation to that suggested by Mills et al. (2003) who claim an array could collect a high 75% of the available beam if used with a reflector with ρ_1 = 91%, and 66% with an inexpensive glass reflector.

Mills and Morrison (2000) describe the design of a CLFR power plant and the effect of the different configurations of the designed plant. These configurations such as north-south orientation, longitude, incline angle of the slope etc all have an important effect on the performance of the plant. A geometric efficiency of 80% is assumed which results in a collector efficiency of 54.5%.

Table 5-5: Optical Characteristics of the Linear Fresnel System

ρ_1 =0.91
τ_1 =0.95
τ_2 =0.95
α =0.94
γ =0.93
ρ_2 =0.95

Solar Field Efficiency

The efficiency of the solar field η_{Sf} is calculated using the same method described by Broesamle et al. (2000) for the thermal modelling of parabolic troughs. The efficiency of the solar field is 40.1% which takes into account the convection and radiation losses as accounted for below. Because of the lower operating temperatures the losses are lower than that of the parabolic trough. The concentration factor is half of that of the parabolic troughs. These values including the operating temperatures have been suggested by Mills et al. (2003). The *DNI* value is Johannesburg's local value as previously discussed.

Table 5-6: Convection Losses for CLFR Collectors

DNI	Direct Normal Radiation	800	W/m^2
U	Convection Loss Factor	2	W/m^2K
C	Factor of Concentration	35	
T_a	Mean Surface Temp of Absorber Tube	593	K
T_{amb}	Ambient Temp	330	K
Convection losses	0.059		

Table 5-7: Radiation Losses for CLFR Collectors

sigma	Stefan-Boltzmann constant	5.6704E-08	$W.m^{-2}K^{-4}$
e	coefficient of emission	0.12	
DNI	Direct Normal Radiation	800	W/m^2
U	Convection Loss Factor	2	W/m^2K
C	Factor of Concentration	35	
T_a	Mean Surface Temp of Absorber Tube	593	K
T_{amb}	Ambient Temp	330	K
Radiation losses	0.085		

5.5.3 Thermal Energy Flow

The plants are designed for a capacity factor of 20% and 30% as discussed. This represents a net electric output calculated using Equation (3) where all the electricity will be produced from thermal energy provided from the solar field. The alternatives are analysed using two different power cycles; a steam cycle and an ORC. The power block design specifications are given in Table 5-8.

Because of the lower efficiency of the ORC, the size of the field will be larger in order to collect the required amount of thermal energy to produce the same amount of electricity.

Table 5-8: Power Block Design Specifications

Design Output		120 kW(e)
Efficiency (n_{pb})	Steam Cycle	0.355
Efficiency (n_{pb})	ORC	0.23

The required thermal energy delivered by the solar field $\dot{Q}_{therm}$ is determined from Equation (18) where the values are initially calculated on an annual basis. This value for the thermal energy input assumes that the power cycle efficiency includes that of pumping losses. The solar field efficiency η_{Sf} is calculated using Equation (17). The values used in this equation have been taken from the Ecostar study where the efficiencies are given in Table 5-9 and the values calculated in Section 5.5.1 and 5.5.2.

Table 5-9: Parabolic Trough Efficiencies

Parasitic losses	0.908
Storage	0.947
Piping	0.851

Summary

This method has been verified against the results obtained in the Ecostar study and details of this are given in Appendix D. The aperture area of the systems is calculated using Equation (16) (results given in Section 7.1). The results for the alternative plant configurations are shown in Table 5-10.

Table 5-10: Design Efficiencies

#	Collector Type	Power Cycle	Optical Efficiency	Geometric Efficiency	Collector Efficiency	Convection Losses	Radiation Losses	Solar Field Efficiency	Parasitic Losses	Piping Losses	Storage Efficiency	Power Block Efficiency [net]	Solar to Electric Efficiency
1&3	Parabolic Trough	Steam Cycle	75.7%	89.0%	67.4%	3.5%	12.6%	51.2%	90.8%	85.1%	100.0%	35.5%	14.1%
2	Parabolic Trough	Steam Cycle	75.7%	89.0%	67.4%	3.5%	12.6%	51.2%	90.8%	85.1%	94.7%	35.5%	13.3%
4&6	Parabolic Trough	ORC	75.7%	89.0%	67.4%	3.5%	12.6%	51.2%	90.8%	85.1%	100.0%	23.0%	9.1%
5	Parabolic Trough	ORC	75.7%	89.0%	67.4%	3.5%	12.6%	51.2%	90.8%	85.1%	94.7%	23.0%	8.6%
7&9	CLFR	Steam Cycle	68.2%	80.0%	54.6%	5.9%	8.5%	40.1%	90.8%	85.1%	100.0%	35.5%	11.0%
8	CLFR	Steam Cycle	68.2%	80.0%	54.6%	5.9%	8.5%	40.1%	90.8%	85.1%	94.7%	35.5%	10.4%
10&12	CLFR	ORC	68.2%	80.0%	54.6%	5.9%	8.5%	40.1%	90.8%	85.1%	100.0%	23.0%	7.1%
11	CLFR	ORC	68.2%	80.0%	54.6%	5.9%	8.5%	40.1%	90.8%	85.1%	94.7%	23.0%	6.8%

5.6 Income and Expenses

5.6.1 Specific Costs

Determining the actual LEC of the CSP design alternatives here is merely a first order estimate that follows the method prescribed by the IEA (1991) given in Section 3.2. To find the relevant LECs the total costs of the system need to be determined. To find the total costs, the calculation has been simplified to incorporate only the major costs of the systems. Only data relevant to the alternatives being analysed has been used.

These costs are taken strictly as specific costs which is the price in Euros (2008 Euro/kW or Euro/m^2 solar field –where applicable). The total specific costs are converted to Rands. The following exchange rates were used in the conversions (Taken on 18 November 2008- (XE, 2008)):

Table 5-11: Exchange Rates

Euro/dollar	0.78
Rand/Euro	13.09

Data from multiple sources have been utilised. A summary of the findings is given below and the results are given in Appendix H.

Ecostar

The model described in Section 3.2.3 has been further adjusted to take into account the *DNI* radiation found in Johannesburg (1780 kWh/m^2a) as well as the net output of 120 kW for the alternatives. These costs have been adjusted from 2005 Euros into 2008 Euros.

Eskom

The same procedure has been performed on the Eskom data, but here the prices are adjusted from 1999 U.S. dollars into 2008 Euros.

MTPP

The report described in Section 2.5 on the MTPP systems has also been incorporated into the comparison. The 2001 dollar costing has been adjusted to present value Euros.

BIO ORC

Obernberger et al. (2002) describe the specific costing of the installation of a biomass fired ORC plant in Austria. It is only the costing of the power block that has been taken here in order to compare these costs to that in the MTPP study. Again the present value of the 2002 Euro quote is found.

Solarmundo

The data described in Section 2.5 has been used in the data comparison. Solarmundo performed a comparison study between a 50 MW parabolic trough plant as well as a 50 MW CLFR plant.

5.6.2 Levelised Electricity Cost

It is important to note that, in evaluating the attractiveness of the CSP technology, the LEC cannot be compared to the current costs of electricity as supplied by City Power. LEC calculations are very sensitive to the economic assumptions used, which do not match the actual accounting procedures used to set electricity tariffs. In addition, an assumption of equivalent service is implicit in technology comparisons using an LEC approach; the only thing that varies between the options is the cost of production. Because of this it makes it inappropriate to compare the cost of energy to that of a coal fired power plant for example. Here the plants will vary in terms of the operating characteristics, dispatchability, modularity and environmental benefits. The results of the LEC analysis will therefore only give a general indication of the economic value to Wits University and more importantly serve as a good relative comparison.

Equation (6) has been used to determine the LEC of the selected systems. To calculate the LEC four components need to be determined.

- Investment costs
- Fuel Costs
- Operating and Maintenance costs
- Total Electricity Production.

Investment costs

The levelised required revenue is a fixed charge given by the first term in Equation (6). It comprises two components-the total investment and the fixed charge rate.

The total investment here is found by taking the average specific investment costs from each of the above mentioned sources for a capacity of 120 kW. The investment into the solar field and the actual land is based on the aperture area required to deliver enough thermal energy to satisfy the required capacity factor for each of the technologies. The results of the analysis are shown in Table 5-13.

Land costs being significantly less in South Africa than in Europe contributed to Eskom's claim that they would be able to produce the cheapest solar electricity in the world (van Heerden, 2001). Because this study looks at the possibility of a distributed plant in urban areas, land will be less available and therefore will come at a greater cost. However, this may not always be the case. If a private firm for example already owns the space which has no other utility value then this land will, in effect, be free. For Wits University's case the land costs are assumed to be zero. The opportunity costs involved with the loss of land are ignored.

Fixed Charge Rate

Because the installation of this system would not be a financial investment decision, the use of debt to finance the project would be inadvisable. The capital costs used for the installation would have an opportunity cost that would be equal to the loss in interest earned in alternative investments. It is assumed here that the opportunity cost will be 10%

which represents a typical return from Standard Bank's money market in South Africa (SB, 2008).

The FCR assumptions are given in Table 5-12 and the FCR is calculated using Equation (7). The insurance rate used in the Eskom study was 0.5%. A value of 1% was chosen because the system alternatives chosen have very little operational experience.

Table 5-12: Economic Assumptions

Annual Insurance Rate	1.00%
Interest Rate	10.00%
Depreciation Life	30.00
FCR (Fixed Charge Rate)	11.61%

Fuel Costs

To determine the effects of hybrid operation on the cost and production, a fuel source needs to be selected. Egoli Gas provides Johannesburg with natural gas that is a convenient, easily tapped and cost effective energy source (EG, 2009). Egoli Gas' pipeline network ensures that gas is instantly available at point-of-use, and they also guarantee that delivery delays will never occur. The gas is lighter than the air and disperses easily and harmlessly into the atmosphere, making it relatively safe. For the above reasons natural gas was chosen as the fuel source for hybrid operation. A detailed analysis of different fuel sources is beyond the scope of this report. The fuel specifications and tariffs are provided in Appendix F.

Operating and maintenance costs

The operating and maintenance costs for the CSP systems are shown in Table 5-13. The data used to find these average values is given in Appendix H.

Table 5-13: Average Economic Data

Economic Data				
Source	Average			
CSP System	Parabolic Trough	CLFR	Steam Cycle	ORC
Capacity	120kW	120kW	120kW	120kW
Specific Investment cost for Solar Field (*/m²)	R 4,159	R 2,009		
Specific Investment cost for Power Block [*/kW(e)]			R 15,845	R 14,536
Specific Land Cost [*/m²]	R 0	R 0	R 0	R 0
Specific Investment in Storage[*/kWh(th)]	R 647	R 647	R 647	R 647
Surcharge for Construction, Engineering and Contingencies %	20.00%	20.00%	20.00%	20.00%
Average O&M costs [% of total capital costs]	2.88%	3.75%		2.00%

5.6.3 Income Sources

There are three possible income streams for renewable energy electricity generators. These are selling physical electrical power through a Power Purchase Agreement (PPA) into the electrical grid at prevailing electricity (energy) market price, Certified Emission Reductions (CERs) trading through the Clean Development Mechanism (CDM) of the Kyoto Protocol and issuing of Tradable Renewable Energy Certificates (TRECs) (Schaffler, 2007). These are further discussed below.

Power Purchase Agreement (PPA)

South Africa has a high level of renewable energy potential and presently has in place targets of 10,000 GWh of renewable energy by 2013 (DME, 2003). To contribute towards this target and stimulate the renewable energy industry in South Africa, there is a need to establish an appropriate market mechanism. It is currently possible to sign a PPA with Eskom who is designated as the single buyer in South Africa (Eskom, 2009), however to stimulate renewable sources of energy NERSA is currently working on he implementation of a Renewable Energy Feed-in Tariff (REFIT) for South Africa (NERSA, 2008). The Renewable Energy Purchasing Agency (REPA), which will act as the single buyer for renewablevenergy dispatched from the independent power producers (IPPs), is still under the authority of Eskom. So whether licenses are correctly handled and the playing field is actually level, is questionable. NERSA have indicated that these ‘loose ends’ would be dealt with over the next three months, during which time the precise tariff flow-through arrangements for cost recovery would also be finalised.

Feed-in Tariffs are, in essence, guaranteed prices for electricity supply rather than conventional consumer tariffs. The basic economic principle underpinning the REFIT is the establishment of a tariff that covers the cost of generation plus a "reasonable profit" to induce developers to invest. This is quite similar to the concept of cost recovery used in utility rate regulation based on the costs of capital. Under this approach it becomes economically appropriate to award different tariffs for different technologies. The PPA signed with at the appropriate REFIT should also be certain and have a long term guarantee to allow for project financing to be raised by the project.

Table 5-14 below is a comparison between the REFITs that are currently being offered overseas. The max capacity specifies the maximum size of a permissible plant that will qualify for the tariff. Other tariffs for larger plants are available. The terms of the Power Purchase Agreement (PPA) for the REFITs may include a certain minimum capacity or designs that include a set storage or hybrid capacity. For example Spain’s REFIT dictates that only 15% of production is allowed from hybrid operation (Geyer, 2007).

Because South Africa is a developing country we will be able to make use of lower labour and with our abundance of land, land is also cheaper, which both translates into a lower LEC. It is hard to estimate what the CSP REFIT will be for South Africa but this value, in order to attract international investors, will have to be competitive with REFITs found elsewhere. The lowest value of the REFITs (R2.05/kWh) in Table 5-14 will be used for the analysis in this study. It is also assumed that this value remains constant over the life of the plant. It is also assumed that this value will have no restrictions on the technology used.

Table 5-14: International CSP REFITs (Geyer, 2007)

Country	Max Capacity	REFIT [/kWh]	REFIT [/kWh]
France	12MW	€ 0.30	R 3.93
Germany	-	€ 0.46	R 6.02
Greece	5MW	€ 0.24	R 3.14
Israel	20MW	$ 0.16	R 2.05
Portugal	10MW	€ 0.21	R 2.75
Spain	50MW	€ 0.27	R 3.54

The main motivator for the use of CSP technology at Wits University is energy security. The main purpose of a REFIT is to stimulate the market, allowing IPPs to invest in renewable energy technologies that, without a guaranteed income, would otherwise be unfeasible. If Wits University (or any other entity) is interested in an alternative source of energy to fulfil energy security and supply issues, it means that they would be generating electricity for themselves and obviously would not be able to sell the electricity to the designated authority under the REFIT. However, it has been decided to investigate generating costs of electricity which would be sold under the REFIT.

Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialised countries with a greenhouse gas reduction commitment (called Annex 1 countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. It has been operational since 2006 and had registered more than 1000 projects equivalent to more than 2.7 billion tonnes of $C0_2$ reduction (CDM UNFCC, 2009).

A crucial feature of an approved CDM carbon project is that it has established that the planned reductions would not occur without the additional incentive provided by emission reductions credits, a concept known as "additionality" (UNFCC, 1998).

Finance from the CDM

Certified Emission Reductions (CER) or "Carbon Credits" can be sold at any stage of the development or implementation of a CDM project. CERs are traded on an internationally regulated market at a price per tonne of carbon dioxide reduced. Over the past few years this value has ranged between €5-€20/ ton CO_2 equivalent.

Because the proposed development will involve the replacement of electricity by a renewable source of energy, the baseline calculation used to analyse the CER income is performed using data from Eskom's current generation mix and the emissions associated with the generation output. The data used has been taken from Eskom's annual report. The figure used represents the Eskom average CO_2 figure. Eskom have calculated the carbon emission factor to be 1,2kg/kWh in accordance with the CDM approved consolidated methodology 0002. Further information can be obtained in Eskom's annual report (Eskom, 2008).

It is uncertain what policies will change 'post Kyoto', however it is recommended that any CSP project is registered as a CDM project as there are various financing options that are attractive such as the forward selling of CERs that can provide development finance. These various options, because of their uncertainty and variety have been excluded from analysis in this study and it is recommended that they be incorporated into a full financial analysis.

Tradable Renewable Energy Certificates (TRECS)

The concept of TRECs is based on separating the various attributes of renewable resource-based energy provision from the physical energy carrier, electrical or otherwise. TRECs represent all of the benefits ("green" attributes, excluding greenhouse gas mitigation) associated with the generation of electricity from renewable energy resources. A major advantage, apart from the "extra" income stream, is that TRECs can be traded worldwide and separately from the electricity grid infrastructure, thereby avoiding the complexities of use-of-grid system charges or grid access problems. TRECs are only applicable to renewable energy and can be issued and traded for all types of renewable energy including non-electrical renewable energy systems, such as solar water heating systems, which would offset fossil-based electricity production requirements (Schaffler, 2007).

In March 2008 the South African National Tradable Renewable Energy Certificate Team (SANTRECT) was formed by the DME with an aim to facilitate and coordinate the establishment of Issuing Body (IB) as Non-Profit Organisation (NPO) that will be responsible for registering, issuing, transfer and redeem certificates in South Africa. The SANTRECT is in the process of developing the constitution and the IB will be registered thereafter. The SANTRECT is intending to register an IB, and hence establishment of IB NPO by March 2009 (DME, 2009).

The use of TRECS to finance the project is certainly an option and will allow for energy security by not having to sell away the electricity under the REFIT. However, there is no solid framework in place and has been excluded from the analysis. It is recommended that this be investigated when in place.

6 ENERGY MODELLING

In order to determine a *nominal* cost of electricity for the chosen alternatives thermal modelling as well as the analysis of the West Campus bill has been performed using Matlab (© 2005). This was done for all the reference plants, as well as for the 480 kW(e) chosen capacity. The models and details are outlined below, and the results are found in Section 7.

- *DNI* synthesis
- Design Analysis and Thermal Modelling
- System integration and bill calculation

6.1 *DNI* Synthesis

The hourly *DNI* data obtained in the TMY2 format comes in the form of a CSV (comma separated values) which is merely a list of 8760 values (number of hours in year). A short code was written that assigns a month, day and hour to each value, allowing for data analysis.

6.2 Design Analysis and Thermal Modelling

The hourly electric performance of the of the twelve design variations described in Section 5.4 was then modelled. This takes into account the design parameters described in Section 5.5 and the *DNI* data for Johannesburg, described above. These input parameters are shown in Table 5-10, Table 7-1 and Table 7-2 (see Section 7.1). The model can be adapted to find the performance of these systems for any design requirement as well as any *DNI* input.

The hourly thermal energy collected by the solar field ($\dot{Q}_{Sf}$) is found using the input *DNI* data in Equation (16). It is merely the *DNI* [W/m^2] multiplied by the aperture area of the field [m^2] to find a value for the initial thermal energy collected [kW].

The thermal energy that is delivered by the system to the power block ($\dot{Q}_{therm}$) is calculated using Equation (17). To overcome the thermal inertia required by the solar field and power block (especially on start-up), the minimum design thermal energy delivered to the power system is taken as 25% of the design thermal input. If the system incorporates no storage, the model assumes that this energy is dumped. In actual operation, this thermal energy (radiation values usually below 200 W/m^2 (Broesamle et al., 2000)) would be used to 'warm up' the system. Anything over the maximum design thermal load will be dumped. In actual operation instances when the *DNI* radiation received is higher than the design point radiation, part of the field will be set 'off concentrate'.

The electric energy delivered by the system takes into account the efficiency of the net solar-to-electric efficiency uses the *gross* efficiency of the power block in Equation (1).

Storage

For the systems that incorporate storage, any thermal energy over the maximum or under the minimum design load is summed as the thermal energy for the day. This thermal energy is then converted to electric energy and dispatched at 18h00 every day. If this thermal energy is more than the required energy to provide an hour's worth of design electric output then the remainder will be used in the second hour (19h00), this is again repeated for the third hour (20h00).

Hybrid Operation

Systems under hybrid operation will run under full rated capacity from 07h00 till 20h00 which is 13 hours per day or a capacity of 54.1%. It's solar-only capacity factor will be the same as the system with no storage (20%). The Matlab model finds the difference between the rated capacity (120kW) and the electric output from the solar system and adds that difference as a hybrid input. This keeps the power generation constant.

The model then finds the average monthly thermal flow from the input radiation to the output electric generation. It also finds the average electricity generated using thermal storage and under hybrid operation. The average thermal energy flow for each hour of the day in one year is also calculated.

Three Excel files are then generated which were used as the input to calculate the exact effect that the systems have on the usage and demand of Wits University. These files include the solar-electric generation of each system, as well as the storage and hybrid outputs for the relevant systems. This is described below.

6.3 System Integration and Bill Calculation

A Matlab code was written by Brink (2008) in order to test the effect that the new electricity pricing from Eskom had on Wits University's electricity bill. This code has been verified and matches that of online bills (MOL, 2008). There is however one discrepancy, the peak complex demand (see below) is being charged on the peak for the billing month as opposed to that set out in the tariff guidelines provided by City Power (City of Johannesburg, 2008). A summary of these guidelines is provided in Appendix E. This code has further been adjusted to incorporate the effects the CSP alternatives have on the cost of electricity.

Wits University is billed yearly for the period 1 July to 30 June. Because the demand charge is calculated using twelve months worth of data (as outlined in Appendix E), to analyse the bill, data from July 2006 - June 2007 as well as July 2007 – June 2008 are used. This can be done for each of Wits University's six campuses.

The three output files from the design analysis of the twelve different CSP systems are inputted into the code (the solar output, the storage output and the hybrid output for each of the twelve configurations). These files merely contain the actual kW of electricity production on a half hourly basis. This data was then integrated with the electricity usage at Wits University and its effect on the electricity consumption and bill was calculated.

Wits University's half hourly consumption data has been arranged into an Excel spreadsheet that contains the real, reactive and complex usage demands for each year. The real and complex power demand is then adjusted in Matlab to take into account the effect of the solar-electricity generation.

Complex power

To calculate the rates for the complex power, 80 % of the average of the three largest peaks of the preceding twelve months for each month is calculated. This value is then compared to find the greater of the measured demand for the month of interest and the demand of 70 kVA (see Appendix E). This process is also performed for the peak demand after the effect of the solar power integration.

The average power factor for Wits University West campus over two years was found to be 0.9. This power factor that is measured when feeding power into the University is assumed to be the same power factor the CSP systems will operate with when feeding electricity into the university's grid.

Reactive power

To determine the billable reactive energy, a charge is made on the kVARh supplied in excess of 30% (0,96PF) of kWh for each month. The reactive energy costs are calculated on a monthly and yearly basis by summing the applicable billable reactive energy.

Real power

The real usage is summed for the month to find the cost of real electric power for each month. The different summer/winter charge rates are applied where applicable. Again, this is also done for the usage that incorporates the effect of the addition of solar power/hybrid generation. These are then summed to find the yearly billing data.

Total Bill

A surcharge of 2% (see Appendix E) of the total energy costs (sum of the electricity usage cost, peak demand cost, billable reactive energy cost and the constant service charge) is added to the cost. Finally the total energy bill is determined by adding a VAT (14%) charge to the total which includes the surcharge.

LEC

The real LEC for each of the CSP systems is also inputted into the code. The actual cost of the CSP electric generation per kWh is found by totalling the actual cost per kWh of solar electricity produced, using the LEC, less the savings made on the complex power and actual power consumption. From this, a monthly value for a *'Wits'* LEC can be found and averaged for the year.

Capacity Factor

Each of the systems has been designed for an average capacity factor for the year. Depending on seasonal variations, the actual capacity factor for each month will vary from this average value. The code finds the average capacity factor for each month to show where production is maximised.

7 RESULTS

7.1 Initial Design Results

Table 7-1 shows the results for the required energy flows for the reference plants on yearly basis. These energy flows, at the set capacity factors, were used to calculate the resulting plant aperture areas shown in Table 7-2 and the aperture and total areas are depicted in Figure 7.1. The plant areas for the 480 kW(e) systems are shown in Figure 7.2.

Table 7-1: Thermal Energy Flow

#	Collector Type	Power Cycle	Design Electric Output [kW(e)]	Solar CF	E_{net} [Wh/a]	Q_{therm} [Wh/a]	Q_{sf} [Wh/a]
1&3	Parabolic Trough	Steam Cycle	120	20%	210,240,000	592,225,352	766,428,395
2	Parabolic Trough	Steam Cycle	120	30%	315,360,000	592,225,352	1,129,332,240
4&6	Parabolic Trough	ORC	120	20%	210,240,000	914,086,957	1,182,965,566
5	Parabolic Trough	ORC	120	30%	315,360,000	914,086,957	1,743,099,761
7&9	CLFR	Steam Cycle	120	20%	210,240,000	592,225,352	778,318,095
8	CLFR	Steam Cycle	120	30%	315,360,000	592,225,352	1,148,019,191
10&12	CLFR	ORC	120	20%	210,240,000	914,086,957	1,201,317,060
11	CLFR	ORC	120	30%	315,360,000	914,086,957	1,771,942,664

Table 7-2: Aperture Areas

#	Collector Type	Power Cycle	Aa [m^2]
1&3	Parabolic Trough	Steam Cycle	841
2	Parabolic Trough	Steam Cycle	1,239
4&6	Parabolic Trough	ORC	1,297
5	Parabolic Trough	ORC	1,912
7&9	CLFR	Steam Cycle	1,090
8	CLFR	Steam Cycle	1,607
10&12	CLFR	ORC	2,480
11	CLFR	ORC	1,682

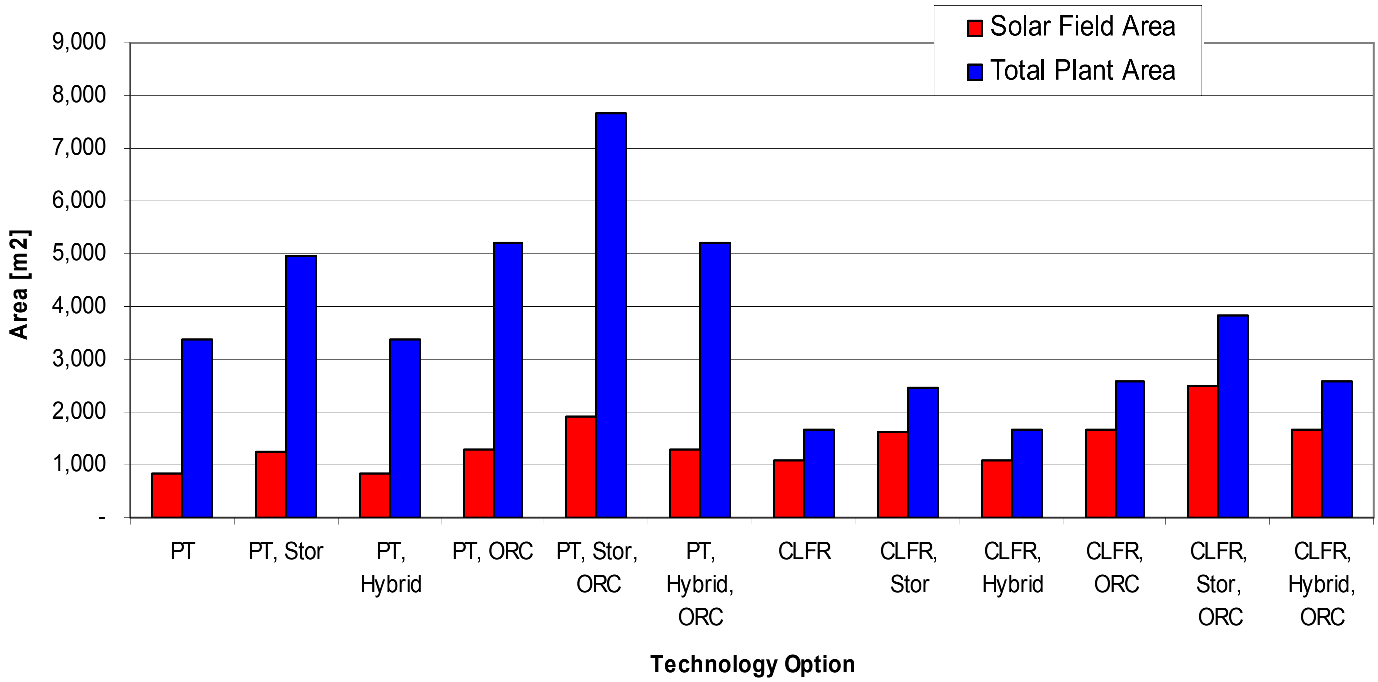


Figure 7.1: Reference Plant Areas (120 kW(e))

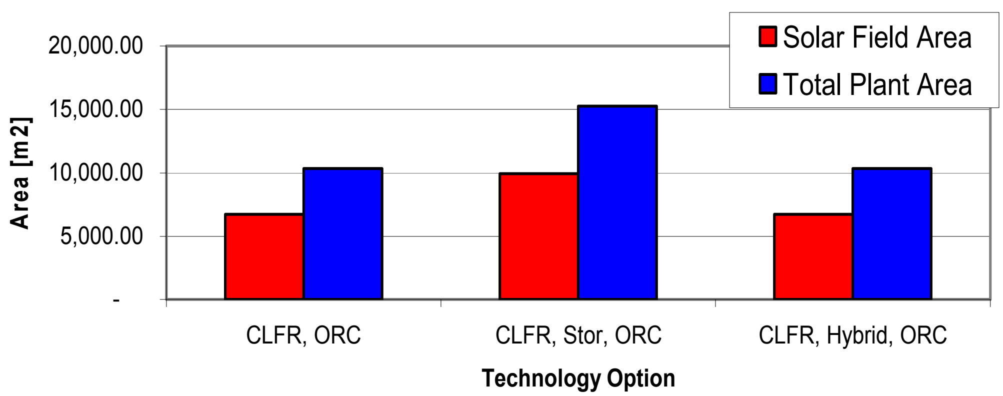


Figure 7.2: Plant Area for CLFR, ORC technologies (480 kW(e))

7.2 Initial Financial Results

Table 7-3 below shows the financial results that are based on the average economic data in Table 5-13. It is this data that has been used to determine the *real* LEC for the solar electricity production. Figure 7.3 below the table is a graph that plots the twelve alternatives against each other. This figure also includes the specific investment requirements of the alternatives.

Table 7-3: Economic Results

System	PT	PT, Stor	PT, Hybrid	PT, ORC	PT, Stor, ORC	PT, Hybrid, ORC	CLFR	CLFR, Stor	CLFR, Hybrid	CLFR, ORC	CLFR, Stor, ORC	CLFR, Hybrid, ORC
Size of field [m2]	841	1,239	841	1,297	1,912	1,297	1,090	1,607	1,090	1,682	2,481	1,682
Total Area	3,362	4,954	3,362	5,189	7,647	5,189	1,676	2,473	1,676	2,587	3,817	2,587
Investment Solar Field	R 3,495,459	R 5,150,559	R 3,495,459	R 5,395,165	R 7,949,776	R 5,395,165	R 2,189,055	R 3,228,857	R 2,189,055	R 3,378,759	R 4,983,670	R 3,378,759
Investment Power Block, BOP	R 1,901,368	R 1,901,368	R 1,901,368	R 1,744,356	R 1,744,356	R 1,744,356	R 1,901,368	R 1,901,368	R 1,901,368	R 1,744,356	R 1,744,356	R 1,744,356
Investment Storage	R 0	R 656,199	R 0	R 0	R 1,012,829	R 0	R 0	R 656,199	R 0	R 0	R 1,012,829	R 0
Investment Land	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
Contingencies	R 1,619,048	R 2,312,438	R 1,619,048	R 2,141,856	R 3,212,088	R 2,141,856	R 1,227,127	R 1,735,927	R 1,227,127	R 1,536,934	R 2,322,256	R 1,536,934
Sum Total Equipment Costs	R 5,396,827	R 7,708,126	R 5,396,827	R 7,139,521	R 10,706,961	R 7,139,521	R 4,090,423	R 5,786,423	R 4,090,423	R 5,123,115	R 7,740,855	R 5,123,115
Total Including indirect Costs	R 7,015,875	R 10,020,564	R 7,015,875	R 9,281,377	R 13,919,049	R 9,281,377	R 5,317,550	R 7,522,350	R 5,317,550	R 6,660,049	R 10,063,111	R 6,660,049
Actual O&M Costs	R 201,706	R 288,091	R 201,706	R 185,628	R 278,381	R 185,628	R 152,880	R 216,268	R 152,880	R 133,201	R 201,262	R 133,201
Annual Financing and insurance Costs	R 814,397	R 1,163,179	R 814,397	R 1,077,375	R 1,615,713	R 1,077,375	R 617,257	R 873,189	R 617,257	R 773,094	R 1,168,118	R 773,094
Annual Fuel Costs			R 587,111			R 904,612			R 587,111			R 904,612
Actual Net Elec [kWh]	210,240	315,360	568,699	210,240	315,360	568,699	210,240	315,360	568,699	210,240	315,360	568,699
Solar Net Electricity(Joburg)	210,240	315,360	210,240	210,240	315,360	210,240	210,240	315,360	210,240	210,240	315,360	210,240
Fossil net Electricity [kWh]	-	-	358,459	-	-	358,459	-	-	358,459	-	-	358,459
Fossil thermal energy required [kWhth]	-	-	1,009,744	-	-	1,558,518	-	-	1,009,744	-	-	1,558,518
Fossil thermal energy [GJ]	-	-	3,635	-	-	5,611	-	-	3,635	-	-	5,611
Fossil thermal energy input [GJ]	-	-	4,544	-	-	7,013	-	-	4,544	-	-	7,013
Total Costs [R]	R 7,015,875	R 10,020,564	R 7,015,875	R 9,281,377	R 13,919,049	R 9,281,377	R 5,317,550	R 7,522,350	R 5,317,550	R 6,660,049	R 10,063,111	R 6,660,049
Specific Investment (R/kW)	R 58,466	R 83,505	R 58,466	R 77,345	R 115,992	R 77,345	R 44,313	R 62,686	R 44,313	R 55,500	R 83,859	R 55,500
LEC -Real (R/kWh)	R 4.83	R 4.60	R 2.82	R 6.01	R 6.01	R 3.81	R 3.66	R 3.45	R 2.39	R 4.31	R 4.34	R 3.18

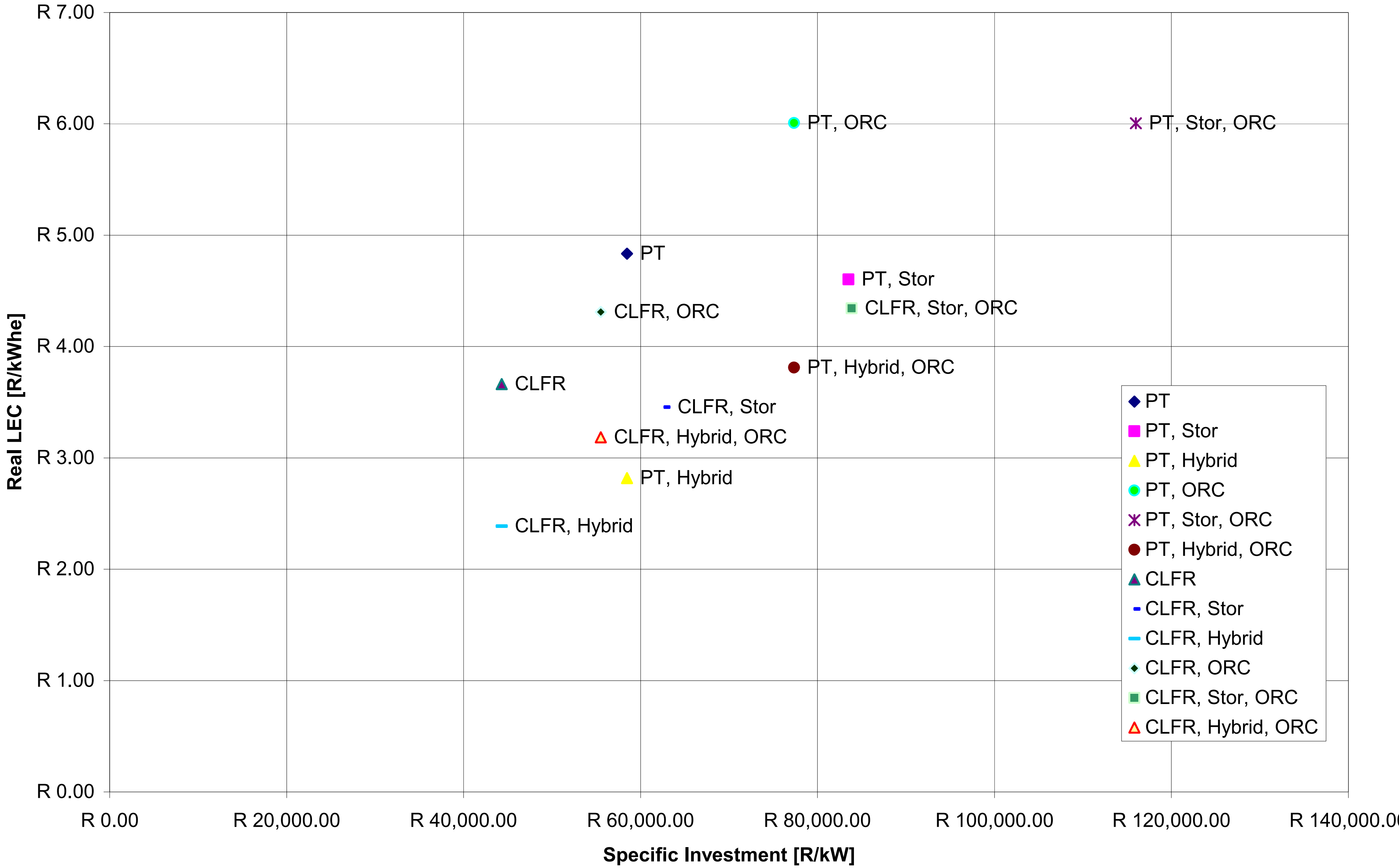


Figure 7.3: Economic Results (120 kW(e) reference systems)

7.3 Matlab Modelling

Chosen Technologies for further investigation

Energy modelling of the twelve reference systems was carried out and a second perspective model was put together that ranks the technologies against one another using the same factors discussed in Section 4. This can be found in Appendix I. This was used as an indicator and is not followed directly. The three options chosen for further investigation are given below with reasons that follow. Modelling of these systems was done at a 480 kW(e) capacity.

- CLFR with ORC
- CLFR with ORC making use of storage
- CLFR with ORC with hybridisation using natural gas.

Solar Field

In terms of urban distributed power generation the solar field that shows the most potential is the CLFR configuration. It is the most compact and offers the smallest plant area for a set electric output. The CLFR option also offers large infrastructure savings. The solar field also requires less water for cleaning and considering the sustainability of the water supply in a rapidly growing city such as Johannesburg, this benefit is favoured.

Power Cycle

In terms of the potential power cycle, an ORC is recommended for further investigation. ORC plants are noted to have less demanding operating assistance because they are capable of automatic start-up, safe shutdown, and regulation with varying solar conditions. It is more common to use ORC systems for small scale generation and because the ORC systems can operate at lower temperatures; the efficiency of the solar field is less important. This allows room for savings in solar field costs.

Energy modelling

The following discusses the modelling that was used for the 120kW(e) reference systems as well as the chosen design alternatives at 480 kW(e). For simplicity, only the results for the three alternatives discussed above have been displayed.

Energy Flow

The *hourly* energy flow from the initial *DNI* collected by the solar field to the electric generation has been tracked and represented in Figure 7.4, Figure 7.6 and Figure 7.8 (Note different scales used). The graphs respectively represent the hourly energy flow for a typical year for the three alternatives discussed above. Figure 7.5, Figure 7.7 and Figure 7.9 show the average hourly energy for a 24 hour period for each of the systems.

Effects on the Usage

Figure 7.10, Figure 7.12 and Figure 7.14 each represent the effect that the three alternatives will have on the electricity usage at the University (for a typical billing year – June to July). The black section on the graphs represent the solar generation. It can be seen that the largest effect on the usage is with the use of hybridisation because it has the highest capacity factor (Figure 7.14).

Figure 7.11, Figure 7.13 and Figure 7.15 show the effects of the three alternatives on the daily consumption. The day chosen is a typical day in winter during term time (17 June 2008). With this scale used the effect of the three alternatives can be seen in greater detail. Figure 7.13 shows the effects of the storage system coming on line at 18h00. The electricity generated using hybridisation can be clearly seen as a constant input between the hours 07h00 and 20h00 in Figure 7.15.

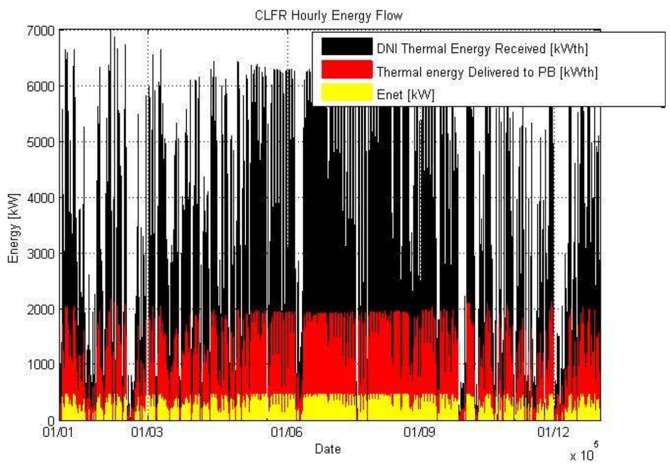


Figure 7.4: Hourly Energy Flow for CLFR, ORC (480 kW(e))

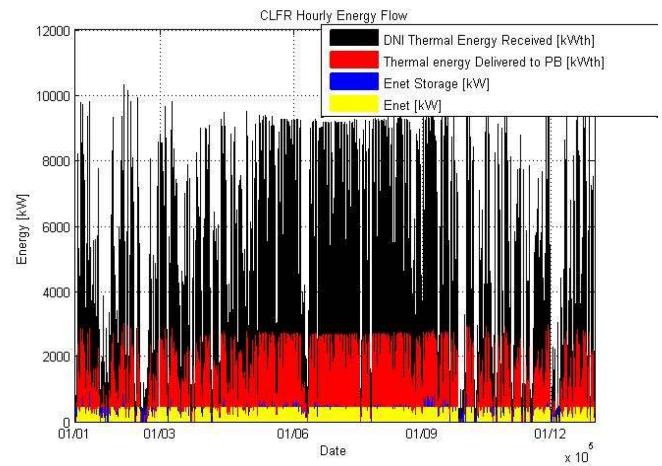


Figure 7.6: Hourly Energy Flow for CLFR, ORC, with Storage (480 kW(e))

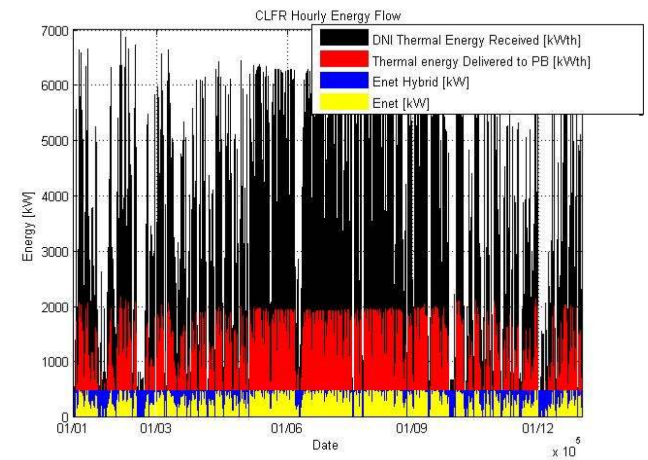


Figure 7.8: Hourly Energy Flow for CLFR, ORC, with Hybridisation (480 kW(e))

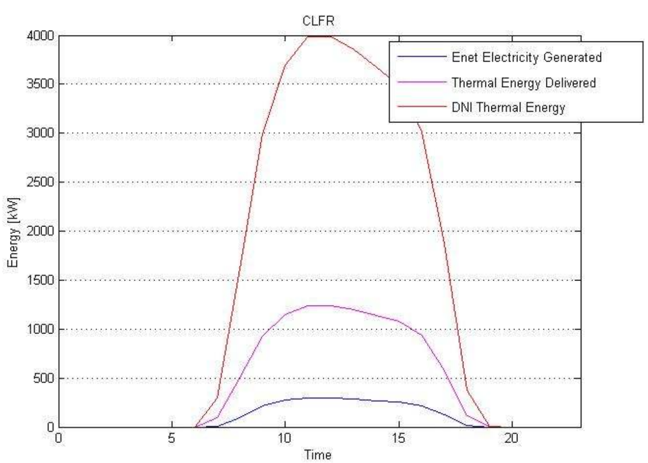


Figure 7.5: Average Energy Flow for CLFR, ORC (480 kW(e))

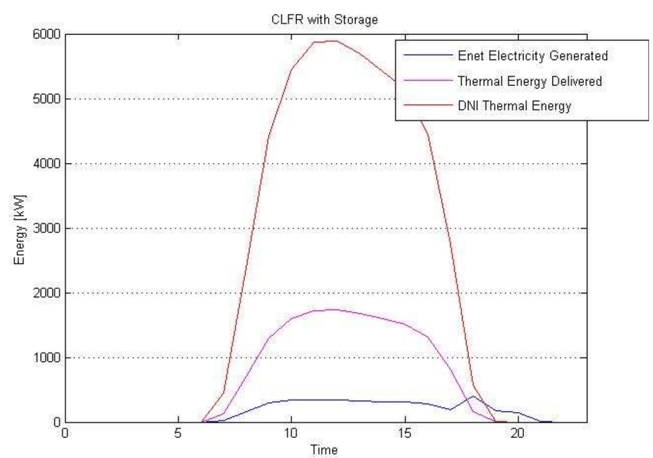


Figure 7.7: Average Energy Flow for CLFR, ORC, with Storage (480 kW(e))

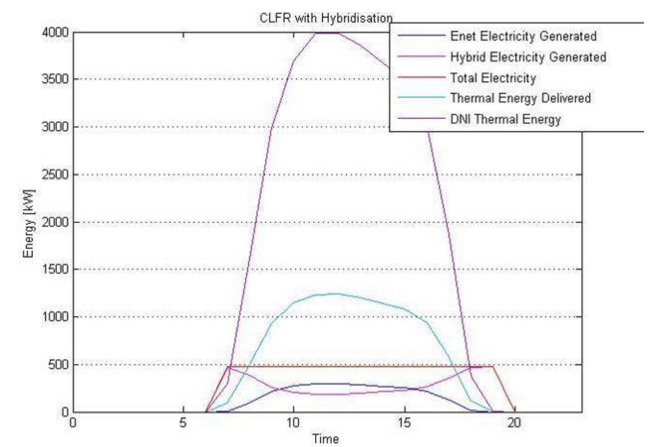


Figure 7.9: Average Energy Flow for CLFR, ORC, with Hybridisation (480 kW(e))

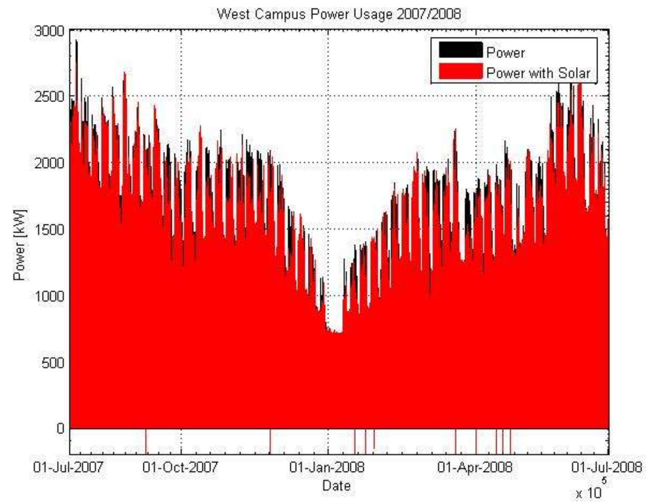


Figure 7.10: West Campus Power Usage - CLFR, ORC (480 kW(e))

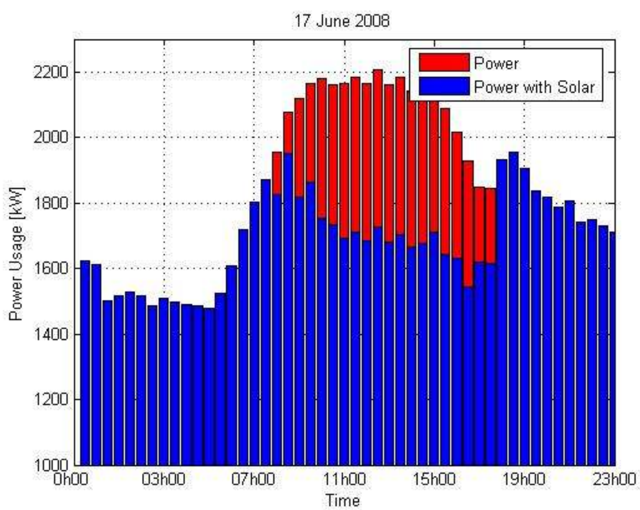


Figure 7.11: West Campus Power Usage - CLFR, ORC (480 kW(e))

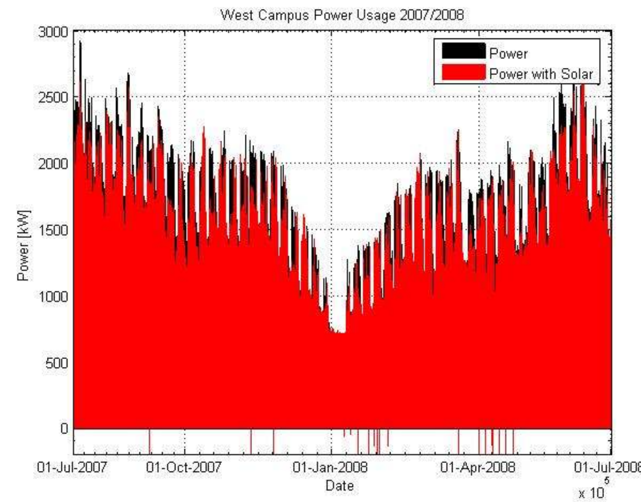


Figure 7.12: West Campus Power Usage - CLFR, ORC, with Storage (480 kW(e))

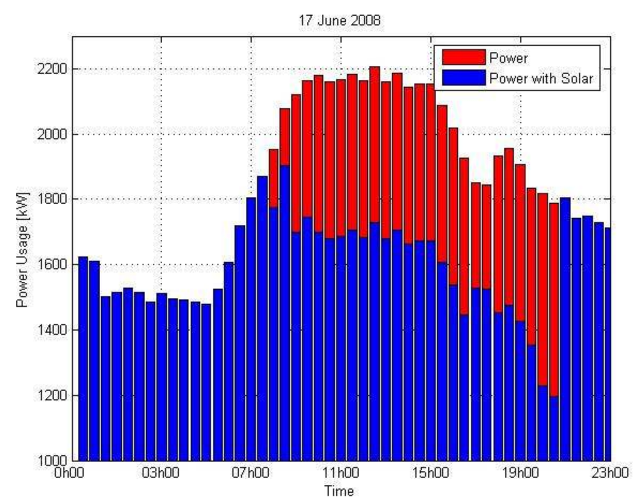


Figure 7.13: West Campus Power Usage - CLFR, ORC, with Storage (480 kW(e))

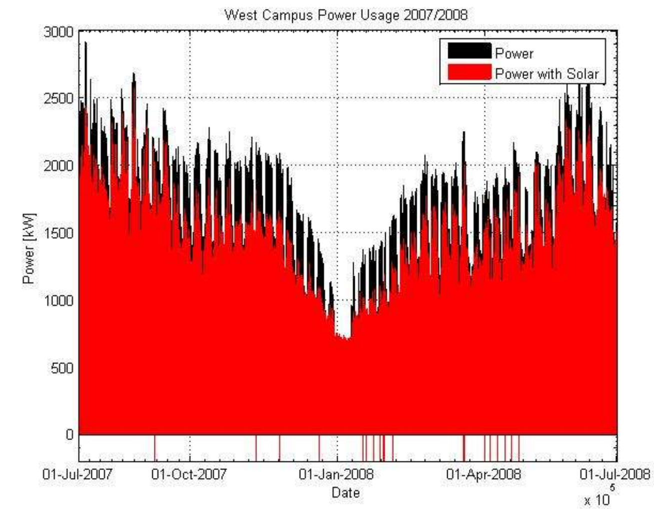


Figure 7.14: West Campus Power Usage - CLFR, ORC, with Hybridisation (480 kW(e))

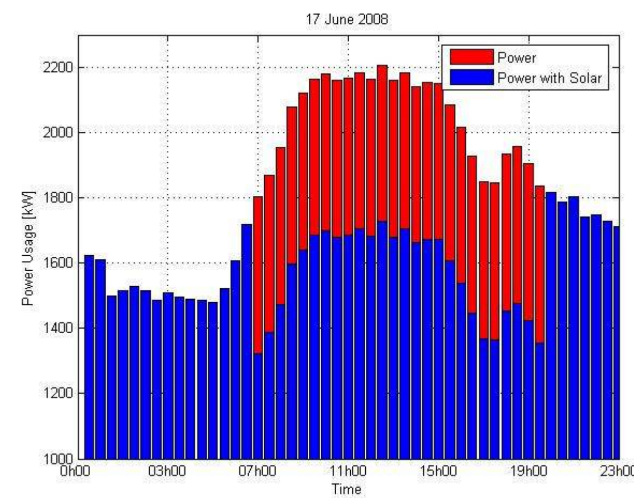


Figure 7.15: West Campus Power Usage - CLFR, ORC, with Hybridisation (480 kW(e))

Energy Usage and Production

Table 7-4, Table 7-5 and Table 7-6 show the monthly energy usage as well as the total energy produced using each of the three alternatives.

Billing Results

Table 7-7, Table 7-8 and Table 7-9 are the billing results for each of the three systems under analysis. A summary of this data is given in Table 7-10. A summary of the billing results for the reference plants is given in Appendix J. As mentioned in Section 5.6.3, the inclusion of the REFIT for a CSP application has been included merely as an indicator for what the nominal LEC would be if the electricity were to be sold.

LEC and Payback

The LEC and payback for the three alternatives analysed are given in Figure 7.16 and Figure 7.17. Figure J1 and Figure J2 in Appendix J show the same results for 120 kW(e) reference plants.

Table 7-4: Energy Results using CLFR, ORC

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Energy Consumption [kWh]	1,441,049	1,341,473	1,097,243	1,143,128	1,017,735	668,810	737,151	952,793	1,022,896	986,482	1,249,898	1,263,414
Peak Complex Power [kVA]	3,043	2,767	2,453	2,372	2,340	1,800	1,870	2,421	2,415	2,321	2,822	2,837
Billable Complex Power [kVA]	3,043	2,767	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,822	2,837
Reactive Energy [kVAR]	457,161	455,943	510,416	488,742	501,856	377,258	413,431	527,204	530,937	494,766	495,731	406,323
Billable Reactive Energy [kVAR]	24,846	53,501	181,243	145,804	196,535	176,615	192,285	241,366	224,068	198,821	120,761	27,299
Solar Energy Generated [kWh]	97,475	93,336	79,003	62,359	50,423	57,750	49,103	51,303	65,737	68,743	95,463	88,162
Capacity Factor	0.28	0.27	0.23	0.18	0.15	0.17	0.14	0.15	0.19	0.20	0.28	0.26

Table 7-5: Energy Results using CLFR, ORC with Storage

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Energy Consumption [kWh]	1,441,049	1,341,473	1,097,243	1,143,128	1,017,735	668,810	737,151	952,793	1,022,896	986,482	1,249,898	1,263,414
Peak Complex Power [kVA]	3,043	2,767	2,453	2,372	2,340	1,800	1,870	2,421	2,415	2,321	2,822	2,837
Billable Complex Power [kVA]	3,043	2,767	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,822	2,837
Reactive Energy [kVAR]	457,161	455,943	510,416	488,742	501,856	377,258	413,431	527,204	530,937	494,766	495,731	406,323
Billable Reactive Energy [kVAR]	24,846	53,501	181,243	145,804	196,535	176,615	192,285	241,366	224,068	198,821	120,761	27,299
Solar Energy Generated [kWh]	148,341	142,137	122,684	98,769	80,896	93,132	84,866	84,441	100,874	104,377	144,202	136,377
Capacity Factor	0.43	0.41	0.35	0.29	0.23	0.27	0.25	0.24	0.29	0.30	0.42	0.39

Table 7-6: Energy Results using CLFR, ORC with Hybridisation

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Energy Consumption [kWh]	1,441,049	1,341,473	1,097,243	1,143,128	1,017,735	668,810	737,151	952,793	1,022,896	986,482	1,249,898	1,263,414
Peak Complex Power [kVA]	3,043	2,767	2,453	2,372	2,340	1,800	1,870	2,421	2,415	2,321	2,822	2,837
Billable Complex Power [kVA]	3,043	2,767	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,552	2,822	2,837
Reactive Energy [kVAR]	457,161	455,943	510,416	488,742	501,856	377,258	413,431	527,204	530,937	494,766	495,731	406,323
Billable Reactive Energy [kVAR]	24,846	53,501	181,243	145,804	196,535	176,615	192,285	241,366	224,068	198,821	120,761	27,299
Solar Energy Generated [kWh]	193,440	193,440	187,200	193,440	187,200	193,440	193,440	180,960	193,440	187,200	193,440	180,960
Capacity Factor	0.56	0.56	0.54	0.56	0.54	0.56	0.56	0.52	0.56	0.54	0.56	0.52

Table 7-7: Billing Results using Normal CLFR, ORC

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Consumption Costs Normal [R]	499,756	465,223	257,304	268,064	238,659	156,836	172,862	223,430	239,869	231,330	433,465	438,152
Consumption Costs with Solar Generation [R]	465,951	432,854	238,777	253,440	226,835	143,294	161,347	211,399	224,454	215,210	400,358	407,578
Demand Costs Normal [R]	245,489	223,188	199,630	199,630	199,630	199,630	199,630	199,630	199,630	199,630	227,646	228,822
Demand Costs with Solar Generation [R]	229,796	223,188	198,109	198,109	198,109	198,109	198,109	198,109	198,109	198,109	204,708	225,746
Billable Reactive Energy Costs [R]	1,523	3,280	11,110	8,938	12,048	10,826	11,787	14,796	13,735	12,188	7,403	1,673
Total Costs Normal [R]	869,730	805,686	545,630	555,616	525,040	428,477	448,229	510,528	528,410	516,681	778,736	778,891
Total Costs with Solar Generation [R]	812,175	768,048	522,319	536,843	509,522	410,960	433,070	494,769	508,716	496,167	713,567	739,763
Total Costs including Costs of Solar Generation [R]	1,232,291	1,170,325	862,821	805,611	726,845	659,862	644,704	715,885	792,043	792,451	1,125,012	1,119,740
Wits Solar LEC [R/kWh]	3.80	3.96	4.06	4.05	4.05	4.05	4.04	4.05	4.05	4.05	3.72	3.93

Table 7-8: Billing Results CLFR, ORC with Storage

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Consumption Costs Normal [R]	499,756	465,223	257,304	268,064	238,659	156,836	172,862	223,430	239,869	231,330	433,465	438,152
Consumption Costs with Solar Generation [R]	448,311	415,930	228,534	244,902	219,689	134,996	152,961	203,629	216,214	206,854	383,455	390,857
Demand Costs Normal [R]	245,489	223,188	199,630	199,630	199,630	199,630	199,630	199,630	199,630	199,630	227,646	228,822
Demand Costs with Solar Generation [R]	217,698	215,417	195,613	195,613	195,613	195,613	195,613	195,613	195,613	195,613	201,688	225,746
Billable Reactive Energy Costs [R]	1,523	3,280	11,110	8,938	12,048	10,826	11,787	14,796	13,735	12,188	7,403	1,673
Total Costs Normal [R]	869,730	805,686	545,630	555,616	525,040	428,477	448,229	510,528	528,410	516,681	778,736	778,891
Total Costs with Solar Generation [R]	777,596	739,332	507,505	524,012	498,310	398,410	420,416	482,831	496,232	483,548	690,401	720,320
Total Costs including Costs of Solar Generation [R]	1,421,394	1,356,205	1,039,955	952,669	849,397	802,604	788,734	849,303	934,026	936,543	1,316,237	1,312,195
Wits Solar LEC [R/kWh]	3.81	3.94	4.07	4.06	4.06	4.06	4.06	4.06	4.07	4.07	3.81	3.97

Table 7-9: Billing Results using CLFR, ORC with Hybridisation

	CLFR, ORC											
Year	2007	2007	2007	2007	2007	2007	2008	2008	2008	2008	2008	2008
Month	7	8	9	10	11	12	1	2	3	4	5	6
Consumption Costs Normal [R]	499,756	465,223	257,304	268,064	238,659	156,836	172,862	223,430	239,869	231,330	433,465	438,152
Consumption Costs with Solar Generation [R]	432,671	398,138	213,405	222,702	194,760	111,474	127,500	180,995	194,507	187,432	366,380	375,395
Demand Costs Normal [R]	245,489	223,188	199,630	199,630	199,630	199,630	199,630	199,630	199,630	199,630	227,646	228,822
Demand Costs with Solar Generation [R]	202,846	215,417	175,540	175,540	175,540	175,540	175,540	175,540	175,540	175,540	195,290	193,158
Billable Reactive Energy Costs [R]	1,523	3,280	11,110	8,938	12,048	10,826	11,787	14,796	13,735	12,188	7,403	1,673
Total Costs Normal [R]	869,730	805,686	545,630	555,616	525,040	428,477	448,229	510,528	528,410	516,681	778,736	778,891
Total Costs with Solar Generation [R]	742,139	718,644	466,573	474,857	445,983	347,718	367,470	433,172	447,652	437,624	663,105	664,448
Total Costs including Costs of Solar Generation [R]	1,357,278	1,333,783	1,061,869	1,089,997	1,041,279	962,857	982,609	1,008,625	1,062,791	1,032,920	1,278,245	1,239,900
Wits Solar LEC [R/kWh]	2.61	2.79	2.82	2.82	2.82	2.82	2.82	2.81	2.82	2.82	2.67	2.64

Table 7-10: Summary for CLFR, ORC Technologies at 480 kW(e)

	CLFR, ORC	CLFR, Stor, ORC	CLFR, Hybrid, ORC
Total Electricity Consumption [kWh]	12,922,073	12,922,073	12,922,073
Total Solar Electricity Generated [kWh]	858,856	1,341,094	2,277,600
Yearly Bill [R]	7,291,654	7,291,654	7,291,654
Total Bill [R] (incl. cost of Solar)	10,647,589	12,559,262	13,452,154
Extra cost for Solar [R/year]	3,355,935	5,267,608	6,160,499
Cost Saved on Bill [R/year]	345,735	552,740	1,082,269
Real LEC [R/kWh]	4.31	4.34	3.18
Wits LEC [R/kWh]	3.98	4.00	2.77
Average Capacity Factor	0.21	0.32	0.55
Total Investment [R]	26,640,198	40,252,445	26,640,198
Payback [years]	77	73	25
	-	-	-
Nominal LEC [R/kWh] (with REFIT)	1.93	1.95	2.01
Extra cost for Solar [R/year] (with REFIT)	1,595,280	2,518,365	4,431,210
Payback [years] (with REFIT)	12.65	12.19	9.48

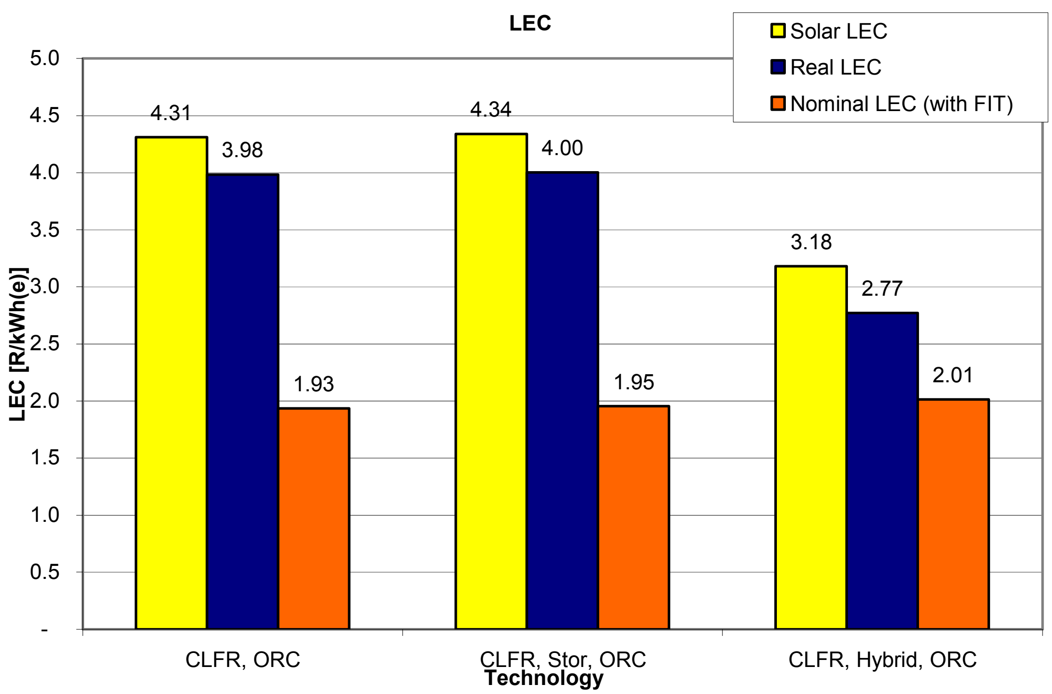


Figure 7.16: LEC Results for CLFR, ORC technologies (480 kW(e))

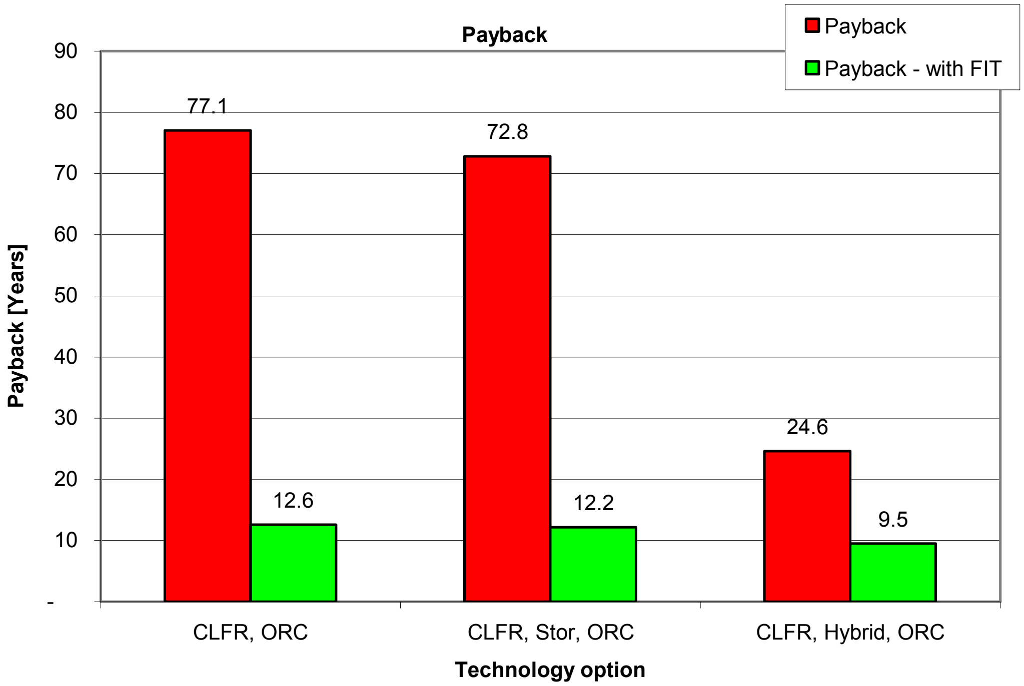


Figure 7.17: Payback Results for CLFR, ORC Technologies (480 kW(e))

8 DISCUSSION

8.1 Suitability of Design Approach

The scope of work only included the analysis of solar-thermal technologies. This excluded conventional diesel generators and other renewable technologies such as photovoltaic systems and biogas digesters. A comparison of these technologies to the solar systems investigated would be useful in showing the cost of distributed power options as opposed to grid-connected power. It is therefore recommended that these be included in future investigations.

Consistency in the data analysis was very important, specifically in terms of the costing of the systems. Because they are all on different levels of maturity, absolute cost data are difficult to estimate, however the relative distribution of the different cost items is considered to be well estimated by the approach followed. Because of the inherent uncertainty and variability of costs, the modelled technical performance of the system designs was more accurate than the costing analysis, however through the methodology followed, certain discrepancies were identified. These are further elaborated.

Scaling effects

The technical and specific cost data from the studies done on utility scale plants (>50 MW(e)) have been included in the analysis. The scaling of the technologies is not linear, as suggested by the scaling methods used and this will lead to several issues, most importantly, where the data provided is based on the economies of scale of the larger plants. Whether these methods are appropriate for scaling down below 1 MW(e) is questionable and should be investigated further. The technical aspects of some of the systems, such as the efficiency of the power block, may not scale as suggested. Freepower (2008) claim efficiencies of up to 22% at 270°C. The scaling of the steam cycle generators at such small capacities usually results in a greater drop in efficiency. These lower efficiencies will therefore require greater solar field areas in order to deliver the required thermal energy.

Whether these methods are also appropriate for cost scaling, as with the technical performance, is also questionable. The scaling effects of the costs will also be manufacturer and country specific and in order to calculate absolute cost data, direct quotes from the various manufacturers as well as a full life-cycle cost analysis will need to be performed.

Costing

In finding the present value of the costs from the multiple sources, the Chemical Engineering Plant Cost index was used. The index is adjusted according to the dollar (USD$) increase in the price of goods. The index also takes into account labour effects which are inherently different at all locations. However, the general cost inflation of the materials and services is what is needed, and the results of this are used in the comparative analysis. Because of the variability of financial parameters, such as interest rates, inflation, incentives and tariffs, and exchange rates, which change on a daily basis, the importance of relative costs is again emphasised.

Levelised electricity cost (LEC)

The LEC approach was chosen for the financial analysis because of its comparative advantages. Other possible decision making tools include the Net Present Value and Internal Rate of Return approach. These criteria are used mainly for specific investment decisions and depend on specific financing policies which can differ dramatically between institutions. An example where the LEC approach is most valuable is when comparing technologies such as the plants with storage, which produce more electricity than plants under solar-only operation, which will have greater installation costs (due to larger solar-field size). Whether the benefits of this added generation will outweigh the added capital costs can be found by levelising the data which will then make a level platform for comparison. (Storage is however a design decision and is, most often than not, utilised for reasons other than economic, such as the timing of dispatch).

The factors that affect the financial feasibility of the installation of a distributed CSP generation system have been outlined through the cost analysis. Several factors affecting the cost of electricity have been identified and are outlined below.

Certain discrepancies in using the cost data from various studies were also identified. For example, the cost of technology will play a significant role in determining the LEC. Whether the technologies are manufactured locally or imported, like the receivers and turbines, which are specialised items, costs will differ from those used in this report. At the same time costs derived from other aspects of the installation and running of the plant will be less than estimated. An example of this is the O&M costs, which are expected to be lower in developing countries. Becker et al. (2000) suggest that O&M costs in developing countries will be approximately 15% less than those found in developed nations such as Europe. Other costs, such as shipping costs to South Africa and international professional fees will increase costs and, the for the purposes of this study, these differences mentioned, have been assumed to approximately balance.

Different institutions have different capital structures and obligations and the value of such an investment will then determine the appropriate financing measures. Whether the project is financed entirely by debt or through the use of equity will determine the fixed charge rate (*fcr*) and hence financing costs. This will have a significant effect on the LEC. Unlike in a lot of the European countries, there are few opportunities in South Africa to invest in CSP systems (especially of this size). Financing the project through the use of debt may be difficult because there little financial return on the capital investment. If the project is then financed through the use of equity, financing costs will therefore translate into an opportunity cost, or the loss in income from an investment of equivalent capital proportion. This is the reasoning behind the choice of a money market interest rate for the fixed charge rate, in Section 5.6.

The installation of a renewable energy system will provide numerous intangible benefits that cannot be measured simply through indicators such as the LEC. These benefits will also reach far beyond those described in the introduction (economic, energy security, climate change) and will often be immeasurable. An example of such benefits may include customer satisfaction, with the view of ethical management, when a firm chooses to 'go green'. Depending on the case, a lot of pressure is placed on certain commercial institutions to consider their environmental policies. This can also have a negative side - customers may view this as negligence on management's behalf because funds are 'unnecessarily spent' and the future growth or prosperity of the firm is questionable. Energy security in commercial and industrial applications often transpires into economic issues. With the power cuts experienced in 2008, the financial and productive losses experienced were, in many cases, far greater than the cost of electricity produced from the various CSP systems investigated here. It is therefore up to each institution to put a price on these benefits.

Plant design and performance

The method used to calculate the required plant areas for the design configurations was based on common annual design capacity factors. This method, as opposed to designing a plant according to a design point peak *DNI*, was chosen because, for the evaluation of the technologies with respect to their effect on Wits University, the same electric production between plants was necessary for level comparison. It is recommended that the three chosen configurations be further designed according to the design point peak *DNI*. This design procedure, especially the optical part of the system (concentrator field arrangement and size, receiver aperture, orientation and height) should also be cost-optimised.

For the energy modelling a Matlab code was written as a shell that is able to analyse hourly *DNI* data from any location. The code has been programmed to analyse the thermal energy conversion of the twelve design alternatives listed in Section 5.4. The model is easily adaptable to any CSP application. The analysis of hourly *DNI* data was necessary because Wits University's electricity bill is determined from half-hourly usage. The effects that the electricity generated from the CSP applications have on the total bill are then calculated with reasonable accuracy.

In order to understand the plant performance, the methodology behind the various studies was verified. Because this report considers the feasibility of CSP systems in terms of basic cost and performance data, a full thermodynamic design/analysis was not required. This level of analysis is satisfactory in order to conclude whether further research needs to be undertaken and at what level.

8.2 Results

In terms of the technical viability, the average solar resource for a typical year in Johannesburg is sufficient for power production but when analysed on an hourly basis, it is seen that the resource is very intermittent. This is due to the amount of cloud cover experienced, especially in the summer months (Figure 7.4). *Solar-only* operation is therefore unsuccessful in generating cost savings benefits by cutting down the *peak usage* at Wits.

Figure 7.1 shows the plant areas as well as the solar field areas of the various design options. The CLFR technologies have larger solar field (aperture) areas due to the lower efficiency of the field but because they are more compact, areas can be smaller than those for parabolic troughs. Because of the complete installation into a space constrained environment it is the total plant area that is deemed the most important here. Comparing the various plant sizes to the space available at Wits University, there are very obvious options for integration. Through modulation, several plants can be installed at various locations. The option of introducing a plant above one of the parking lots will also create shading benefits for cars, and if installed on a building roof, similar shading benefits are found.

According to Figure 7.3, which shows the *real* LEC (LEC without the savings from generation at Wits University and excluding the REFIT), the hybrid options result in a significantly lower LEC. The CLFR which uses a normal steam cycle with hybrid generation came out financially the most feasible option. The CLFR collector that uses an ORC with hybrid mode resulted in the third cheapest option. This shows the effect that the specific investment for the ORC technology has on the LEC. Here, in order to provide enough thermal energy to the ORC (which has lower conversion efficiency than a normal steam cycle), a larger solar field is required. It is the higher costs attributed to this field as well as the higher costs demanded from the power block that make the ORC alternatives more expensive than their steam cycle counterpart. Even the lower operating costs incurred by the ORC do not compensate for the higher investment costs.

Storage

It is interesting to note that, in Figure J1 (Appendix J), the storage options actually bring the LEC down in most cases whereas for the chosen CLFR, ORC system, the price of electricity increases. The combination of CLFR with the ORC electric generation causes the efficiency to be significantly low enough to cause the cost of storage to be higher. This higher required thermal input results in infrastructure costs that cause the price of electricity to be higher than the option that doesn’t incorporate storage. A cost optimisation for the amount of heat storage and solar multiple is recommended to find the optimal storage level.

Out of the three 480 kW(e) options investigated, the hybrid option was the only system that successfully brought down the peak electricity demand (Figure 7.15). The option with no storage wasn’t able to eliminate the evening peak (Figure 7.11), and the option with storage (Figure 7.13) eliminated the evening peak but the morning peak remained, which is almost equivalent to the evening peak. To successfully eliminate the morning peak as well, the storage capacity will have to be greatly increased and dispatched the following morning. The use of storage is therefore effective in bringing down the evening peak load when sunlight is available on the same the day. In terms of financial feasibility and space utilisation, energy storage is unlikely to be feasible. Storage for the systems was designed to provide 3 hours of electricity to match the evening peak load, which is appropriate for this investigation but it is recommended that the storage be sized optimally in terms of costs as well as for reliable dispatch. Benefits, which will be gained by the evening dispatch through storage, include energy security and the possibility of a higher cost saving with the possible introduction of a Time of Use (TOU) charge.

Hybridisation

Including hybridisation into the design configurations resulted in the lowest cost of electricity. These results however do not take into account the added infrastructure costs needed, such as linking of a gas line and boiler costs. The price is therefore underestimated but still assumed to be the cheapest option. It is important to note here that the hybrid options, that yield the lowest LEC, include the generation of electricity from natural gas and are not representative of a solar-only LEC. This value may be misleading if not considered in context. The hybrid options are designed to run off a capacity factor of 54%. If the solar-only systems incorporated the cost of electricity from City Power and a new LEC was determined where the capacity factor of these systems was increased to 54% (from 20 and 30%), the solar-only systems would in fact be cheaper. However, the analysis here was done to determine the cost of electricity that can be *generated,* in this case, at Wits University. It is energy security that is the priority and the cost of this security that is determined.

Arising from this point is the possibility of creating a natural gas-only generation system which would offer even further reductions in the cost of electricity generated. This would eliminate the reliance on the intermittent solar resource as well as provide better energy security, similar to diesel generators, which have become very popular in industry. The advantage of electricity production from piped natural gas at Wits University is that the fuel does not need to be transported like diesel for example. So the implementation of such distributed CSP systems will perhaps find better feasibility in off-grid communities where the cost of extending the grid and transporting liquid fuels is expensive. The renewable energy argument has however been debated for decades and the aim of this report is to investigate the feasibility of using the *solar resource* for electricity generation through CSP.

Also a technical issue with the hybrid options is the emissions from the combustor. Wits University and urban areas in general are relatively dense. The pollution from cars in most cities is a problem and to add a co-generation plant in an urban environment will only make the situation worse. If the system is located on a roof-top this will be less of a problem to immediate bystanders. One of the reasons for installing such a renewable energy system is to combat emissions and mitigate climate change, so the hybrid options from this point of view are less viable.

8.3 Recommendations for Implementation

Financing options – REFITs, CDM and TRECs

The main motivation of energy security for the CSP application investigated here, is again restated. The sale of electricity under the REFIT, especially for large scale commercial applications, can make CSP feasible in South Africa. However an application that satisfies a certain energy load, through off-grid, distributed power, will not be able to sell electricity to the Renewable Energy Purchasing Agency (REPA) itself (under current conditions (NERSA, 2008)).

A cap on the amount of renewable energy REPA is willing to purchase is expected. However, after the introduction of the REFIT, it is also expected that there will be an increased market demand for clean energy. This will make it more likely that certain institutions will be interested in signing off-grid PPAs whereby clean electricity is supplied to them directly. This is expected because of international pressure for climate change mitigation as well as energy security. The CSP application investigated would generate energy to be used by Wits University itself and therefore will not sell electricity to external parties. The effect of a REFIT was however analysed in order to indicate results for a nominal LEC should an institution (in this case Wits University) be willing to pay the market related price (CSP REFIT) for CSP generated electricity.

At the time of writing, a CSP REFIT of R2.10/kWh (Fin24, 2009) was announced by NERSA. The value of this tariff is only slightly higher than the one used in the analysis (R2.05/kWh) and should greatly boost investment in the sector, to reach the renewable energy targets set out in the RE White Paper (DME, 2003).

The fact that Eskom's price of electricity in essence, does not allow for the recovery of all the prudently incurred costs and the building of reserves to sustain the current asset base; nor does it support the capital expansion, especially with their intention of doubling capacity by 2026 (Eskom (b), 2009). This indicates heavy tariff increases in the future. Price parity will be reached in the near future where the cost of CSP technology will be more competitive than traditional fossil-fuelled power generation. It is recommended that financial predictions be performed with respect to the South African electricity tariffs (as well as other distributed sources of power) to aid investors in decision-making.

Other financing options mentioned in Section 5.6.3 include financing through the Clean Development Mechanism (CDM) and Tradable Renewable Energy Certificates (TRECs). Certain disadvantages with these sources of finance have been discussed, and with the instability of the world's economy, the reliance on such mechanisms makes firm investment decisions debateable (IETA, 2009). These financing options have not been incorporated into the analysis and it is recommended that these be further investigated. These should be incorporated into a full discounted cash flow to predict the future costs of electricity. Other factors to be considered is carbon taxing that, if implemented in South Africa, would influence the price of electricity.

Technical Recommendations

From the results, it can be concluded that power production costs through small scale CSP systems are currently higher than conventional fossil fuel options. Exploiting the full potential of high efficiencies and economies of scale of plants with power levels above 50 MW(e), a very high investment cost is required. Although, Eskom is currently pursuing the installation of a 100 MW(e) plant, independent power producers may find such scales intimidating. With the introduction of these technologies at lower power levels, cost savings with the incorporation of other design options should be pursued. These options are now discussed.

Culwick (2008) makes an interesting point about the current energy use in South Africa. Currently 30% of South Africa's domestic energy usage is to heat water (80% of which is electrical energy). Electricity generation is a high quality use of solar power, necessitating the requirement for concentrating collectors and to use electricity to heat water at low temperatures is therefore a waste of the high quality source. According to Aitken (2003) one square metre of surface area can deliver 100 W of peak electrical power with PV technology. Comparing this to CSP generation, one square metre of mirror can also deliver about 100 W of peak electrical energy. However, one square metre of intercepted solar energy can also deliver 300 W of thermal power for heating domestic water, displacing 300 W of electric water heating.

Therefore, by considering the matching of the energy source to the energy use, certain design options result. These may include the incorporation of waste heat from the power cycle into Wits University's hot water or heating and air-conditioning systems. This will have a significant impact on the cost of electricity, and is definitely worth pursuing. It will be necessary to investigate how much of the electric energy is used for hot water and heating. Perhaps the best implementation approach, which would also kick-start CSP research, is by first installing a solar field that is used solely to collect heat for various systems such as hot-water or HVAC requirements. An advantage of installing such fields on top of buildings is the shading they will provide, which will bring down the air-conditioning demand. Further, 5% of electricity consumed in South Africa is used for process heating in the commercial and industrial sectors (Culwick, 2008). This provides additional reasons for the research, as well as possible funding into concentrating solar technologies.

There are also countless institutional benefits that will be gained by the implementation of CSP technology at the University. This can be expanded to also include the commercial advantages gained from research at the University. Research, development and demonstration practices aim at alleviating technical barriers and reducing costs altogether in improving materials, components and system design for installers and users. South Africa, because of its traditionally low cost of coal electricity, has not created an environment where renewable energy is a viable topic for research and implementation. South Africa has one of the greatest solar resources in the world and should therefore be technology leaders and pioneers. With greater emphasis being placed on the need for renewable energy systems, it is imperative that South Africa develops its skills and a knowledge base that will work at making the implementation of renewable energy, and in particular CSP generation, a reality.

According to Sargent and Lundy (2003) there is much R&D still to be done with the CSP technologies. Countries with the most advanced R&D programs will become the technology leaders. In the case of renewable energy, the technologies are still improving and developing while, at the same time, fully market-ready applications of the technologies are also being continuously improved from experience gained in commercial applications in the field. Potential R&D efforts should aim to reduce the cost of mirrors, heliostats, collectors and electric energy generators. Also to develop and refine thermal energy storage systems that can give up to the critical 12 hours of thermal storage, which will greatly enhance the economics and potential of solar thermal electric systems. There is currently research being performed at the University of Stellenbosch and a number of other universities but this research is mainly focused on Parabolic Trough and Solar Chimney Technology. If the University of the Witwatersrand were to incorporate a Linear Fresnel System, huge benefit will be gained locally as well as through the international exposure in CSP research.

An analysis of different fuels and emission rates is recommended. Ideally if it were to be incorporated, a renewable fuel such as landfill-gas should be used to take advantage of the REFIT. However, as mentioned, with an external fuel source there are certain logistical and fuel storage options that would need to be investigated.

Assuming that the plans for implementation continue, it is advised that insolation measurements are recorded, at Wits University, or other potential sites. This should include *DNI* measurements as well as other meteorological parameters. This ground measurement will then need to be calibrated with other data sets such as satellite data. The uncertainty of this data significantly affects the bankability of the project.

The need for full hourly solar resource mapping for the entire country was also identified. The TMY2 data used in this study (which is only available for Johannesburg and Cape Town) is not sufficient to make full bankable decisions. This service should ideally be government sponsored or through the use of institutional grants, so that the feasibility of such projects is more accessible and uncertainty in eliminated.

During this study it was found that distributed solar energy can be a possible solution to the various energy problems faced around the world. A more appropriate application for distributed solar power generation is possibly in rural areas where the grid connection costs are high. Many of the existing international technology providers have the view of developing for large electric capacity’s (50MW(e) and above). These systems will most likely be locally manufactured but revenues and intellectual property will remain in hands of international companies. South Africa in general is blessed with an amazing solar resource yet we are not developing any of our own technology. There is therefore definite scope to develop niche technology that will break some of the barriers to make this technology feasible in South Africa. Mr Thomas Roos at the CSIR is currently working on a heliostat field with an air Brayton cycle turbine. Other technologies that should be pursued for distributed generation include Linear Fresnel collectors that are easy to manufacture and don't involve complicated receiver systems. There is also scope for developing thermal storage technologies in order to make generation more reliable. There are also very few off the shelf ORC turbines, especially small scale (<100kW(e)), which is a technology option worth pursuing.

9 CONCLUSIONS AND RECOMMENDATIONS

The objective of the study was to investigate the potential of distributed CSP integration in urban areas, specifically investigating Johannesburg's solar resource. This is done by assessing the technical performance and financial characteristics of the different technologies in order to identify certain systems that may have the potential for deployment.

The following conclusions and recommendations address the objectives (Section 1.3) of the report as well and summarise important points identified in the discussion (Section 8).

9.1 Conclusions

- A relevant literature review was performed which outlines relevant data with regards the scope of the study.

- Several existing systems, whether they are in research or commercial operation, were compared.

- Johannesburg has a very intermittent source of *DNI* solar energy. Even though the summer months in Johannesburg yield a higher peak *DNI*, it is actually the winter months that provide a more consistent average. This is due to the high amount of cloud cover experienced in summer. The values obtained for the average yearly insolation was 1781 kWh/m^2 based on TMY2 data. With this insolation, CSP electric generation is possible however, compared to the other locations, it is not ideal. Also, because of its intermittency is has been advised that certain applications such as HVAC and process heat and steam requirements be pursued.

- A technology screening was performed in order to identify suitable technologies for application at Wits University. The technical and financial viability of these technologies identified were then explored. Certain methodologies and conclusions from this analysis are explored below.

Through the technology screening process, twelve reference systems were identified for a capacity of 120 kW(e). After a performance and cost analysis for the reference size plants, three technologies were identified that prove to be the most suitable for implementation as a distributed energy source for Wits University. These three technologies are listed below; each with a design capacity of 480 kW(e).

1. CLFR solar collector field with an Organic Rankine Cycle
2. CLFR solar collector field with an Organic Rankine Cycle that integrates storage for timed dispatch
3. CLFR solar collector field with an Organic Rankine Cycle that integrates hybridisation with natural gas.

The technologies are intended to be modular in design and would not necessarily be located on the same site. The field areas and real LECs are summarised in Table 9-1.

With the thermal modelling of the hourly *DNI* input to the CSP systems, Wits University's West Campus Electricity bill was recalculated. The addition of the solar energy input resulted in certain savings and a new LEC that is Wits-specific. A third LEC was calculated that integrates an estimated REFIT (R2.05/ kWh). At the time of writing a CSP REFIT of R2.10/kWh was released and the licensing terms for independent power production (IPP), using CSP, should be further researched. It is important to note that the applications considered will not qualify for the REFIT because the electricity generated is not intended to be sold. It has however been included in the analysis in order to aid in decision making by indicating what the market price for this electricity would be. This gives an indication of the price of electricity generated after this tariff has been taken into account.

A summary of the plant areas, LEC as well as the payback of these systems is given in Table 9-1.

Table 9-1: Summary (480 kW(e) systems)

	CLFR, ORC	CLFR, Stor, ORC	CLFR, Hybrid, ORC
Average Capacity Factor	0.21	0.32	0.55
Solar Field Area [m^2]	6,727	9,923	6,727
Total Plant Area [m^2]	10,350	15,266	10,350
Real LEC [R/kWh]	4.31	4.34	3.18
Wits LEC [R/kWh]	3.98	4.00	2.77
Nominal LEC [R/kWh] (with REFIT)	1.93	1.95	2.01
Payback [years]	77.1	72.8	24.6
Payback [years] (with REFIT)	7.8	7.5	6.5

Including hybridisation in the design configurations successfully decreased the peak usage and resulted in the lowest cost of electricity. It is important to note here that the hybrid options includes the generation of electricity from natural gas and is not representative of a solar-only LEC. Hybrid operation will increase emissions and in urban areas can be a problem. One of the main reasons for using a renewable source for electricity generation is climate change mitigation and therefore the use of a renewable fuel should rather be pursued.

The implementation of a storage system results in the highest LEC of the three options. The use of storage is effective in bringing down the evening peak load when sunshine is available during day time. Benefits, which will be gained by the evening dispatch through storage, include energy security and the possibility of a higher cost saving through the possible introduction of a Time of Use (TOU) charge but in terms of financial feasibility and space utilisation, energy storage may be less feasible.

From the results, it can be concluded that power production costs through small scale CSP systems are higher than conventional fossil fuel options, however several options that may favour implementation were recognised. If the institution values the CSP generated electricity at the market price as indicated by the CSP REFIT, the payback time of such systems can be decreased from 73 to 12 years (CLFR, ORC with storage). Further, due to the scale of the plants analysed, the exploitation of high efficiencies and economies-of-scale of plants with power levels above 50 MW(e), is not possible. With the introduction of these technologies at lower power levels, cost savings through the incorporation of other design options (such as using waste heat for hot water and building HVAC requirements of buildings, process heat and steam) should be pursued.

9.2 Recommendations

The data comparison of existing technologies is satisfactory but the accuracy of the results is unknown due to scaling methods used and finding the present value of past quoted cost data. The economies-of-scale method was used and is suitable for utility scale plant sizes but discrepancies may arise in the technical performance when scaling below 1 MW(e). However data was used for a comparative analysis and thus sufficiently fulfils the scope of work. To gain a full understanding of the actual cost implications at Wits University, a full cost analysis which would include equipment as well as implementation costs would need to be performed, for specific designs. The work scope for this study, as mentioned, did not include independent research for information or developing independent cost-estimates.

The analysis excluded conventional diesel generators and other distributed renewable technologies such as photovoltaic systems. A comparison of these technologies to the solar systems investigated would be useful in showing the cost of distributed power options as opposed to grid-connected power and is recommended for future investigations.

The design of these three configurations was based on common annual capacity factors. This method, was chosen because the same electric production between plants was necessary for level comparison. It is recommended that the three chosen configurations be further designed according to the design point peak *DNI*. This design procedure should also be cost-optimised.

Price parity will be reached in the near future where the cost of CSP technology will be more competitive than traditional fossil-fuelled power generation. It is recommended that financial predictions be performed with respect to the South African electricity tariffs (as well as other distributed sources of power) to aid investor decision-making.

Carbon financing and the sale of TRECS have not been incorporated into the analysis and it is recommended that these be further investigated. These should be incorporated into a full discounted cash flow to predict the future costs of electricity. Other factors to be considered is carbon taxing that, if implemented in South Africa, would influence the price of electricity.

South Africa has one of the greatest solar resources in the world and should therefore be technology leaders and pioneers. With greater emphasis being placed on the need for renewable energy systems, it is imperative that South Africa develops its skills and a knowledge base that will work at making the implementation of renewable energy, and in particular CSP generation, a reality. There are countless institutional benefits that will be gained by the implementation of CSP technology at the University. This can be expanded to also include the commercial advantages gained from research at the University. Research, development and demonstration practices aim at alleviating technical barriers and reducing costs altogether in improving materials, components and system design for installers and users.

Technologies identified that should be pursued for distributed generation include Linear Fresnel collectors that are easy to manufacture and don't involve complicated receiver systems. There is also scope for developing thermal storage technologies in order to make generation more reliable. There are also very few off the shelf ORC turbines, especially small scale (<100kW(e)), which is a technology option worth pursuing.

Because of the lack of solar resource data in the country, it is advised that insolation levels are measured. This is necessary if plans for implementation continue. This ground measurement will then need to be calibrated with other data sets such as satellite data.

REFERENCES

Aitken D (2003) *Transitioning to a Renewable Energy Future - White Paper*, International Solar Energy Society White Paper 2003

Becker M, Meinecke, Geyer M, Trieb F, Blanco M, Romero M, Ferrière A (2000) *Solar Thermal Power Plants*, Prepared for the EUREC-Agency

Beerbauma S, Weinrebeb G (2000) *Solar thermal power generation in India-a techno-economic analysis*, Renewable Energy 21 pp.153-174

Black and Veatch Corporation (2007) *Arizona Renewable Energy Assessment*, Arizona Public Service Company, Salt River Project, Tucson Electric Power Corporation

Bureau of Land Management (BLM) (2003*) Assessing the Potential for Renewable Energy on Public Lands*, U.S. Department of the Interior Bureau of Land Management DOE/GO-102003-1704

Brink E (2008) Matlab © source code for Wits University bill adjustments

Broesamle H, Mannstein H, Schillings C, Trieb F (2000) *Assessment of Solar Electricity Potentials in North Africa Based On Satellite Data and a Geographic Information System*, Prepared for DLR

CDM UNFCC (2009) Clean Development Mechanism, INTERNET, Last Accessed 02/02/2009, http://cdm.unfccc.int/about/index.html

City Of Johannesburg (2008) *Schedule of Tariffs for 2008/2009*

CSP (2008) Concentrating Solar Power, INTERNET - http://www.solar-energy-at-home.com/concentrating-solar-power.html

Culwick L (2008) *An Investigation into the Solar Resource for Electricity Generation in South Africa*, Final year research project reports of the School of Mechanical, Industrial and Aeronautical Engineering and the Built Environment, University of the Witwatersrand, Johannesburg

Department of Minerals and Energy (DME) (2003) *White paper on Renewable Energy,* DME, South Africa

Department of Minerals and Energy (DME) (2009) Tradable Renewable Energy Certificates (TRECS) – INTERNET, Last Accessed 04/02/2009, http://www.dme.gov.za/energy/renew_TRECS.stm

Egoli Gas (EG) (2009) INTERNET, Last Accessed 05/11/2008, http://www.egoligas.co.za/

Engineering Toolbox (2009*) Boiler room Sizes*, INTERNET - Last Accessed 05/11/2008, http://www.engineeringtoolbox.com

Eskom (2008) Annual Report, Corporate governance and tables - INTERNET - Last Accessed 02/02/2009 – http://www.eskom.co.za/annreport08/ar_2008/table_one_kilowatt.htm

Eskom (2009) Power Purchase Programmes; An initiative by Eskom to bridge the Gap between the supply and demand of energy, INTERNET - Last Accessed 02/02/2009 – http://www.eskom.co.za/live/content.php?Item_ID=6865, lat accessed

Eskom (b) (2009) New build Programme, INTERNET - Last Accessed 02/02/2009 – http://www.eskom.co.za/live/content.php?Item_ID=5981

Fin24 (2009) *"Green Energy Tariffs Hiked",* INTERNET -Last Accessed 21/03/2009– http://www.fin24.com/articles/default/display_article.aspx?Nav=ns&ArticleID=1518-25_2494501

Freepower (2008) *Renewable Energy and Energy Saving Solutions*, INTERNET - Last Accessed 09/11/2008 – http://www.freepower.co.uk

Geyer M (1999) *Concrete Thermal Energy Storage for Parabolic Trough Plants-A Proposal to the 5th Framework Program of the European Union*, Deutsches Zentrum für Luft- und Raumfahrt, Plataforma Solar de Almeria, Spain

Geyer M (2007) *Introducing Concentrated Solar Power on the International Markets Worldwide Incentives*, Policies and Benefits, Solar Paces/Abengoa Solar

Haaf W, Friedrich K, Mayr G, Schlaich J (1983) Solar Chimneys Part 1: Principle and Construction of the Pilot Plant in Manzanares. International Journal of Solar Energy 2, pp. 3–20

Häberle A , Zahler C, Lerchenmüller H (2002) *The Solarmundo line focussing Fresnel collector Optical and thermal performance and cost calculations,* Fraunhofer Institute for Solar Energy Systems

Hassani V, Price H (2001) *Modular Trough Power Plants*, Proceedings of Solar Forum 2001 Solar Energy, Washington, DC, pp.1-7, © ASME

Hosseini R, Soltani M, Valizadeh G (2005) *Technical and economic assessment of the integrated solar combined cycle power plants in Iran*, Renewable Energy 30 1541–1555

Hoff T (2000) *The Benefits of Distributed Resources to Local Governments: An Introduction*, Clean Power Research, Napa, CA 94558

Huber (2008) *Value Engineering and Analysis,* VM Services handbook lecture series 2008

IEEE (2005) *Standard for Interconnecting Distributed Resources with Electric Power Systems*, IEEE 1547

International Emissions Trading Association (IETA) (2009) *Europe Fails Kyoto Standards as Trading Scheme Helps Polluters*, INTERNET - Last Accessed 10/03/2009 –http://www.ieta.org/ieta/www/pages/index.php?IdSitePage=1149

International Energy Agency (IEA) (1991) *Guidelines for the Economic Analysis of Renewable Energy Applications*, IEA, Quebec

ISRAEL21c (2007) *Israel's Solel to build largest solar park in world in California*, INTERNET - Last Accessed 16/10/2008 – http://www.israel21c.org/bin/en.jsp?enDispWho=Articles^l1721&enPage=BlankPage&enDisplay=view&enDispWhat=object&enVersion=0&enZone=Technology

Kolb G (1998) *The Economic Evaluation of Solar-only and Hybrid power Towers using Molten Salt Technology*, Solar Energy Vol 62 No1

Lotker, M. (1991) *Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ Experience*, Sandia National Laboratories, Albuquerque, New Mexico: Report SAND91-7014.

Matlab © (2005) Version 7, The Mathworks Inc.

MOL (2008) *Metoring online Muncipal Electricity Bills,* INTERNET - Last Accessed 28/02/2009 –http://www.meteringonline.org.za

Mills D, Morrison G, Lievre P (2003) *Project Proposal for a Compact Linear Fresnel Reflector Solar in Thermal Plant in the Hunter Valley,* School of Physics, University of Sydney, Australia

Mills D, Morrison G (2000) *Compact Linear Fresnel Reflector Solar Thermal Powerplants*, Solar Energy, Vol 68 No3, pp.263-283

National Renewable Energy Laboratory (NREL) (1995) *User's Manual for TMY2s Meteorological Years Derived from the 1961-1990 National Solar Radiation Data Base*, CD-ROM. Golden, Colorado, NREL/SP-463-7668

National Renewable Energy Laboratory (NREL) (2008) *DNI* Radiation Data, INTERNET - Last Accessed 14/10/2008 – http://www.nrel.gov/csp/troughnet/pdfs/2007/stoffel_solar_data.pdf

NERSA (2008*) Renewable Energy Feed - In Tariff* – December, 2008, NERSA Consultation Paper, South Africa

Obernberger I, Thornhofer P, Reisenhofer E, (2002) *Description and Evaluation of the New 1000kW(e) Organic Rankine Cycle Process Integrated in the biomass CHP plant, Lienz, Austria*, Euroheat and Power, Vol 10/1002

Peters M, Timmerhaus E (1991) *Plant Design and Economics for Chemical Engineer*, McGraw-Hill, pp.164-266

Philibert C (2005*) The Present And Future Use Of Solar Thermal Energy As A Primary Source Of Energy*, International Energy Agency, Paris, France

Pilkington Solar International GmbH (2000) *Survey of Thermal Storage for Parabolic Trough Power Plants*, NREL Technical Report, Subcontract No. AAR-9-29442-05

Pitz-Paal R, Dersch J, Milow B (2005) *European Concentrated Solar Thermal Road-Mapping (ECOSTAR)*, Road Map Document (WP 3 Deliverable Nº 7)

Power Technology (2009) *Solar Arguments Heat Up*, INTERNET - Last Accessed 21/01/2000 – http://www.power-technology.com/features/feature1480/

Price H, Kearney D (1999) *Parabolic-Trough Technology Roadmap: A Pathway for Sustained Commercial Development and Deployment of Parabolic- Trough Technology,* U.S. Department of Energy (DOE)

Price H, Kearney D (2003*) Reducing the Cost of Energy from Parabolic Trough Solar Power Plants Preprint*, National Renewable Energy Laboratory

Prabhu E (2006) *Solar Trough Organic Rankine Electricity System (STORES) Stage 1: Power Plant Optimization and Economics*, *Subcontract Report,* NREL/SR-550-39433

Roos T (2009) *Personal Communication*, DPSS, CSIR

Sargent and Lundy (S&L) (2003) *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*, Subcontractor Report, NREL/SR-550-34440,

Schaffler (2007) Tradable Renewable Energy Certificate System Feasibility, Prepared for the Department of New and Renewable Energy Pretoria, Report Number DME/CE/001/260301, pp 8

Sitenet (2008) *Solar Power Systems*, INTERNET - Last Accessed 18/10/2008 –
http://www.sitenet.com/futureSeries/2008/Solar-Power.htm

Solargenix Energy (2005) *Solar Thermal Parabolic Trough Electric Power Plants for Electric Utilities in California*, California Energy Commission, Public Interest Energy Research (Pier) Program, CEC-500-2005-175

Solar Thermal Industry Association (STI) (2005) *Concentrating Solar Thermal Power – NOW!*, Solar Paces, Estia, Greenpeace

Solar Heat and Power Europe (2008) *Sustainable Power*, INTERNET - Last Accessed 15/11/2009 – http://www.shp-europe.com/

Stine W, Geyer M (2008) *Power from the sun*, INTERNET - Last Accessed 10/12/2009 –http://www.powerfromthesun.net

Standard Bank (SB) (2008) *Standard Bank Fees and rates*, INTERNET - Last Accessed 10/11/2009 – http://www.standardbank.co.za/SBIC/Frontdoor_02_05/0,2358,3447_1091713_0,00.html

Stoddard L, Abiecunas J, O'Connell R (2006) *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*, Subcontract Report NREL/SR-550-39291

Trieb F, Langnib O, Klaib H (1997) *Solar electricity Generation-A Comparative view of Technologies, Costs, and Environmental Impact*, Solar Energy, Vol 59, Nos. 1-3, pp.89-99

UNFCC (1998) *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 12, UNFCCC pp. 11.

Van Heerden (2001) *Research Report, CSP Pre-feasibility Study*, Eskom Research RES/RR/01/15662

Westney (1997*) The Engineer's Cost Handbook*, Marcal Dekker, New York, USA

World Bank (2006) *Assessment Of The World Bank Group/Gef Strategy For The Market Development Of Concentrating Solar Thermal Power*, The International Bank for Reconstruction and Development, Washington D.C., USA

Wolf C Jnr (1969) *The Present Value of the Past*, The Rand Corporation, P4067

XE (2008) *Exchange rates*, INTERNET Last Accessed 11/11/2009 – http://www.xe.com

APPENDIX A STORAGE CONCEPTS

Storage concepts can be classified as active or passive systems. Active storage is mainly characterised by forced convection heat transfer into the storage material. The storage medium itself circulates through a heat exchanger. This heat exchanger can also be a solar receiver or a steam generator.

The main characteristic of a passive system is that a heat transfer medium passes through storage only for charging and discharging. The heat transfer medium itself does not circulate.

Active Thermal Energy Storage

Active thermal systems typically utilize tank storage. They can be designed as one tank or two tank systems. Active storage is again subdivided into direct and indirect systems. In a direct system the heat transfer fluid, which collects the solar heat, serves also as the storage medium, while in an indirect system, a second medium is used for storing the heat. An example of the two-tank systems for solar electric applications are the storage systems of the SEGS I (Pilkington, 2000). Figure 1 shows a schematic flow diagram of SEGS I.

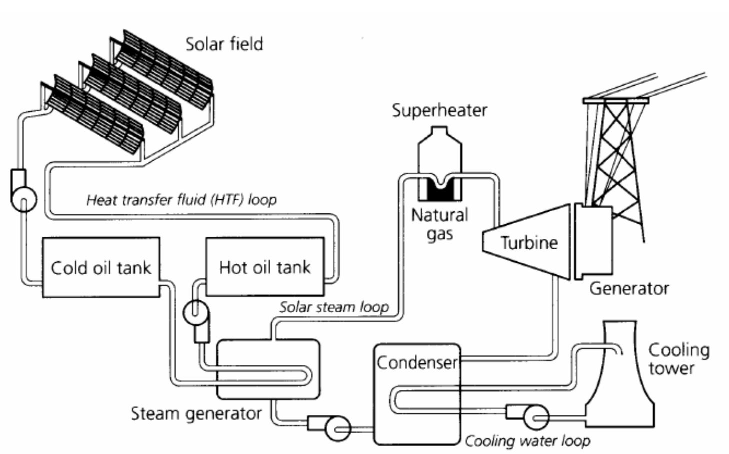


Figure A1: Schematic Flow Diagram of the SEGS 1 plant

A two-tank system uses one tank for cold heat transfer fluid (HTF) coming from the steam generator and one tank for the hot HTF coming directly out of the solar receiver before it is fed to the steam generator. The advantage of this system is that cold and hot HTF are stored separately. The main disadvantage is the need for a second tank (Pilkington, 2000).

The single-tank system reduces storage volume and cost by eliminating a second tank. However, in a single-tank system it is more difficult to separate the hot and cold HTF. Because of the density difference between hot and cold fluid, the HTF naturally stratifies in the tank, from coolest layers at the bottom to warmest layers at the top. These systems are called thermocline storage. Maintaining the thermal stratification requires a controlled charging and discharging procedure, and appropriate methods or devices to avoid mixing. Filling the storage tank with a second solid storage material (rock, iron, sand etc.) can help to achieve the stratification (Pilkington, 2000).

Passive Thermal Energy Storage

Passive systems are generally dual medium storage systems. The HTF carries energy received from the energy source to the storage medium during charging and receives energy from the storage material when discharging. These systems are also called regenerators.

The storage medium can be a solid, liquid, or phase change medium. In general, a chemical storage system employs at least two media.

The main disadvantage of regenerators is that the HTF temperature decreases during discharging as the storage material cools down. Another problem is the internal heat transfer. Especially for solid materials, the heat transfer is rather low, and there is usually no direct contact between the HTF and the storage material as the heat is transferred via a heat exchanger (Pilkington, 2000).

APPENDIX B TECHNOLOGIES USED IN THE COMPARISON

The majority of the technologies that have been used in this comparison have been specified in the Ecostar study (2003) (where information is not sourced from the Ecostar Study it is appropriately referenced). This is done to keep the information as closely comparable as possible. This section serves as a basic reference to the background of each technology.

Parabolic Trough with Storage

Ecostar based their model on a few existing technologies. These include all the SEGS plants in the USA as well as two 50 MW plants built in Guadix in the province of Granada/Spain. Based on these reference data, they designed a power plant for the selected site, load curve and other boundary conditions with the lowest solar LEC according to the model. The degree of detail in their model appears sufficient to analyse the overall impact of changes in cost and performance.

Parabolic Trough with Direct Steam Generation (DSG)

The need for high operating temperatures forced the developer of the existing SEGS plants, the company LUZ, to work in the solar field with thermal fluids (synthetic oils) able to withstand 400ºC. One of the most important objectives of LUZ was the replacement of this expensive heat carrier by water which is directly heated up and converted into superheated steam in the absorber pipes of parabolic trough collectors. During the first phase of the EU co-funded DISS project (1996-1998) a life-size solar test facility was designed and implemented at the Plataforma Solar de Almería (PSA) to investigate under real solar conditions the DSG process and evaluate the open technical questions concerning this new technology.

Once the feasibility of the DSG process was proven in the project DISS 10, and design/simulation tools had been developed, the EU co-funded project INDITEP (2002-2005) undertook the detail design of a first pre-commercial DSG power plant of 5 MW(e). The optimisation of some key components for DSG plants (e.g., water/steam separators, selective coatings, etc.) was also included in the work program of INDITEP.

The reference plant used in the Ecostar evaluation is composed of ten INDITEP plants, working in parallel, with a net electrical power of the DSG reference plant being 47 MW(e). No storage system is foreseen because of technical problems.

CLFR

The linear Fresnel system may be considered as innovation for the direct steam generating (DSG) parabolic trough system, since it is also designed for DSG rather than for the utilisation of a heat transfer fluid. Since the plant design and characteristics differ significantly from a parabolic trough plant, Linear Fresnel systems have been treated in a separate model and the results are shown in a special manner compared to the other innovations. Linear Fresnel systems suffer from performance drawbacks due to higher intrinsic optical losses compared to parabolic trough systems. The model is a 50 MW system that is based on the performance data given by the Fraunhofer Institute.

Central receiver with Molten Salt

Several molten salt development and demonstration experiments have been conducted over the past two and half decades in the USA and Europe to test entire systems and develop components. The largest demonstration of a molten salt central receiver was the Solar Two project- a 10 MW central receiver located near Barstow, CA.

The Solar Tres concept is considered as the current state of the art for molten salt central receivers. Thus, a 50 MW reference system composed of several modules based on 17 MW Solar Tres project with molten salt technology has been sized to accomplish with the common restriction agreed in this project.

Central receiver with Atmospheric air

A central receiver solar power plant with an atmospheric air heat transfer circuit based on the so-called PHOEBUS scheme, where atmospheric air is heated up through a porous absorber receiver to temperatures in the order of 700ºC and used to produce steam at 480-540ºC and 35-140 bar.

This concept has been studied by the German company TSA and the operational results attracted the interest of the Spanish company Abengoa that decided to analyze the Phoebus scheme as one of the options for the design of its first commercial demonstration plant. The project named PS10 started in 1999 and its goal is the construction and connection to the grid of a 10 MW plant is located in Seville (Spain).

Central receiver using pressurised air in combination with a solar hybrid gas-turbine

This is based on the Refos receiver type, which is a pressurised volumetric air receiver. Differently from all other concepts, solar high temperature heat is introduced into a gas-turbine. The concept needs additional fuel to increase the temperature above the level achieved by the solar system.

This concept has been investigated in a project with the following partners: ORMAT, (Israel) CIEMAT (Spain), DLR (Germany), SOLUCAR (Spain) and TUMA (Switzerland). This project has included experimental investigations of a REFOS system at the Plataforma Solar at Almería, Spain as well as theoretical studies concerning the up scaling of the plant to 16 MW(e). In the experimental part of the SOLGATE project a cluster of three receivers with 1 MWth power was integrated into a gas turbine with a design power output of 250 kW.

Since the reference system (Solgate PGT10) only has a capacity of 14.6 MW(e), a power park of four equal systems at one site is investigated to account for similar O&M conditions. Specific costs for the power block, receiver, and storage were scaled using an exponent of 0.93 resulting in 90% of the specific costs figures of the original design.

Dish Stirling

Seven 10 kW EURODISH systems are currently in operation in several countries (Spain, Italy, France, Germany, India). A WGA dish with a SOLO Stirling engine is still running at the Sandia National laboratory. Numerous solar receivers were also designed and tried with the Stirling engines. More recent designs (e.g. the SAIC system) include a fuel combustion option to boost power during periods of insufficient solar input.

Based on these reference data a power plant for the selected site was designed. Since one reference system unit has only a power capacity of 22 kW(e) a power park of many equal systems at one site, to account for similar O&M conditions, was investigated.

ISCCS

During the late nineties and earlier this century, the Global Environment Fund (GEF) and the World Bank considered a number of ISCCS configurations. Spencer Management Associates found the incremental solar costs for a 30 MW power plant to be below $0.1/kWh. Eskom took this study and detailed their findings for a site in Upington.

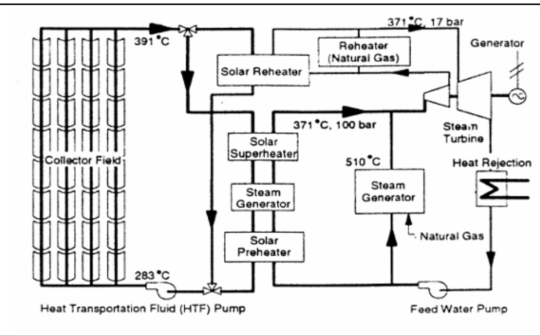
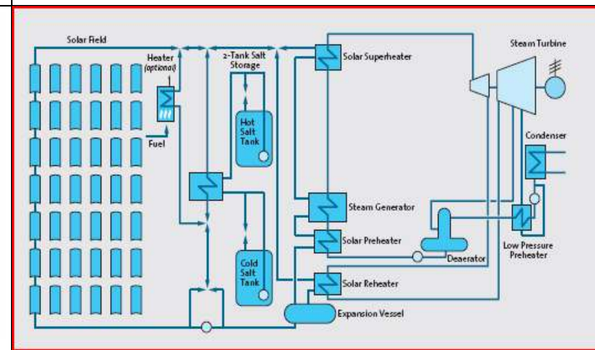
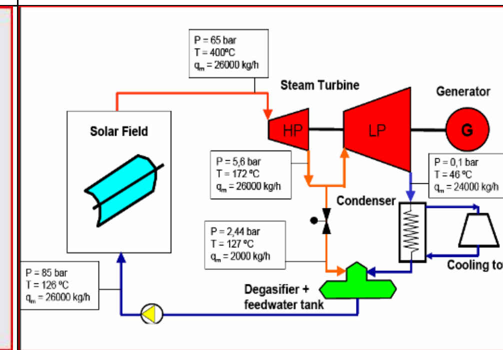
Solar Chimney

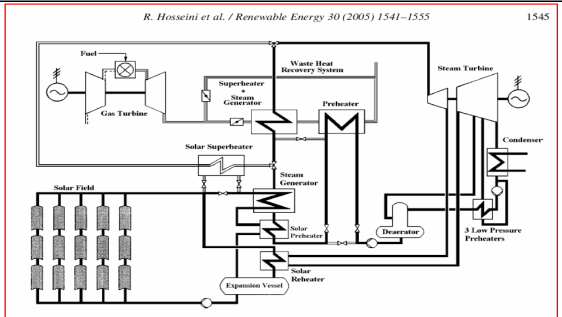
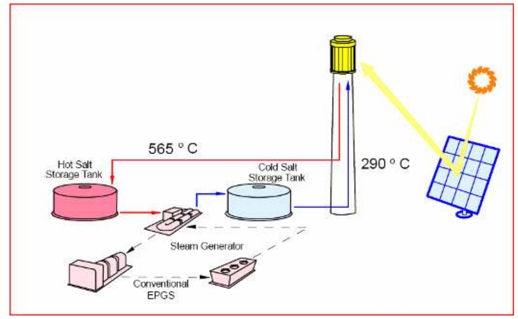
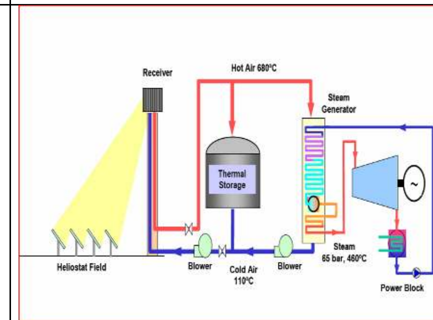
In 1979, a prototype power plant employing the solar chimney concept was funded by the Federal German Ministry of Research and technology. A site was provided by the Spanish utility Union Electrica Fenosa in Spain. The utility completed construction in 1982 with a peak design output of 50 kW. Schlaich, Bergermann and Partner designed three further plants at 5, 30 and 100 MW (Schlaich et al., 1995). The chimneys were designed for operation in Manzanares which receives a Global insulation of 2301 kWh/m2/a. The Eskom study adjusts these values to values expected in South Africa.

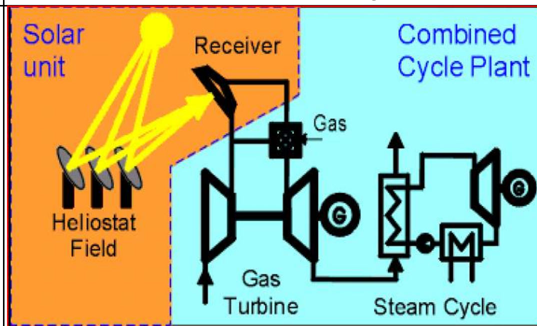
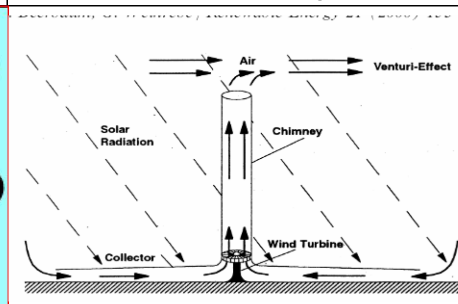
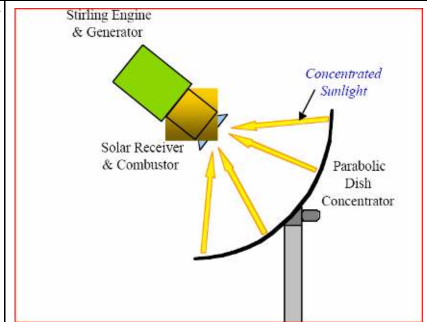
Modular Parabolic Trough plants using Organic Rankine Cycles (ORC)

A preliminary analysis has been completed to assess the potential economic feasibility of small trough ORC power plants. NREL has developed an hourly simulation model capable of modelling the performance of parabolic trough solar power plants. Using the ORC power cycle performance for the system developed by Barber Nichols, NREL has modified the trough power plant model to predict the performance from a parabolic trough ORC plant. A nominally 1 MW(e) net parabolic trough ORC power plant with thermal storage was modelled for this analysis (Hassani, 2001). The assumptions used in the model are listed in the paper but some important differences in their model are given here. The location of the analysis is Barstow California, which has an annual *DNI* of 2800 kWht/m2. The solar field availability was assumed to be 99% as opposed to 96% used in the Ecostar study. It is based on thermal storage of 9 hours. The financial data such as the discount rate and annual insurance, gives a FCR of 12.25%. (In the comparison and analysis, this value has been adjusted down to Ecostar level 9.88%).

Table B1 Summary of Evaluated Technologies

Property	SEGS	SEGS with Storage	SEGS DSG
			
Collector	Parabolic Trough	Parabolic Trough	Parabolic Trough
Receiver	Linear receiver (tubes)	Linear receiver (tubes)	Linear receiver (tubes)
Total Area of Plant [m^2]	884070	884070	884070
Cycle	Rankine Steam	Rankine Steam	Rankine Steam
Storage	None	Two-tank molten Salt Storage	No Storage System
Storage Capacity [h]	0	3	0
Planned/built power size	This is the reference case, several 30 MW hybrid plants are currently operating in the US	50 MW Andasol I completed 2008 and Andasol II, under preparation, Spain	4.7 MW INDITEP study - DLR at PSA in Spain
Maturity	Several 80MW plants built in US operating since the 1980's	Several 80MW plants built in US operating since the 1980's	Single row experimental plant in Spain
Temperature	390	393	411
Reference Size	100	50	10x4.7
Solar Capacity Factor	25%	29%	22%

Property	CLFR	ISCC	Central receiver Molten Salt	Central receiver Atmospheric Air
		 Fig. 1. Schematic of an integrated solar combined cycle system.		
Collector	CLFR	Parabolic Trough	Heliostat field	Heliostat Field
Receiver	Fixed Linear Receiver	Linear receiver (tubes)	Molten Salt Receiver	Saturated Steam Central Receiver
Total Area of Plant [m^2]	752400		916320	1045800
Cycle	Rankine Steam	Combined Cycle	Rankine Steam	Rankine Steam
Storage	None		2-tank-molten-salt storage	Water/steam buffer storage
Storage Capacity [h]	0		3	0.4
Planned/built power size		World bank Studies	Solar Tres (17MW), planed, Spain	PS 10 (11MW),
Maturity	Solarmundo prototype	Algeria 140 MW ISCCS	Solar 2 (11 MW) experimental plant in California in the 1990s	Several experimental plants up to 2MWth have been tested
Temperature	411	400	565	680
Reference Size	50	50	3x17	5x11
Solar Capacity Factor	18%	25%	33%	26%

Property	Central receiver Brayton	Solar Chimney	Dish Stirling	MTPP
				
Collector	Heliostat Field	Solar Collector	Parabolic Dish	Parabolic Trough
Receiver		Chimney and Turbine	Cavity receiver with tube bundle	Linear Receiver
Total Area of Plant [m^2]	942000		700000	
Cycle	Combined Cycle		Stirling Cycle	Organic Rankine Cycle
Storage	No storage system available		None to Date	Two-tank thermal storage system
Storage Capacity [h]	0		0	
Planned/built power size	Solgate study 14.6 MW(e)		22kW	
Maturity		Pilot Plant in Australia	About 30 units up to 25 kW(e) are in operation at different sites	
Temperature	800		800	304
Reference Size	4x14.6	100	2907 × 25 kW(e)	1 x 50MW
Solar Capacity Factor	19% Solar Only (55%)	33%	22%	54%

APPENDIX C SOLAR RADIATION DATA

Table C1: Average Hourly Statistics for Direct Normal Solar Radiation Wh/m²

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0:01- 1:00	0	0	0	0	0	0	0	0	0	0	0	0
2	1:01- 2:00	0	0	0	0	0	0	0	0	0	0	0	0
3	2:01- 3:00	0	0	0	0	0	0	0	0	0	0	0	0
4	3:01- 4:00	0	0	0	0	0	0	0	0	0	0	0	0
5	4:01- 5:00	0	0	0	0	0	0	0	0	0	0	0	0
6	5:01- 6:00	0	0	0	0	0	0	0	0	0	0	0	0
7	6:01- 7:00	88	54	12	0	0	0	0	0	12	76	142	151
8	7:01- 8:00	250	233	289	234	263	203	158	177	246	271	262	296
9	8:01- 9:00	356	366	446	467	525	486	477	472	479	436	386	433
10	9:01-10:00	411	401	508	591	682	671	632	634	603	530	424	484
11	10:01-11:00	416	405	523	624	740	736	729	726	657	576	454	499
12	11:01-12:00	385	423	498	591	759	769	799	791	643	551	425	467
13	12:01-13:00	361	394	482	528	747	772	821	785	640	491	413	424
14	13:01-14:00	360	389	410	483	715	762	823	769	623	454	352	399
15	14:01-15:00	358	378	426	478	685	719	781	731	590	403	312	343
16	15:01-16:00	323	352	396	409	589	628	675	611	499	330	263	288
17	16:01-17:00	253	289	341	263	288	361	345	314	304	184	177	210
18	17:01-18:00	145	177	158	11	0	0	0	0	23	24	43	104
19	18:01-19:00	2	3	0	0	0	0	0	0	0	0	0	0
20	19:01-20:00	0	0	0	0	0	0	0	0	0	0	0	0
21	20:01-21:00	0	0	0	0	0	0	0	0	0	0	0	0
22	21:01-22:00	0	0	0	0	0	0	0	0	0	0	0	0
23	22:01-23:00	0	0	0	0	0	0	0	0	0	0	0	0
24	23:01-24:00	0	0	0	0	0	0	0	0	0	0	0	0

Sum Month [Wh/m2	114948	108192	139159	140370	185783	183210	193440	186310	159570	134106	109590	127038
Max Hour	11	12	11	11	12	13	14	12	11	11	11	11
Min Hour	1	1	1	1	1	1	1	1	1	1	1	1
Sum Year [kWh/m2a	1781.71											

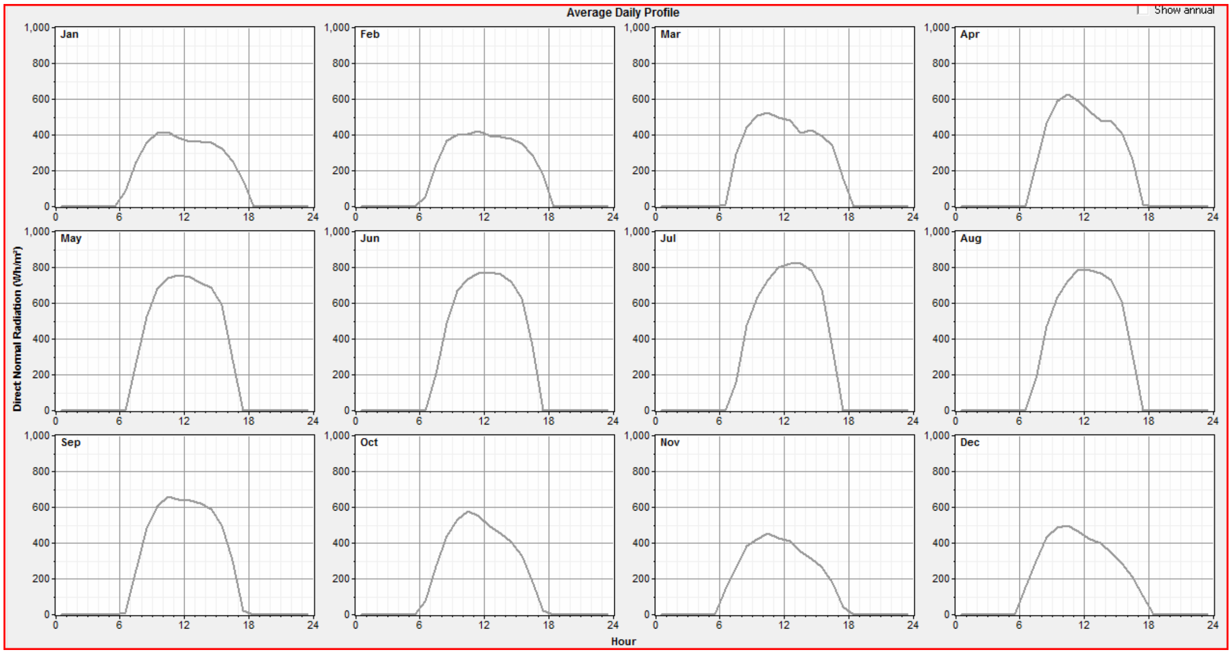


Figure C1: Average Daily Data - JHB

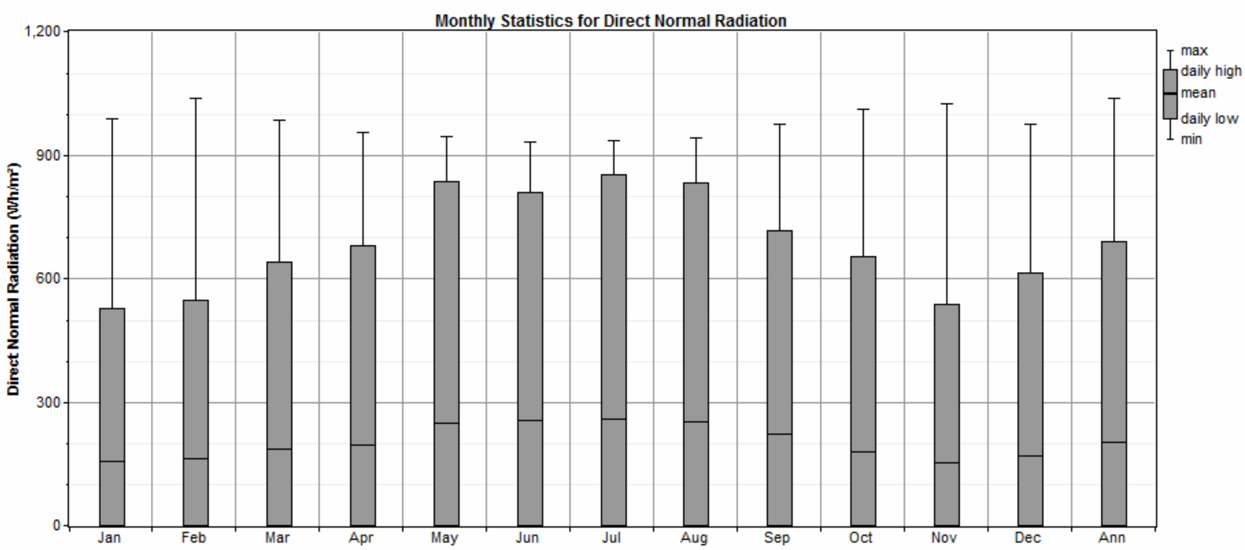


Figure C2: Monthly Statistics-JHB

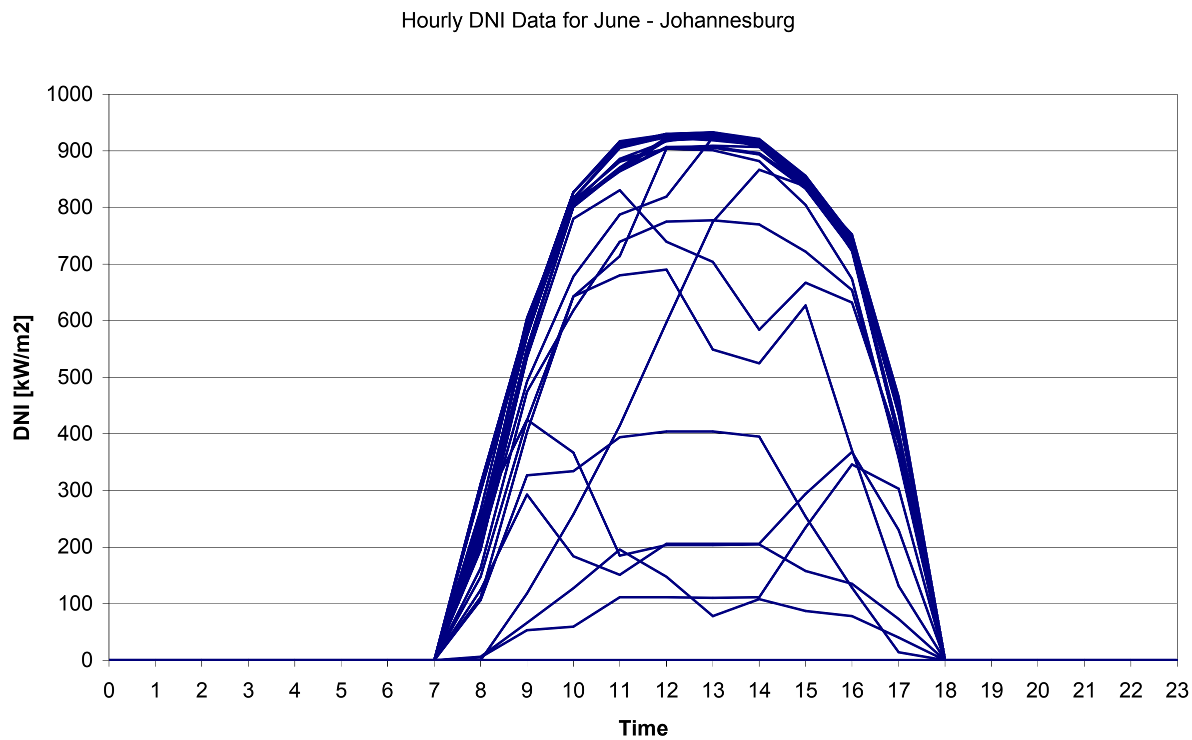


Figure C3: Hourly *DNI* Data - June- JHB

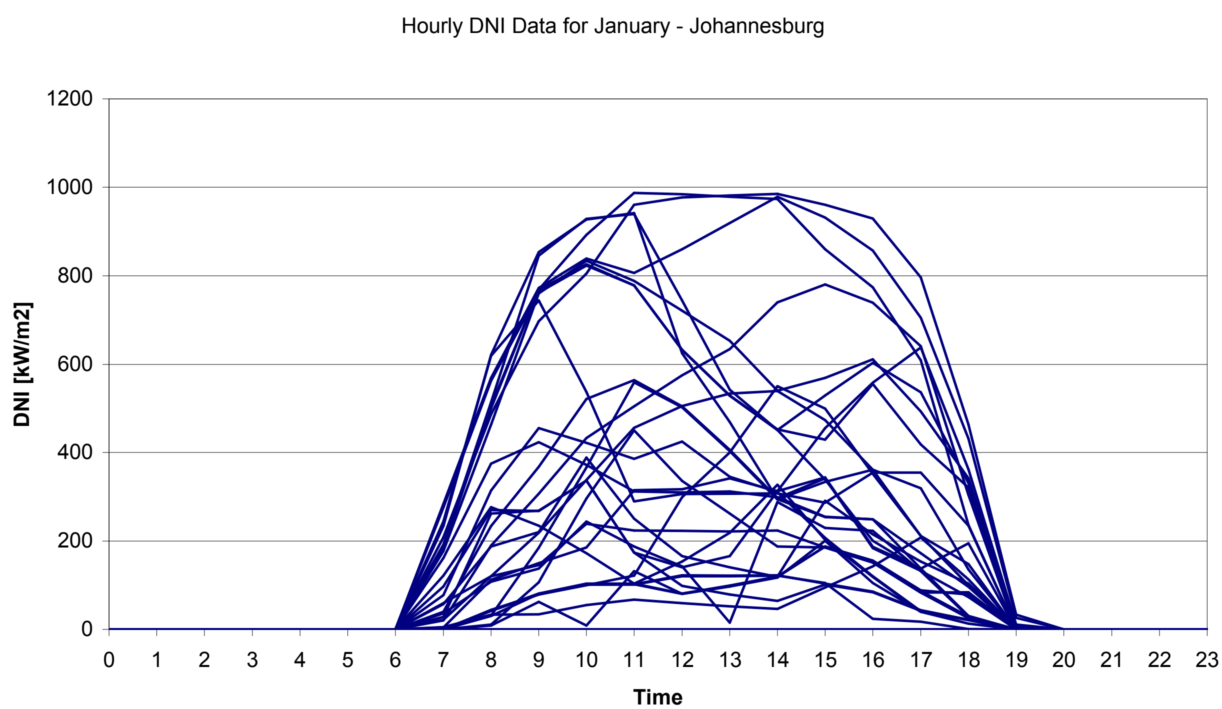


Figure C4: Hourly *DNI* Data - January- JHB

APPENDIX D DATA VERIFICATION

The optical efficiency obtained is 76 % and is confirmed by both NREL and Broesamle et al..

To verify the Ecostar results a design net electric output of 50MW is used. By using a design peak *DNI* of 950 W/m^2 and equation (16) results in an aperture area of 451 488 m^2, which includes three hours of storage and a solar multiple of 1.4. The value for the solar field in the Ecostar study is 442035 m^2. The calculated area is 1.9% larger (due to lower solar field efficiency) which is a satisfactory result and confirms the model for the parabolic trough. For the CLFR with no storage in the Ecostar design, the method was again verified with a slightly lower difference of 0.4%.

The details are summarised in Table D1.

Table D1: Parabolic Trough and CLFR Verification

	Parabolic Trough		CLFR	
	Ecostar	Calculated	Ecostar	Calculated
P_{net}	50MW	50MW	50MW	50MW
DNI	2,014	2,014	2,014	2,014
n_{opt}	75%	76%	64%	68%
n_{sf}	54.2%	53.8%	42.2%	42.0%
ns-e	14.08%	13.97%	10.54%	10.51%
A_a	442035	451,488	376200	377,567
E_{net}	124,670,470	127,020,000	79,886,327	79,891,200
Difference	1.9%		0.4%	

APPENDIX E JOHANNESBURG ELECTRICITY RATES

Wits University is medium voltage kVA business customer and the following charge rates are applicable (City of Johannesburg, 2008). A 2% surcharge will be levied on business and large power users.

Service Charge: R 1194.14 per month

Energy Charge (Subject to a seasonal change):
The summer rate is September through to April with both months inclusive (8 Months) and the winter rate is May through to August (4 Months)

Summer: 23.45 cents per kWh
Winter: 34.68 cents per kWh

Demand Charge:
R 78.24 per kVA
R 80.67 per kVA

Reactive Energy Charge:
6.13 cents per kVARh supplied in excess of 30% (0,96PF) of kWh recorded during the entire billing period. The excess reactive energy is determined using the billing period total.

Minimum Demand Charge Determination
The minimum demand charge payable monthly in terms of this tariff shall be calculated using the greater of:
(i) The measured demand;
(ii) A demand of 70 kVA
(iii) A demand based on the 80% average of the three highest demands recorded over the preceding 12 months.

APPENDIX F NATURAL GAS PRICING TARIFF FROM EGOLI GAS

Properties

Energy Content: 36.10MJ/m3 (@15C and 101.3 kPa)

<u>TARIFF BANDS:</u>

Tariff Band 01 - R 158.19 (Excl. VAT)

0 to 599 GJ/Annum

Tariff Band 02 - R 142.61 (Excl. VAT)

600 to 2,399 GJ/Annum

Tariff Band 03 - R 128.57 (Excl. VAT)

2,400 to 4,799 GJ/Annum

Tariff Band 04 - R 115.91 (Excl. VAT)

4,800 to 9,599 GJ/Annum

Tariff Band 05 - R 104.50 (Excl. VAT)

9,600 to 17,999 GJ/Annum

Tariff Band 06 - R 94.21 (Excl. VAT)

18,000 to 35,999 GJ/Annum

Tariff Band 07 - R 84.93 (Excl. VAT)

36,000 to 119,999 GJ/Annum

<u>MONTHLY BASIC CHARGES:</u>

R 242.36 (Excl. VAT)

There is an annual tariff increase on the 1st of July.

APPENDIX G WITS UNIVERSITY USAGE AND BILLING TRENDS

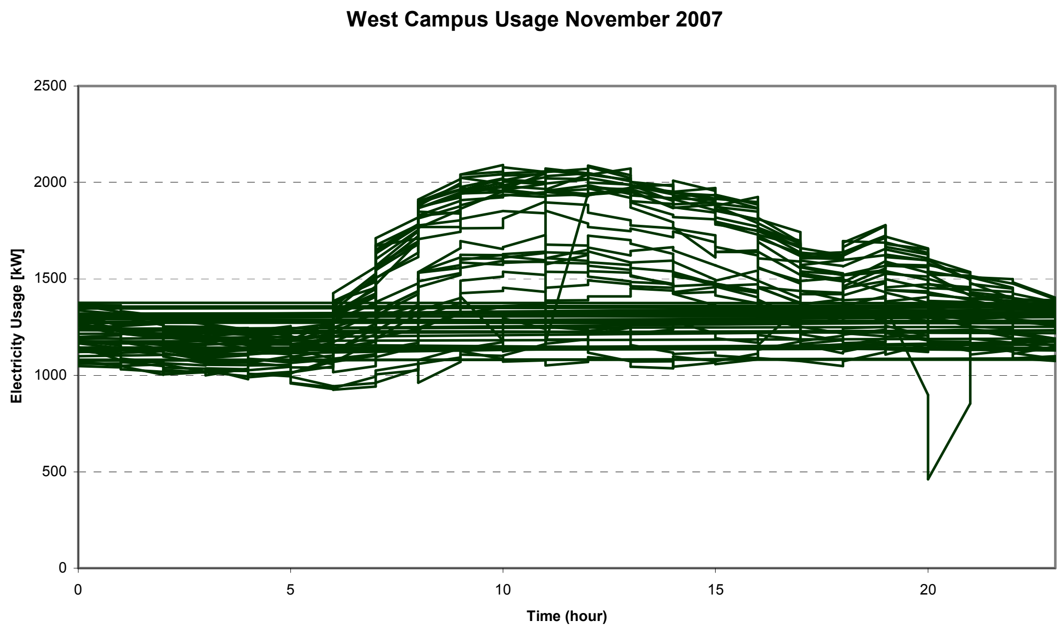


Figure G1: West Campus Usage- November 2007

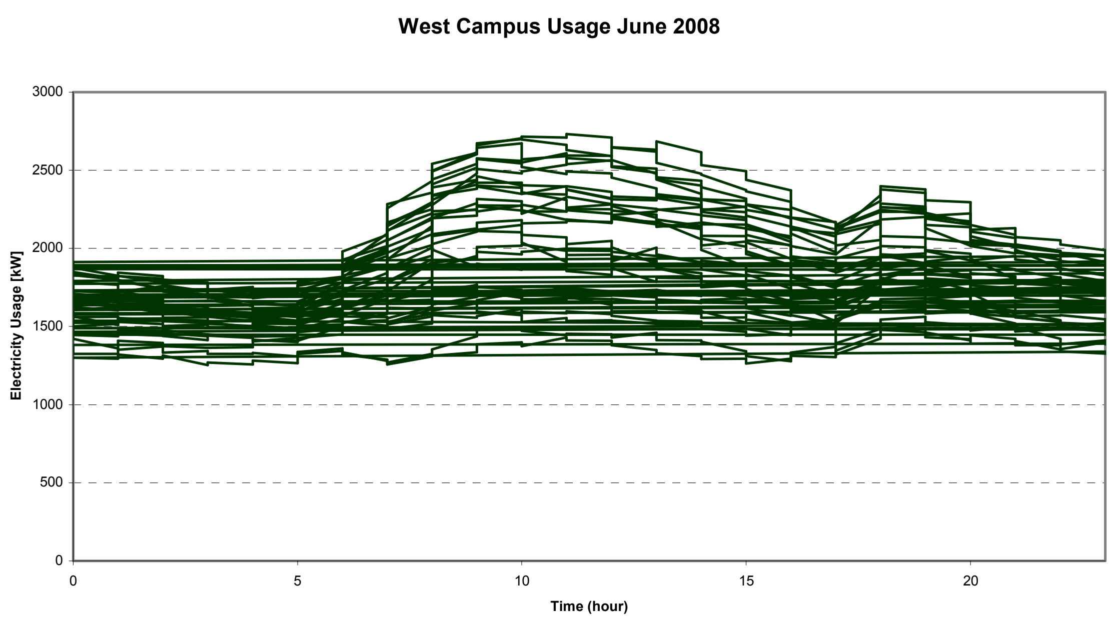


Figure G2: West Campus Usage- June 2008

Monthly Bill

Customer:	Wits West Campus	**Document date:**	2008-07-03 09:04
Account Number:	220045938	**Stand:**	none
Period:	From 2008-06-01 00:00:00.0 to 2008-07-01 00:00:00.0		

Electricity

Tariff	Description	Units	Rate[R]	Amount
Energy (HS)		1302900kWh	0.2338	R304,618.02
Reactive Energy		419600kvarh	0.0000	R0.00
Max Demand (HS)	0.963pf 2008-06-04 11:30	02836.5kVA	54.3800	R154,248.87
Service Charge		1month	805.0100	R805.01
Excess varh	Reactive	28730kvar	0.0416	R1,195.16
Surcharge		2%	460,867.0680	R9,217.34
			Sub Total:	R470,084.40

Total before VAT: R470,084.40
VAT(14.0%): R65,811.81
Total: R535,896.21

Figure G3: Monthly bill June 2008

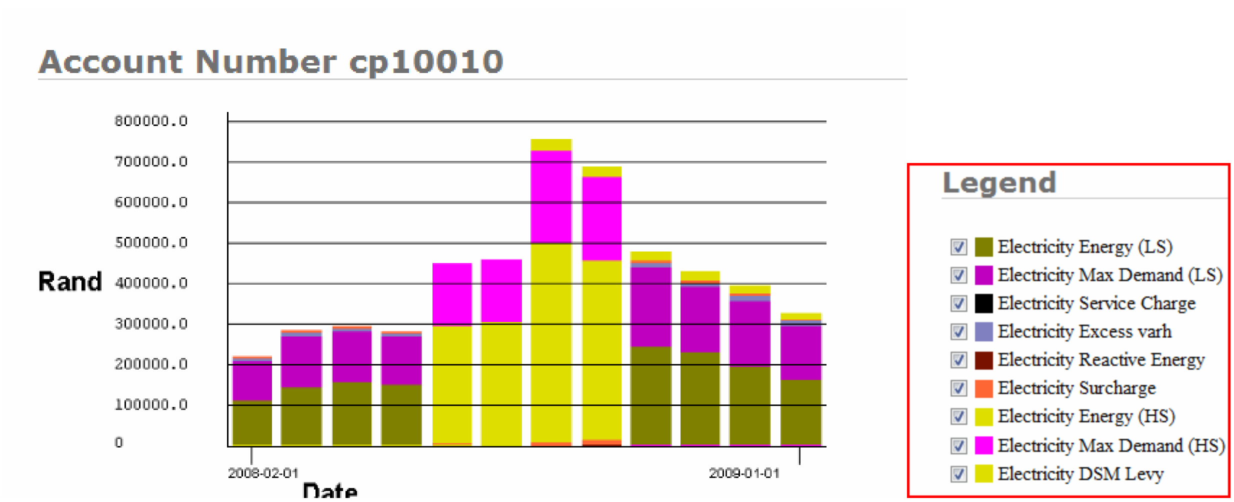


Figure G4: Historical Billing Trend for West Campus

APPENDIX H SPECIFIC COSTS

Table H1: Specific Costs

Source	**Ecostar**				**MTPP**		**Eskom**		**Solar mundo**				**BIO ORC**	
CSP System	**Parabolic Trough**	**Parabolic Trough**	**CLFR**	**CLFR**	**Parabolic Trough**	**Parabolic Trough**	**Parabolic Trough**	**Parabolic Trough**	**Parabolic Trough**	**Parabolic Trough**	**CLFR**	**CLFR**	**bio**	**bio**
Capacity	50MW	120kW	50MW	120kW	1MW	120kW	100MW	120kW	50MW	120kW	50MW	120kW	1MW	120kW
Specific Investment cost for Solar Field (*/m²)	€ 251.59	€ 341.84	€ 146.56	€ 199.13	€ 196.66	€ 219.03	€ 291.65	€ 541.98	€ 280.78	€ 429.08	€ 117.00	€ 129.35	€ 0.00	€ 0.00
Specific Investment cost for Power Block [*/kW(e)l]	€ 854.91	€ 1,306.60	€ 854.91	€ 1,306.60	€ 1,671.59	€ 1,940.35	€ 733.00	€ 1,431.95	€ 933.56	€ 1,198.60	€ 933.56	€ 1,198.60	€ 1,809.43	€ 2,100.27
Specific Land Cost [*/m²]	€ 2.44	€ 2.44	€ 2.44	€ 2.44			€ 1.44	€ 1.44					€ 0.00	€ 0.00
Specific Investment in Storage[*/kWhth]	€ 37.86	€ 57.21			€ 17.31	€ 20.01	€ 32.73	€ 62.89					€ 0.00	
Surcharge for Construction, Engineering and Contingencies %	20.00%	20.00%	20.00%	20.00%	10.00%	10.00%	20.00%	20.00%	10.00%	10.00%	10.00%	10.00%	0.00%	0.00%
Average O&M costs [% of total capital costs]	2.50%	3.75%	2.50%	3.75%	1.50%	3.00%							0.00%	0.00%

APPENDIX I PERSPECTIVE MODEL

Table I1: Perspective Model for Twelve Alternatives

		Functions									
	Alternatives	1. Produce Electricity		2. Minimise costs		3. Simplify integration		4. Reduce Emissions		Total	Rank
	Score	13		11		9		9			
1	**PT**	5	65	5	55	7	63	10	90	273	10
2	**PT, Stor**	7	91	5	55	5	45	10	90	281	9
3	**PT, Hybrid**	10	130	10	110	7	63	5	45	348	4
4	**PT, ORC**	5	65	4	44	5	45	10	90	244	12
5	**PT, Stor, ORC**	7	91	4	44	4	36	10	90	261	11
6	**PT, Hybrid, ORC**	10	130	9	99	5	45	5	45	319	6
7	**CLFR**	5	65	7	77	10	90	10	90	322	5
8	**CLFR, Stor**	7	91	7	77	9	81	10	90	339	3
9	**CLFR, Hybrid**	10	130	10	110	10	90	5	45	375	1
10	**CLFR, ORC**	5	65	6	66	9	81	10	90	302	7
11	**CLFR, Stor, ORC**	7	91	6	66	6	54	10	90	301	8
12	**CLFR, Hybrid, ORC**	10	130	10	110	9	81	5	45	366	2

APPENDIX J REFERENCE PLANT RESULTS

Table J1: Reference Plant Results

	PT	PT, Stor	PT, Hybrid	PT, ORC	PT, Stor, ORC	PT, Hybrid, ORC	CLFR	CLFR, Stor	CLFR, Hybrid	CLFR, ORC	CLFR, Stor, ORC	CLFR, Hybrid, ORC
Total Electricity Consumption [kWh]	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073	12,922,073
Total Solar Electricity Generated [kWh]	206,424	312,376	569,400	211,466	319,725	569,400	209,641	317,484	569,400	214,714	324,954	569,400
Yearly Bill [R]	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654	7,291,654
Total Bill [R] (incl. cost of Solar)	8,182,181	8,564,679	8,598,830	8,453,947	9,045,429	9,162,401	7,951,079	8,220,164	8,353,900	8,107,095	8,531,930	8,803,593
Extra Cost for Solar [R/year]	890,527	1,273,025	1,307,176	1,162,293	1,753,775	1,870,747	659,425	928,510	1,062,246	815,441	1,240,275	1,511,939
Cost Saved on Bill [R/year]	106,501	163,905	298,532	108,615	167,774	298,667	107,863	166,810	298,620	109,976	170,023	298,753
Solar LEC [R/kWh]	4.83	4.60	2.82	6.01	6.01	3.81	3.66	3.45	2.39	4.31	4.34	3.18
Real Solar LEC [R/kWh]	4.41	4.17	2.37	5.59	5.58	3.36	3.24	3.02	1.94	3.89	3.91	2.73
Average Capacity Factor	0.20	0.30	0.55	0.20	0.31	0.55	0.20	0.31	0.55	0.21	0.31	0.55
Total Investment [R]	7,015,875	10,020,564	7,015,875	9,281,377	13,919,049	9,281,377	5,317,550	7,522,350	5,317,550	6,660,049	10,063,111	6,660,049
Payback [years]	65.9	61.1	23.5	85.5	83.0	31.1	49.3	45.1	17.8	60.6	59.2	22.3
	-	-	-	-	-	-	-	-	-	-	-	-
Nominal LEC [R/kWh] (with REFIT)	2.36	2.12	1.61	3.54	2.01	2.04	1.19	0.97	1.18	1.84	1.86	1.97
Extra cost for Solar [R/year] (with REFIT)	467,358	632,654	874,853	728,788	612,356	1,117,873	229,660	277,668	629,923	375,278	574,121	1,079,616
Payback [years] (with REFIT)	13.2	12.5	9.6	17.1	10.6	8.8	9.9	9.2	7.3	12.1	12.0	9.1

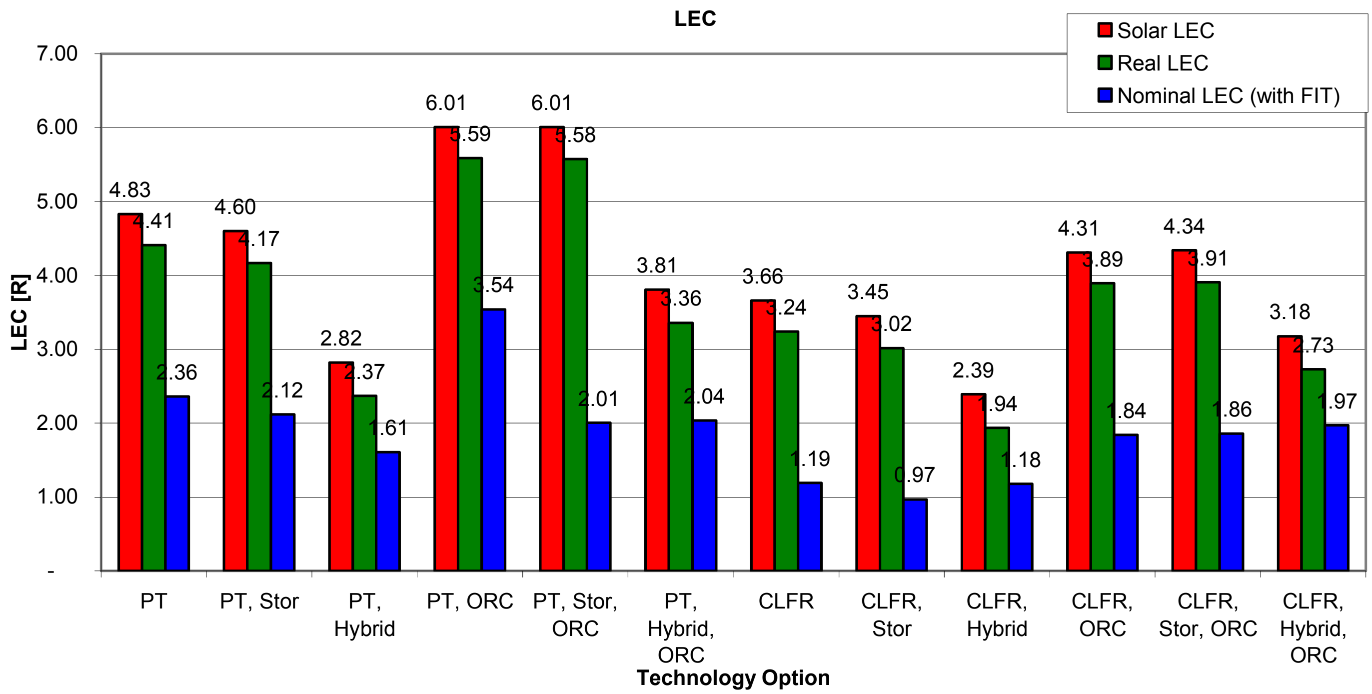


Figure J1: LEC for 120 kW(e) Reference Plants

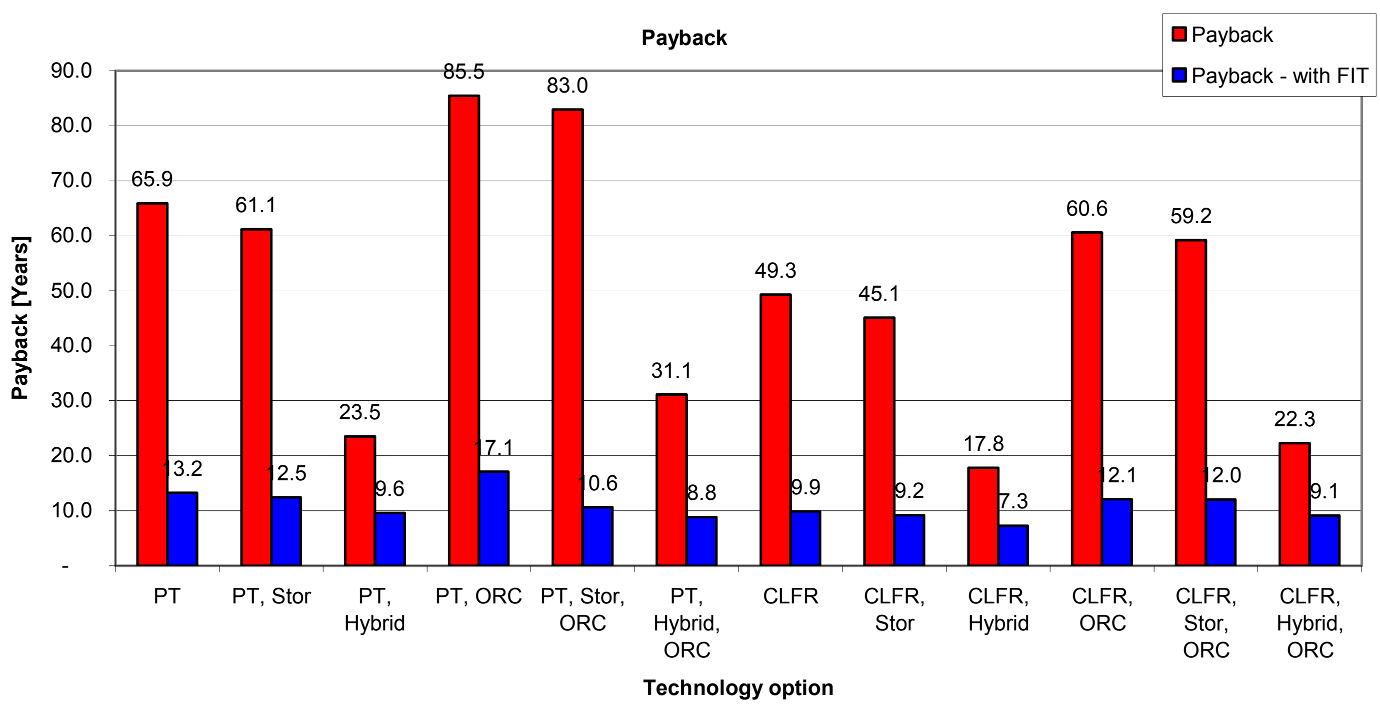


Figure J2: Payback for 120 kW(e) Reference Plants

APPENDIX K MODEL INPUT

DESIGN

```
format long;
clc;
clear;


T=csvread('C:\Users\user\Desktop\wits\design.csv');

[row1,col1] = size(T);

 i = 1;
 for i = 1:(col1)
   Asf(i) = T(2,i)*4;    %Solar Field Area
   nsf(i) = T(3,i);  %solar field efficiency
    parloss(i) = T(4,i);  %parasitic losses
   npbn(i) = T(7,i); %net power block efficiency
   storloss(i)=T(6,i);%storage efficiency
   piploss(i) = T(5,i);  % PIPING/RECEIVER EFFICIENCY
  % solcapf(i)=T(9,i);%solar capacity factor
  % actualcapf(i)=T(10,i); %total capacity factor

 end


%1 parabolic trough with steam cycle no storage, no hybridisation
% 2parabolic trough with steam cycle+storage
% 3parabolic trough with steam cycle+hybrid

%4parabolic trough with orc no storage, no hybridisation
%5parabolic trough with orc cycle +storage
%6parabolic trough with orc cycle +hybrid

%7clfr trough with orc no storage, no hybridisation
%8clfr trough with orc cycle +storage
%9clfr trough with orc cycle +hybrid

%10clfr trough with orc no storage, no hybridisation
%11clfr trough with orc cycle +storage
%12clfr trough with orc cycle +hybrid


%Common variables
Enet=480; %kW

k=1;
for k=1:(col1)
thermmax(k)=Enet/(npbn(k));
thermmin(k)=thermmax(k)*0.25; %kW
end


A=csvread('C:\Users\user\Desktop\wits\joburg\date.csv');


[row, col] = size(A);

i = 1;
for i = 1:(row)
   month(i,1) = A(i,1);
   day(i,1) = A(i,2);
   hour(i,1) = A(i,3);
   dni(i,1) = A(i,4);
end


start=1;
finish=24;
i=1;
 k=1;
      while i<row
   for i=start:finish
      daynum(i)=k;

   end

   start=finish+1;
      finish=start+23;
   k=k+1;
      end

  k=1;
thermout=zeros(8760,k);

%find thermal output from given dni
i=1;

col1
for i = 1:(row)
for k=1:col1
   dnitherm(i,k)=dni(i)*Asf(1,k)/1000;

thermout(i,k)=dni(i)*Asf(1,k)*nsf(1,k)*parloss(1,k)*piploss(1,k)*storloss(1,k)/1000; %kW

end
end


Eout=zeros(8760,k);
thermstor=zeros(8760,k);


k=1;
i=1;

   row2=row*2;

for i=1:(row)
 for k=1:col1
    %storage or dumping

   if thermout(i,k)>thermmax(k)
    Eout(i,k)=thermmax(k)*npbn(1,k);
      thermstor(i,k)=(thermout(i,k)-thermmax(k));


     %min therm dumped
   else if thermout(i,k)<thermmin(k)
          Eout(i,k)=0.0;
        thermstor(i,k)=thermout(i,k);

    else if thermmin(k)<thermout(i,k)<thermmax(k)
      Eout(i,k)=thermout(i,k)*npbn(1,k);

    end
      end

   end
 end

end

 %thermalstorage

i=1;
for i=1:row
tstoras_trough_steam(i,1)=thermstor(i,2);
tstoras_trough_orc(i,1)=thermstor(i,5);
tstoras_clfr_steam(i,1)=thermstor(i,8);
tstoras_clfr_orc(i,1)=thermstor(i,11);

% tdump_trough_steam_n(i,1)=thermstor(i,1);
% tdump_trough_orc_n(i,1)=thermstor(i,4);
% tdump_trough_steam_h(i,1)=thermstor(i,3);
% tdump_trough_orc_h(i,1)=thermstor(i,6);
%
% tdump_clfr_steam_n(i,1)=thermstor(i,7);
% tdump_clfr_steam_h(i,1)=thermstor(i,9);
% tdump_clfr_orc_n(i,1)=thermstor(i,10);
% tdump_clfr_orc_h(i,1)=thermstor(i,12);
%
end

sumthermstor=zeros(365,col1);
% sumthermdump=zeros(365,col1);

  j=1;
   c=1;
% for i = 1:(row)
  while c<(366)
      j=c*24;

sumthermstor(c,2)=sum(tstoras_trough_steam((j-23):j));
 sumthermstor(c,5)=sum(tstoras_trough_orc((j-23):j));
  sumthermstor(c,8)=sum(tstoras_clfr_steam((j-23):j));
   sumthermstor(c,11)=sum(tstoras_clfr_orc((j-23):j));


% sumthermdump(c,1)=sum(tdump_trough_steam_n((j-23):j));
% sumthermdump(c,3)=sum(tdump_trough_steam_h((j-23):j));
% sumthermdump(c,4)=sum(tdump_trough_orc_n((j-23):j));
% sumthermdump(c,6)=sum(tdump_trough_orc_h((j-23):j));
% sumthermdump(c,7)=sum(tdump_clfr_steam_n((j-23):j));
% sumthermdump(c,9)=sum(tdump_clfr_steam_h((j-23):j));
% sumthermdump(c,10)=sum(tdump_clfr_orc_n((j-23):j));
% sumthermdump(c,12)=sum(tdump_clfr_orc_h((j-23):j));

 c=c+1;
%    end
  end


  k=1;
i=1;

%sum the storage and see how much electricity the thermal storage over the
%period of a day can produce. doesnt take into account max and min therm
%energy delivered to the powerblock. assumes all storage heat is used to
%produce electricity.

for i=1:(c-1)
 for k=1:col1
```

```
        Estor(i,k)=sumthermstor(i,k)*npbn(1,k);
        Estor(i,col1)=i;
    end
end


Estora=zeros(8760,12);


    for k=1:col1
    for i=1:row
   for j=1:365
   if (daynum(i)==Estor(j,13)) && (hour(i) == 18)

       if  Estor(j,k)<481
       Estora(i,k)=Estor(j,k);


      else if Estor(j,k)>481 && Estor(j,k)<960
      Estora(i,k)=480;
     Estora(i+1,k)=Estor(j,k)-480;

      else if Estor(j,k)>960&& Estor(j,k)<1440
             Estora(i,k)=480;
             Estora(i+1,k)=480;

             Estora(i+2,k)=Estor(j,k)-480;

      else if  Estor(j,k)>960
      Estora(i,k)=480;
      Estora(i+1,k)=480;
      Estora(i+2,k)=480;
      Estora(i+3,k)=Estor(j,k)-1440;


      end
      end
      end

       end

   end
      end
       end
         end


     Ehybrid=zeros(row,col1);

for i=1:row
  for j=7:19
    % for k=1:col1
   %while j>6 && j<21
   if hour(i)== j
       Ehybrid(i,3)=480-Eout(i,3);
       Ehybrid(i,6)=480-Eout(i,6);
       Ehybrid(i,9)=480-Eout(i,9);
       Ehybrid(i,12)=480-Eout(i,12);

  %  end
   end
  end
end


E=zeros(10000,col1);
thermoutc=zeros(17520,col1);
Estorac=zeros(17520,12);

i=1;
odd=1;
even=2;

  while odd<(row2)

  for i=1:(row)

      for k=1:col1

          dnithermc(odd,k)=dnitherm(i,k);
          dnithermc(even,k)=dnitherm(i,k);

      thermoutc(odd,k)=thermout(i,k);
      thermoutc(even,k)=thermout(i,k);

%     thermoutdump(odd,k)=thermdump

      E(odd,k)=Eout(i,k);
      E(even,k)=Eout(i,k);

      Estorac(odd,k)=Estora(i,k);
      Estorac(even,k)=Estora(i,k);

      Ehybridc(odd,k)=Ehybrid(i,k);
      Ehybridc(even,k)=Ehybrid(i,k);

 end
   dayc(odd,1)= day(i);
   monthc(odd,1)=month(i);
   hourc(odd,1)=hour(i);
   daynumc(odd,1)=daynum(i);

   dayc(even,1)=   day(i);
   monthc(even,1)=month(i);
   hourc(even,1)=hour(i);
   daynumc(even,1)=daynum(i);



    even = even+2;
    odd=odd+2;

end
 end

 %rearrange to start with July1st
Es=circshift(E,[8832,0]);     %july 1 is on the 8689 th day: 17520-8688=8832
%Estoras=circshift(Estora,[8832,0]);
daycs=circshift(dayc,[8832,0]);
monthcs=circshift(monthc,[8832,0]);
thermoutcs=circshift(thermoutc,[8832,0]);
daynumcs=circshift(daynumc, [8832,0]);
Ehybridcs=circshift(Ehybridc,[8832,0]);
Estoras=circshift(Estorac,[8832,0]);

 Ewh=Es+Ehybridcs;

% for i=1:row2
%     Enot(i)=Es(i,1);
% end

  %check

%totals and capacity factors

sumEsolar=sum(Es)/2;
sumEstorout=sum(Estor);
solartotal=sumEsolar+sumEstorout;

total=sum(Ewh)/2+sumEstorout;

 solarcapacity=(solartotal/Enet)/(365*24);
totalcapacity=(total/Enet)/(365*24);

%min=zeros(row2,1);
i=1;
 while i<17520
    min(i)=0.0;
min(i+1)=30.0;
i=i+2;
 end
% for i=1:row2
%     year(1:8832,1)=2007;
%     year(8833:17520,1)=2008;
% end

%populating the date matrix
%year of interest,min(i)
for i = 1:row

%l=[2008,monthcs(i),daycs(i),hourc(i),min(i),0];
   l = [num2str(month(i)) '/' num2str(day(i)) '/' num2str(2008) ' ' num2str(hour(i)) ':' num2str(min(i)) ':' '00'];
    DateNumber(i) = datenum(l);
end


    %%%%monthlythermal energy flow
    p=1;
n=1;
for n=1:3
    if n==1
       for p=1:row
    P1(p,1)=dnitherm(p,10);
    P1(p,2)=thermout(p,10);
    P1(p,3)=Eout(p,10);
    end
    end

   if n==2
      for p=1:row
     P2(p,4)=Estora(p,11);
    P2(p,1)=dnitherm(p,11);
    P2(p,2)=thermout(p,11);
    P2(p,3)=Eout(p,11);
   end
   end
    if n==3
       for p=1:row
    P3(p,3)=Ehybrid(p,12);
    P3(p,1)=dnitherm(p,12);
    P3(p,2)=thermout(p,12);
    P3(p,4)=Eout(p,12);
       end
    end

end

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes(...
  'XGrid','on',...
  'XTick',[7.33408e+005 7.33468e+005 7.33562e+005 7.33652e+005 7.33743e+005],...
'XTickLabel',{'01/01','01/03','01/06','01/09','01/12'},...
  'YGrid','on',...
  'Parent',figure1);
xlim(axes1,[7.33408e+005 7.33773e+005]);
title(axes1,'CLFR Hourly Energy Flow');
xlabel(axes1,'Date');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(...
 DateNumber,P2(1:8760,1),...
  'Parent',axes1,...
  'DisplayName','DNI Thermal Energy Received [kWth]',...
  'FaceColor',[0 0 0]);

%% Create bar
bar2 = bar(...
  DateNumber,P2(1:8760,2),...
```

```
 'Parent',axes1,...
 'DisplayName','Thermal energy Delivered to PB
[kWth]',...
 'EdgeColor',[1 0 0],...
 'FaceColor',[1 0 0]);

%% Create bar
bar3 = bar(...
 DateNumber,P2(1:8760,4),...
 'Parent',axes1,...
 'DisplayName','Enet Storage [kW]',...
 'EdgeColor',[0 0 1],...
 'FaceColor',[0 0 1]);

%% Create bar
bar4 = bar(...
 DateNumber,P2(1:8760,3),...
 'Parent',axes1,...
 'DisplayName','Enet [kW]',...
 'EdgeColor',[1 1 0],...
 'FaceColor',[1 1 0]);


%% Create legend
legend1 = legend(axes1,{'DNI Thermal Energy
Received [kWth]','Thermal energy Delivered to PB
[kWth]','Enet Storage [kW]','Enet
[kW]'},'Position',[0.5965 0.7548 0.3076 0.1684]);

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes(...
 'XGrid','on',...
 'XTick',[7.33408e+005 7.33468e+005 7.33562e+005
7.33652e+005 7.33743e+005],...

'XTickLabel',{'01/01','01/03','01/06','01/09','01/12'},...
.
 'YGrid','on',...
 'Parent',figure1);
xlim(axes1,[7.33408e+005 7.33773e+005]);
title(axes1,'CLFR Hourly Energy Flow');
xlabel(axes1,'Date');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(...
 DateNumber,P3(1:8760,1),...
 'Parent',axes1,...
 'DisplayName','DNI Thermal Energy Received
[kWth]',...
 'FaceColor',[0 0 0]);

%% Create bar
bar2 = bar(...
 DateNumber,P3(1:8760,2),...
 'Parent',axes1,...
 'DisplayName','Thermal energy Delivered to PB
[kWth]',...
 'EdgeColor',[1 0 0],...
 'FaceColor',[1 0 0]);

 %% Create bar
bar3 = bar(...
 DateNumber,P3(1:8760,3),...
 'Parent',axes1,...
 'DisplayName','Enet Hybrid [kW]',...
 'EdgeColor',[0 0 1],...
 'FaceColor',[0 0 1]);

%% Create bar
bar4 = bar(...
 DateNumber,P3(1:8760,4),...
 'Parent',axes1,...
 'DisplayName','Energy [kW]',...
 'EdgeColor',[1 1 0],...
 'FaceColor',[1 1 0]);


%% Create legend
legend1 = legend(axes1,{'DNI Thermal Energy
Received [kWth]','Thermal energy Delivered to PB
[kWth]','Enet Hybrid [kW]','Enet
[kW]'},'Position',[0.5911 0.7628 0.3084 0.1557]);

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes(...
 'XGrid','on',...
 'XTick',[7.33408e+005 7.33468e+005
7.33562e+005 7.33652e+005 7.33743e+005],...

'XTickLabel',{'01/01','01/03','01/06','01/09','01/12
'},...
 'YGrid','on',...
 'Parent',figure1);
xlim(axes1,[7.33408e+005 7.33773e+005]);
title(axes1,'CLFR Hourly Energy Flow');
xlabel(axes1,'Date');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(...
 DateNumber,P1(1:8760,1),...
 'Parent',axes1,...
 'DisplayName','DNI Thermal Energy Received
[kWth]',...
 'FaceColor',[0 0 0]);

%% Create bar
bar2 = bar(...
 DateNumber,P1(1:8760,2),...
 'Parent',axes1,...
 'DisplayName','Thermal energy Delivered to PB
[kWth]',...
 'EdgeColor',[1 0 0],...
 'FaceColor',[1 0 0]);

%% Create bar
bar3 = bar(...
 DateNumber,P1(1:8760,3),...
 'Parent',axes1,...
 'DisplayName','Enet [kW]',...
 'EdgeColor',[1 1 0],...
 'FaceColor',[1 1 0]);


%% Create legend
legend1 = legend(axes1,{'DNI Thermal Energy
Received [kWth]','Thermal energy Delivered to PB
[kWth]','Enet [kW]'},'Position',[0.5911 0.7628
0.3084 0.1557]);



%%%%%%%find the average data on an hourly
basis- this is for modelling the
%%%%%%%energy conversion from collected dni
to electricity
dnithermhour=zeros(24,13);
thermouthour=zeros(24,13);
Estorhour=zeros(24,13);
Ehybridhour=zeros(24,13);
Ehour=zeros(24,13);

%%%%%%%%%%%%%%%%%%%%%%
h=1;
 m=1;
  while h<25

for i = 1:row
   for k=1:col1

  if hour(i) == h
   dnithermhour(h,k) =  dnithermhour(h,k) +
dnitherm(i,k);
 dnithermhouraverage=(dnithermhour)/(365);

 Ehybridhour(h,k) =  Ehybridhour(h,k) +
Ehybrid(i,k);
 Ehybridhouraverage=(Ehybridhour)/(365);

   thermouthour(h,k) =  thermouthour(h,k) +
thermout(i,k);
  thermouthouraverage=(thermouthour)/(365);

   Ehour(h,k) =  Ehour(h,k) + Eout(i,k);
  Ehouraverage=(Ehour)/(365);

  Estorhour(h,k) =  Estorhour(h,k) + Estora(i,k);
 Estorhouraverage=(Estorhour)/(365);

  end
    end

end
h=h+1;
 end

 for m=1:24
  for k=1:12
%

Ehourtotal(m,k)=Ehouraverage(m,k)+Ehybridh
ouraverage(m,k);

Ehourtotal1(m,k)=Ehouraverage(m,k)+Estorhou
raverage(m,k);
%
  end
    end

 %thermal energy flow
n=1;
for n=1:3
   if n==1
     for h=1:24
   H1(h,3)=dnithermhouraverage(h,10);
   H1(h,2)=thermouthouraverage(h,10);
   H1(h,1)=Ehourtotal(h,10);
   end
   end

  if n==2
    for h=1:24

   H2(h,3)=dnithermhouraverage(h,11);
   H2(h,2)=thermouthouraverage(h,11);
   H2(h,1)=Ehourtotal1(h,11);
  end
  end
   if n==3
     for h=1:24
   H3(h,2)=Ehybridhouraverage(h,12);
   H3(h,5)=dnithermhouraverage(h,12);
   H3(h,4)=thermouthouraverage(h,12);
   H3(h,1)=Ehouraverage(h,12);
   H3(h,3)=Ehourtotal(h,12);
   end
   end
```

```
end


%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes('YGrid','on','Parent',figure1);
xlim(axes1,[0 23]);
title(axes1,'CLFR');
xlabel(axes1,'Time');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create mutliple lines using matrix input to plot
plot1 = plot(H1);
set(plot1(2),'Color',[1 0 1]);

%% Create legend
legend1 = legend(axes1,{'Enet Electricity Generated','Thermal Energy Delivered','DNI Thermal Energy'},'Position',[0.6797 0.7441 0.2583 0.1684]);



%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes('YGrid','on','Parent',figure1);
xlim(axes1,[0 23]);
title(axes1,'CLFR with Storage');
xlabel(axes1,'Time');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create mutliple lines using matrix input to plot
plot1 = plot(H2);
set(plot1(2),'Color',[1 0 1]);

%% Create legend
legend1 = legend(axes1,{'Enet Electricity Generated','Thermal Energy Delivered','DNI Thermal Energy'},'Position',[0.6797 0.7441 0.2583 0.1684]);


% %%%%%%%%%%%%%%%%%%

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes('YGrid','on','Parent',figure1);
xlim(axes1,[0 23]);
title(axes1,'CLFR with Hybridisation');
xlabel(axes1,'Time');
ylabel(axes1,'Energy [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create mutliple lines using matrix input to plot
plot1 = plot(H3);
set(plot1(2),'Color',[1 0 1]);

%% Create legend
legend1 = legend(axes1,{'Enet Electricity Generated','Hybrid Electricity Generated','Total Electricity','Thermal Energy Delivered','DNI Thermal Energy'},'Position',[0.6797 0.7441 0.2583 0.1684]);

%% %
  %end


k=1;
 i=1;
 B=zeros(row2,col1+3);
  H=zeros(row2,col1+3);

for k=1:col1
for i=1:(row2)

 B(i,1)=monthcs(i);

B(i,2)=daycs(i);

B(i,3)=hourc(i);

B(i,4)=daynumcs(i);

B(i,k+4)=Es(i,k);

end
end

  success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designsolar.xls', B);
  success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designstorage.xls', Estoras);
  success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designhybrid.xls', Ehybridcs);

   success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designsolar.xls', B);
  success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designstorage.xls', Estoras);
  success = xlswrite('C:\Users\user\Desktop\wits\joburgchoice\designhybrid.xls', Ehybridcs);
```

BILL ANALYSIS

```
format long;
clc;
clear;

%this code is written to read in two years of data. Each year spans from
%July to June of the following year.  This is in conjunction with the
%billing period of city power.
%determination of the monthly and yearly cost

%service charge
service_charge = 1194.14;

%energy charge (current) (kWh)
energy_cost_summer = 0.2345;
energy_cost_winter = 0.3468;

%demand charge (current) (kVA)
demand_cost_summer = 78.24;
demand_cost_winter = 80.67;

reactive_energy_cost = 0.0613;
surcharge = 0.02;


 M = csvread('C:\Users\user\Desktop\wits\Christiaan files\West Campus\West_July07_to_June08.csv');
%this will be the year for which the bill is to be determined
 N = csvread('C:\Users\user\Desktop\wits\Christiaan files\West Campus\West_July06_to_June07.csv');
 %this is the previous year required to determine the bill

  E = csvread('C:\Users\user\Desktop\wits\joburg\designsolar.csv');
  % S = csvread('C:\Users\user\Desktop\wits\joburg\designstorage.csv');
   %  H = csvread('C:\Users\user\Desktop\wits\joburg\designhybrid.csv');

L=csvread('C:\Users\user\Desktop\wits\joburg\lec.csv');

[row,col] = size(M);

[row_previous, col_previous] = size(N);
[rows,cols] = size(E);


LEC= L(1,1);
LECf=L(2,1);
invest=L(3,1);
investf=L(4,1);

i = 1;
for i = 1:(rows)

 solar(i)=E(i,5);
  %Estoras(i)= S(i,5);
end

%populating the year of interest's matrices
i = 1;
for i = 1:(row)
   Power(i,1) = M(i,1);
   Reactive(i,1) = M(i,2);
   Complex(i,1) = M(i,3);
   Day(i,1) = M(i,4);
   Month(i,1) = M(i,5);
   Year(i,1) = M(i,6);
   Hour(i,1) = M(i,7);
   Minute(i,1) = M(i,8);
end

%populating the previous year's matrices
i = 1;
for i = 1:(row_previous)
   Power_previous(i,1) = N(i,1);
   Reactive_previous(i,1) = N(i,2);
   Complex_previous(i,1) = N(i,3);
   Day_previous(i,1) = N(i,4);
   Month_previous(i,1) = N(i,5);
   Year_previous(i,1) = N(i,6);
   Hour_previous(i,1) = N(i,7);
   Minute_previous(i,1) = N(i,8);
end

%with solar reduction- assuming solar takes away from kVa as well as kW
for i=1:row
   Powers(i)=Power(i)-solar(i);
   Complexs(i)=Complex(i)-solar(i);

end

for i=1:row_previous

   Power_previouss(i)=Power(i)-solar(i);
```

```
Complex_previouss(i)=Complex_previous(i)-solar(i);
end


[row, col] = size(Minute)
[row_previous, col_previous] = size(Minute_previous)

%populating the date matrix
%year of interest
for i = 1:row
   l = [num2str(Month(i)) '/' num2str(Day(i)) '/' 
num2str(Year(i)) ' ' num2str(Hour(i)) ':' 
num2str(Minute(i)) ':' '00'];
   DateNumber(i,1) = datenum(l);
end
%previous year
for i = 1:row_previous
   l = [num2str(Month_previous(i)) '/' 
num2str(Day_previous(i)) '/' 
num2str(Year_previous(i)) ' ' 
num2str(Hour_previous(i)) ':' 
num2str(Minute_previous(i)) ':' '00'];
   DateNumber_previous(i,1) = datenum(l);
end

%combined_complex_power_month_matrix is used to 
determine the three largest
%peaks of the preceding twelve months for each 
month of interest.  The fist
%twelve columns is the
combined_complex_power_matrix = zeros(2000, 24);
k = 1;
for j = 7:12
   for i = 1:row_previous
      if Month_previous(i) == j
         combined_complex_power_matrix(k,j-6) = 
Complex_previous(i);
         k = k+1;
      end
   end
   k = 1;
end
k = 1;
for j = 1:6
   for i = 1:row_previous
      if Month_previous(i) == j
         combined_complex_power_matrix(k,j+6) = 
Complex_previous(i);
         k = k+1;
      end
   end
   k = 1;
end
k = 1;
for j = 7:12
   for i = 1:row
      if Month(i) == j
         combined_complex_power_matrix(k,j+6) = 
Complex(i);
         k = k + 1;
      end
   end
   k = 1;
end
k = 1;
for j = 1:6
   for i = 1:row
     if Month(i) == j
       combined_complex_power_matrix(k,j+18) = 
Complex(i);
        k = k+1;
     end
   end
   k = 1;
end
sorted_combined_complex_power_matrix = 
sort(combined_complex_power_matrix,1,'descend');
%this is the combined_complex_power_matrix 
sorted in descending order for each month
beginning = 0;
ending = 0;

%temp matrix is all the complex power readings of 
the previous twelve
%months (w.r.t each month of interest) combined 
into one large matrix which
%is then sorted in descending order to obtain the 
three largest peaks of
%these twelve months of readings.

temp_matrix = zeros(24000,1);
three_largest_peaks = zeros(3,12);
for i = 13:24
   beginning = 1;
   ending = 2000;
   for j = i-12:i-1
      temp_matrix(beginning:ending,1) = 
combined_complex_power_matrix(1:2000,j);
      beginning = ending + 1;
      ending = beginning + 1999;
   end
   temp_matrix = sort(temp_matrix, 'descend');
   three_largest_peaks(1:3,i-12) = 
temp_matrix(1:3,1);
end

three_largest_peaks_average = zeros(1,12)
%80% average of the three highest peaks w.r.t. each 
of the months of
%interest
for i = 1:12
      three_largest_peaks_average(i) = 
0.8*(three_largest_peaks(1,i) + 
three_largest_peaks(2,i) + 
three_largest_peaks(3,i))/3;
end

 %extraction of the peak complex power of each 
month of interest.  The
%twelve months of interest correspond to columns 
13 to 24 of the
%combined_complex_power_matrix.
peaks = sorted_combined_complex_power_matrix(1,
13:24);

%%%%%solar peaks
 %combined_complex_power_month_matrix is used 
to determine the three largest
%peaks of the preceding twelve months for each 
month of interest.  The fist
%twelve columns is the
combined_complex_power_matrixs = zeros(2000, 
24);
k = 1;
for j = 7:12
   for i = 1:row_previous
      if Month_previous(i) == j
         combined_complex_power_matrixs(k,j-6) = 
Complex_previouss(i);
         k = k+1;
      end
   end
   k = 1;
end
k = 1;
for j = 1:6
   for i = 1:row_previous
      if Month_previous(i) == j
         combined_complex_power_matrixs(k,j+6) = 
Complex_previouss(i);
         k = k+1;
      end
   end
   k = 1;
end
k = 1;
for j = 7:12
   for i = 1:row
      if Month(i) == j
         combined_complex_power_matrixs(k,j+6) 
= Complexs(i);
         k = k + 1;
      end
   end
   k = 1;
end
k = 1;
for j = 1:6
   for i = 1:row
     if Month(i) == j
       combined_complex_power_matrixs(k,j+18) 
= Complexs(i);
        k = k+1;
     end
   end
   k = 1;
end

sorted_combined_complex_power_matrixs = 
sort(combined_complex_power_matrixs,1,'desce
nd'); %this is the 
combined_complex_power_matrix sorted in 
descending order for each month
beginning = 0;
ending = 0;


%temp matrix is all the complex power readings 
of the previous twelve
%months (w.r.t each month of interest) 
combined into one large matrix which
%is then sorted in descending order to obtain 
the three largest peaks of
%these twelve months of readings.
temp_matrix = zeros(24000,1);
three_largest_peakss = zeros(3,12);
for i = 13:24
   beginning = 1;
   ending = 2000;
   for j = i-12:i-1
      temp_matrix(beginning:ending,1) = 
combined_complex_power_matrixs(1:2000,j);
      beginning = ending + 1;
      ending = beginning + 1999;
   end
   temp_matrix = sort(temp_matrix, 'descend');
   three_largest_peakss(1:3,i-12) = 
temp_matrix(1:3,1);
end


three_largest_peaks_averages = zeros(1,12)
%80% average of the three highest peaks w.r.t. 
each of the months of
%interest

for i = 1:12
      three_largest_peaks_averages(i) = 
0.8*(three_largest_peakss(1,i) + 
three_largest_peakss(2,i) + 
three_largest_peakss(3,i))/3;
end


%extraction of the peak complex power of each 
month of interest.  The
%twelve months of interest correspond to 
columns 13 to 24 of the
%combined_complex_power_matrix.
```

```
peakss = sorted_combined_complex_power_matrixs(1,
13:24);

%determine the energy consumption for each month
of the year of interest
%this is correct. Checked against known data
energy_months = zeros(1,12);
for i = 1:row
  if Month(i) == 1
    energy_months(7) = energy_months(7) +
Power(i)*0.5;
  elseif Month(i) == 2
    energy_months(8) = energy_months(8) +
Power(i)*0.5;
  elseif Month(i) == 3
    energy_months(9) = energy_months(9) +
Power(i)*0.5;
  elseif Month(i) == 4
    energy_months(10) = energy_months(10) +
Power(i)*0.5;
  elseif Month(i) == 5
    energy_months(11) = energy_months(11) +
Power(i)*0.5;
  elseif Month(i) == 6
    energy_months(12) = energy_months(12) +
Power(i)*0.5;
  elseif Month(i) == 7
    energy_months(1) = energy_months(1) +
Power(i)*0.5;
  elseif Month(i) == 8
    energy_months(2) = energy_months(2) +
Power(i)*0.5;
  elseif Month(i) == 9
    energy_months(3) = energy_months(3) +
Power(i)*0.5;
  elseif Month(i) == 10
    energy_months(4) = energy_months(4) +
Power(i)*0.5;
  elseif Month(i) == 11
    energy_months(5) = energy_months(5) +
Power(i)*0.5;
  elseif Month(i) == 12
    energy_months(6) = energy_months(6) +
Power(i)*0.5;
    end
end

%%%%%%%%solar months

%determine the energy consumption for each month
of the year of interest
%this is correct. Checked against known data
energy_monthss = zeros(1,12);
for i = 1:row
  if Month(i) == 1
    energy_monthss(7) = energy_monthss(7) +
Powers(i)*0.5;
  elseif Month(i) == 2
    energy_monthss(8) = energy_monthss(8) +
Powers(i)*0.5;
  elseif Month(i) == 3
    energy_monthss(9) = energy_monthss(9) +
Powers(i)*0.5;
  elseif Month(i) == 4
    energy_monthss(10) = energy_monthss(10) +
Powers(i)*0.5;
  elseif Month(i) == 5
    energy_monthss(11) = energy_monthss(11) +
Powers(i)*0.5;
  elseif Month(i) == 6
    energy_monthss(12) = energy_monthss(12) +
Powers(i)*0.5;
  elseif Month(i) == 7
    energy_monthss(1) = energy_monthss(1) +
Powers(i)*0.5;
  elseif Month(i) == 8
    energy_monthss(2) = energy_monthss(2) +
Powers(i)*0.5;
  elseif Month(i) == 9
    energy_monthss(3) = energy_monthss(3) +
Powers(i)*0.5;
  elseif Month(i) == 10
    energy_monthss(4) = energy_monthss(4) +
Powers(i)*0.5;
  elseif Month(i) == 11
    energy_monthss(5) = energy_monthss(5) +
Powers(i)*0.5;
  elseif Month(i) == 12
    energy_monthss(6) = energy_monthss(6) +
Powers(i)*0.5;
    end
end

%determination of the kVArh consumption for each
month of the year of interest
%correct.  checked against known data
reactive_energy_months = zeros(1,12);
for i = 1:row
  if Month(i) == 1
    reactive_energy_months(7) =
reactive_energy_months(7) + Reactive(i)*0.5;
  elseif Month(i) == 2
    reactive_energy_months(8) =
reactive_energy_months(8) + Reactive(i)*0.5;
  elseif Month(i) == 3
    reactive_energy_months(9) =
reactive_energy_months(9) + Reactive(i)*0.5;
  elseif Month(i) == 4
    reactive_energy_months(10) =
reactive_energy_months(10) + Reactive(i)*0.5;
  elseif Month(i) == 5
    reactive_energy_months(11) =
reactive_energy_months(11) + Reactive(i)*0.5;
  elseif Month(i) == 6
    reactive_energy_months(12) =
reactive_energy_months(12) + Reactive(i)*0.5;
  elseif Month(i) == 7
    reactive_energy_months(1) =
reactive_energy_months(1) + Reactive(i)*0.5;
  elseif Month(i) == 8
    reactive_energy_months(2) =
reactive_energy_months(2) + Reactive(i)*0.5;
  elseif Month(i) == 9
    reactive_energy_months(3) =
reactive_energy_months(3) + Reactive(i)*0.5;
  elseif Month(i) == 10
    reactive_energy_months(4) =
reactive_energy_months(4) + Reactive(i)*0.5;
  elseif Month(i) == 11
    reactive_energy_months(5) =
reactive_energy_months(5) + Reactive(i)*0.5;
  elseif Month(i) == 12
    reactive_energy_months(6) =
reactive_energy_months(6) + Reactive(i)*0.5;
    end
end

%determination of the months of interest
%extracting the months of interest into a matrix
from the Months matrix
%extracting the year associated with each month of
interest into a matrix
%from the years matrix
Months_of_interest = zeros(1,12);
Years_of_interest = zeros(1,12);
j = 1;
for i = 1:row
  if Months_of_interest(j) == 0
    Months_of_interest(j) = Month(i);
    Years_of_interest(j) = Year(i);
  end
  if i < row
    if abs(Month(i) - Month(i+1)) > 0
      j = j+1;
    end
  end
end

 %determining the demand chargable for each
month is calculated by using the
%greater of: 1) the measured demand, 2) a
demand of 70kVA 3) a demand based
%on the 80% average of the three highest
demands recorded over the
%preceding 12 months.
demand = zeros(1,12);
for i=1:12
    demand(i) = peaks(i);
    if three_largest_peaks_average(i) >
demand(i)
      demand(i) =
three_largest_peaks_average(i);
    elseif 70 > demand(i)
      demand(i) = 70;
    end
end

%%%%%%%% solar

%determining the demand chargable for each
month is calculated by using the
%greater of: 1) the measured demand, 2) a
demand of 70kVA 3) a demand based
%on the 80% average of the three highest
demands recorded over the
%preceding 12 months.
demands = zeros(1,12);
for i=1:12
    demands(i) = peakss(i);
    if three_largest_peaks_averages(i) >
demands(i)
      demands(i) =
three_largest_peaks_averages(i);
    elseif 70 > demands(i)
      demands(i) = 70;
    end
end

%%%%%%%%%%%%%%

%determination of the excess reactive energy.  A
charge will be made on the
%kVAh in excess of 30% of the kWh for each
month. Checked against known
%data
billable_reactive_energy = zeros(1,12);
for i = 1:12
  if
(reactive_energy_months(i)/energy_months(i))
> 0.3
    billable_reactive_energy(i) =
reactive_energy_months(i) -
0.3*energy_months(i);
  end
end

%determination of the montly and yearly
energy cost
energy_year = 0;
energy_cost_year = 0;
energy_cost_months = zeros(1,12);

for i = 1:12
   energy_year = energy_year +
energy_months(i);
   if  ((2 < i) && (i < 11)) %summer rates are
from September to April
      energy_cost_months(i) =
energy_months(i)*energy_cost_summer;
      value_i_1 = i
```

```
    end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
        energy_cost_months(i) = energy_months(i)*energy_cost_winter;
        value_i_2 = i
    end
    energy_cost_year = energy_cost_year + energy_cost_months(i);

end

%%%%%%%solar year

%determination of the montly and yearly energy cost
energy_years = 0;
energy_cost_years = 0;
energy_cost_monthss = zeros(1,12);


for i = 1:12
    energy_years = energy_years + energy_monthss(i);
    if ((2 < i) && (i < 11)) %summer rates are from September to April
        energy_cost_monthss(i) = energy_monthss(i)*energy_cost_summer;
        value_i_1 = i
    end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
        energy_cost_monthss(i) = energy_monthss(i)*energy_cost_winter;
        value_i_2 = i
    end
    energy_cost_years = energy_cost_years + energy_cost_monthss(i);

end
%%%%%%%%%%%%%%%%


%determination of the montly and yearly energy cost
energy_years = 0;
energy_cost_years = 0;

energy_cost_monthss = zeros(1,12);

solarenergyyear=0;
solarcostyear=0;
solarcostmonth=zeros(1,12);

for i = 1:12
    energy_years = energy_years + energy_monthss(i);
    if ((2 < i) && (i < 11)) %summer rates are from September to April
        energy_cost_monthss(i) = energy_monthss(i)*energy_cost_summer;
         value_i_1 = i
    end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
        energy_cost_monthss(i) = energy_monthss(i)*energy_cost_winter;
         value_i_2 = i
    end
    energy_cost_years = energy_cost_years + energy_cost_monthss(i);

   solarmonth(i)=energy_months(i)-energy_monthss(i);
   solarcostmonth(i)=LEC*solarmonth(i);
   solarcostmonthf(i)=(LEC-fit)*solarmonth(i);
   solarenergyyear= solarenergyyear+solarmonth(i);
   solarcostyear=solarcostyear+solarcostmonth(i);

end

%%%%%%%%%%

billable_reactive_energy_year = 0; %kVArh
billable_reactive_energy_cost_year = 0;
billable_reactive_energy_cost_months = zeros(1,12);

for i = 1:12
    billable_reactive_energy_year = billable_reactive_energy_year + reactive_energy_months(i);
    billable_reactive_energy_cost_months(i) = billable_reactive_energy(i)*reactive_energy_cost;
    billable_reactive_energy_cost_year = billable_reactive_energy_cost_year + billable_reactive_energy_cost_months(i);

end


%determination of the monthly and the yearly demand costs
demand_cost = zeros(1,12);

demand_cost_year = 0;

for i = 1:12
   if  ((2 < i) && (i < 11)) %summer rates are from September to April
      demand_cost(i) = demand(i) * demand_cost_summer;
      demand_1 = i
   end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
       demand_cost(i) = demand(i) * demand_cost_winter;
       demand_2 = i
    end
end

%this is the determination of the max. demand through the use of the peaks
%of each month.  This should not be used according the the document on the
%electricity tariff structure.  However, it seems someone is billing wits
%by taking the max. demand for each month as the peaks for each month.
peaks_cost = zeros(1,12);


for i = 1:12
   if  ((2 < i) && (i < 11)) %summer rates are from September to April
      peaks_cost(i) = peaks(i) * demand_cost_summer;
      peaks_demand_1 = i
   end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
       peaks_cost(i) = peaks(i) * demand_cost_winter;
        peaks_demand_2 = i
    end
end

%%%%%%%%%%%%%%%solar demand

%determination of the monthly and the yearly demand costs
demand_costs = zeros(1,12);
demand_cost_years = 0;

for i = 1:12
   if  ((2 < i) && (i < 11)) %summer rates are from September to April
      demand_costs(i) = demands(i) * demand_cost_summer;
      demand_1 = i
   end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
       demand_costs(i) = demands(i) * demand_cost_winter;
       demand_2 = i
    end
end

%this is the determination of the max. demand through the use of the peaks
%of each month.  This should not be used according the the document on the
%electricity tariff structure.  However, it seems someone is billing wits
%by taking the max. demand for each month as the peaks for each month.
peaks_costs = zeros(1,12);


for i = 1:12
   if  ((2 < i) && (i < 11)) %summer rates are from September to April
      peaks_costs(i) = peakss(i) * demand_cost_summer;
      peaks_demand_1 = i
   end
    if ((i < 3) || (i > 10)) %winter rates are from May to August
       peaks_costs(i) = peakss(i) * demand_cost_winter;
       peaks_demand_2 = i
    end
end


%%%%%%Find the total cost
powercostsave=energy_cost_months-energy_cost_monthss;
demandcostsave=demand_cost-demand_costs;

for i=1:12
cfmonth(i)=solarmonth(i)/(120*24*30);
actualLEC(i)=(solarcostmonth(i)-(powercostsave(i)+demandcostsave(i)))/solarmonth(i);
actualLECf(i)=(solarcostmonthf(i)-(powercostsave(i)+demandcostsave(i)))/solarmonth(i);
end

averagecf=(sum(cfmonth))/12;
averageLEC=(sum(actualLEC))/12;
averageLECf=(sum(actualLECf))/12;

%%%%%%%%%%%%%

%computation of the total monthly bills.  The total cost per month will
%consist of the energy cost, demand charge, reactive energy charge and
%service charge
cost = zeros(1,12);
surcharge_cost = zeros(1,12);
tax = zeros(1,12);
total_cost = zeros(1,12);

for i = 1:12
    cost(i) = energy_cost_months(i) + demand_cost(i) + billable_reactive_energy_cost_months(i) + service_charge;
    surcharge_cost(i) = surcharge*cost(i);
    tax(i) = (cost(i) + surcharge_cost(i)) * 0.14;
    total_cost(i) = cost(i) + surcharge_cost(i) + tax(i);

end
```

```
%%%%%solar bill

%computation of the total monthly bills.  The total cost per month will
%consist of the energy cost, demand charge, reactive energy charge and
%service charge
costs = zeros(1,12);
surcharge_costs = zeros(1,12);

taxs = zeros(1,12);

total_costs = zeros(1,12);

total_costss= zeros(1,12);

for i = 1:12
    costs(i) = energy_cost_monthss(i) + demand_costs(i) + billable_reactive_energy_cost_months(i) + service_charge;
    surcharge_costs(i) = surcharge*costs(i);
    taxs(i) = (costs(i) + surcharge_costs(i)) * 0.14;
    total_costs(i) = costs(i) + surcharge_costs(i) + taxs(i);
          total_costss(i)=total_costs(i)+solarcostmonth(i);

total_costssf(i)=total_costs(i)+solarcostmonthf(i);
end

%%%%%%%%%%%

result=zeros(18,13);
payback=invest/(sum(total_cost)-sum(total_costs));
paybackf=invest/(sum(total_cost)-(sum(total_costs))+fit*sum(solarmonth));

result(2,2:13) = Years_of_interest;
result(3,2:13) = Months_of_interest;
result(4,2:13) = energy_months;
result(5,2:13) = peaks;
result(6,2:13) = demand;
result(7,2:13) = reactive_energy_months;
result(8,2:13) = billable_reactive_energy;
result(9,2:13)=solarmonth;
result(10,2:13)=cfmonth;

%bill
bill(2,2:13) = Years_of_interest;
bill(3,2:13) = Months_of_interest;
bill(4,2:13)=energy_cost_months;
bill(5,2:13)=energy_cost_months;
bill(6,2:13)=demand_cost;
bill(7,2:13)=demand_costs;
bill(8,2:13)=billable_reactive_energy_cost_months;
bill(9,2:13)=total_cost;
bill(10,2:13)=total_costs;
bill(11,2:13)=total_costss;
bill(12,2:13)=actualLEC;

summary=zeros(17,1);
summary(2,1)=sum(energy_months);
summary(3,1)=sum(solarmonth);
summary(4,1)=sum(total_cost);
summary(5,1)=sum(total_costss);
summary(7,1)=sum(total_cost)-sum(total_costs);
summary(6,1)=sum(total_costss)-sum(total_cost);
summary(8,1)=LEC;
summary(9,1)=averageLEC;
summary(10,1)=averagecf;
summary(11,1)=invest;
summary(12,1)=payback;
summary(14,1)=averageLECf;
summary(15,1)=sum(total_costssf)-sum(total_cost);%extra cost of solar with fit
summary(16,1)=paybackf;

success = xlswrite('C:\Users\user\Desktop\wits\joburg\1\summary.xls', summary);
success = xlswrite('C:\Users\user\Desktop\wits\joburg\1\result.xls', result);
success = xlswrite('C:\Users\user\Desktop\wits\joburg\1\bill.xls', bill);

%Hourly usage

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes(...
  'XGrid','on',...
  'XMinorTick','on',...
  'XTick',[7.33224e+005 7.333e+005 7.334e+005 7.335e+005 7.33590e+005],...
  'XTickLabel',{'01-Jul-2007','01-Oct-2007','01-Jan-2008','01-Apr-2008','01-Jul-2008'},...
  'YGrid','on',...
  'YMinorTick','on',...
  'Parent',figure1);
axis(axes1,[7.33224e+005 7.33590e+005 -200 3000]);
title(axes1,'West Campus Power Usage 2007/2008');
xlabel(axes1,'Date');
ylabel(axes1,'Power [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(...
  DateNumber,Power,...
  'Parent',axes1,...
  'DisplayName','Power',...
  'BarLayout','stacked',...
  'FaceColor',[0 0 0]);

%% Create bar
bar2 = bar(...
  DateNumber,Powers,...
  'Parent',axes1,...
  'DisplayName','Power with Solar',...
  'BarLayout','stacked',...
  'EdgeColor',[1 0 0],...
  'FaceColor',[1 0 0]);

%% Create legend
legend1 = legend(axes1,{'Power','Power with Solar'});

%%%%%%%%%%%%%day

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes(...
  'XGrid','on',...
  'XMinorTick','on',...
  'XTick',[7.33224e+005 7.333e+005 7.334e+005 7.335e+005 7.33590e+005],...
  'XTickLabel',{'01-Jul-2007','01-Oct-2007','01-Jan-2008','01-Apr-2008','01-Jul-2008'},...
  'YGrid','on',...
  'YMinorTick','on',...
  'Parent',figure1);
axis(axes1,[7.33224e+005 7.33590e+005 -200 3000]);
title(axes1,'West Campus Power Usage 2007/2008');
xlabel(axes1,'Date');
ylabel(axes1,'Power [kW]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(...
  DateNumber,Power,...
  'Parent',axes1,...
  'DisplayName','Power',...
  'BarLayout','stacked',...
  'FaceColor',[0 0 0]);

%% Create bar
bar2 = bar(...
  DateNumber,Powers,...
  'Parent',axes1,...
  'DisplayName','Power with Solar',...
  'BarLayout','stacked',...
  'EdgeColor',[1 0 0],...
  'FaceColor',[1 0 0]);

%% Create legend
legend1 = legend(axes1,{'Power','Power with Solar'});

%%%%%total bill

%% Create figure
figure1 = figure;

%% Create axes
axes1 = axes('XTickLabel',{'07/07','08/07','09/07','10/07','11/07','12/07','01/08','02/08','03/08','04/08','05/08','06/08'},'Parent',figure1);
xlim(axes1,[0.5 12.5]);
title(axes1,'West Campus Total Bill ');
xlabel(axes1,'Date');
ylabel(axes1,'Total Bill Cost [Rand]');
box(axes1,'on');
hold(axes1,'all');

%% Create bar
bar1 = bar(total_costss,...
  'Parent',axes1,...
  'BarLayout','stacked',...
'DisplayName','Solar Addition',...
  'FaceColor',[1 0 0]);

%% Create bar
bar2 = bar(total_cost,...
  'Parent',axes1,...
 'BarLayout','stacked',...
'DisplayName','Normal Bill',...
  'FaceColor',[0 0 1]);

%% Create legend
legend1 = legend(axes1,{'Solar Addition','Normal Bill'},'Position',[0.4709 0.7746 0.1511 0.08917]);
```

APPENDIX L COMPARISON MODEL

The following table is the results from the Microsoft Excel model drawn up that compares the Ecostar, Eskom and MTPP comparison under common assumptions. The development of this model is given in Section 3.2 and the LECs are compared under similar local conditions for the technology screening outlined in Section 4.1. The first four pages of tables given here are the results from the Ecostar and MTPP analysis and the last two from Eskom. As described, various scaling factors are extracted and applied to the technologies allowing for scaling. Common *DNI* assumptions are also applied. Through this, annual electricity generation can be verified and localised. Present day cost assumptions are given by applying inflating costs according to the Chemical Engineering Plant Cost Index.

COMPARISON MODEL

	PT with Thermal Oil		PTwith DSG		CLFR		CRS Salt				CRS Steam			
	given	Scaled Plant	**given**	Scaled Plant	**given**	Scaled Plant	**Given**		sf	Scaled Plant	**Given**		sf	Scaled Plant
Design Electrical Output	50	100	47	100	50	100	17	51		100	11	55		100
Solar Field														
Aperture Area of Solar Field [m2]	442035	884070.4094	448191	953598.3533	376200	752,400.35	152720	458160	1	898,352.94	93006	465032	1.00	845,514.08
Total Area of Plant[km2]	1.72	3.453128189	1.6	3.418409243	0.5643	1.13290711	0.611	1.833	1	3.594117647	0.372	1.86	1.00	3.38
	0.256997093	0.256020154	0.280119375	0.278959681	0.666666667	0.664132424	0.2499509	0.2499509	0	0.2499509	0.250016129	0.250017204	1E-06	0.250017604
Area solar field for Adjusted	306,985.69	613,971.66	311,260.92	662,257.62	261,264.41	522,529.07	106,061.41	318,184.22	0.69	623,890.63	64,591.06	322,956.71	0.69	587,194.95
Total Area of Plant[km2] Adjusted	1,194,510.34	2,398,137.99	1,111,172.41	2,374,026.28	391,896.62	786,784.46	424,328.97	1,272,986.90	694,482.76	2,496,052.74	258,347.59	1,291,737.93	694,482.76	2,348,614.42
Lenght of Single Collector [m]	150	150	150	150	1000	1,000.00	121.34	121.34	0	121.34	121.34	121.34	0.00	121.34
Focal Length [m]	2.12	2.12	2.12	2.12		-				0			#DIV/0!	#DIV/0!
Collector Row Spacing/Aperature Width	3	5.991031882	3	6.372587207		-	1259	3776	0.999758973	7402.720051	766	3776	0.99	6829.34
Average Reflectivity	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0	0.88	0.88	0.88	0.00	0.88
Optical Peak Efficiency	0.75	0.75	0.75	0.75	0.64	0.64	0.75	0.75	0	0.75	0.75	0.75	0.00	0.75
HTF Temp at entrance [C]	291	291	126	126	126	126.00	0	0		0	0	0	#DIV/0!	#DIV/0!
HTF Temp at exit [C]	391	391	411	411	411	411.00	0	0		0	0	0	#DIV/0!	#DIV/0!
Factor for Solar field Parasitics [kW/m]	0.0098	0.0098		0	0.009	0.01	0	0		0	0.116	0.0016	-2.66	0.00
design parasitics for pumping and Tracking [kW]	4332	4332	4034	4034	3386	3,386.00	2482	7445	0.999877746	14596.83757	1490	7445	1.00	13532.99
Factor for Power Block Parasitics	0.03	0.03		0	0.03	0.03	0	0		0	0	0	#DIV/0!	#DIV/0!
Operataing Mode		0		0		-	0	0		0	0	0	#DIV/0!	#DIV/0!
Heat Loss factor piping [W/m2]	0.02	0.02	0.02	0.02	0.02	0.02	-	-		#VALUE!	-	-	#VALUE!	#VALUE!
Concentrator efficiency	54.20%	0.542	54.20%	0.542	42.20%	0.42	61.00%	61.00%	0	0.61	57.00%	57.00%	0.00	0.57
Efficiency loss due to parasitics	90.80%	0.908	89.90%	0.899	90.90%	0.91	85.00%	85.00%	0	0.85	96.00%	96.00%	0.00	0.96
Power Block Design														
Design net Electrical Otput [kW]	50000	100000	47000	100000	50000	100,000.00	17000	51000	1	100000	11000	55000	1.00	100000.00
Design Efficiency of Power Block	0.375	0.375	26%	0.26	39%	0.39	38%	38%	0	0.38	30%	30%	0.00	0.30
Storage Capacity [h]	3	3	0	0	0	-	3	3	0	3	0.4	0.4	0.00	0.40
Thermal Capacity of the Storage [kWh]	434656	869312	0	0	0	-	153803	461409	1	904723.5294	14718	73590	1.00	133800.00
HTF temp in Storage Discharging [C]	371	371	0	0	0	-	560	560	0	560	260	260	0.00	260.00
Efficiency Factor dur to lower storage fluid Temp	0.975	0.975	0	0	0	-	0.997	0.997	0	0.997	0.8	0.8	0.00	0.80
overall Plant Availibility	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0	0.96	0.96	0.96	0.00	0.96
Power Block Efficiency (incl. availibility and dumping)	35.30%	0.353	23%	0.228	32.80%	0.33	33%	33%	0	0.33	28%	28%	0.00	0.28
Storage Efficiency	94.70%	0.947	100%	1	100%	1.00	95%	95%	0	0.95	100%	100%	0.00	1.00
Receiver														
design solar thermal input tp receiver	-		-		-		73993	221979	1	435252.9412	45062	225308	1.00	409649.56
Max. Temp at receiver exit	-		-		-		565	565	0	565	260	260	0.00	260.00
Receiver/Piping Efficiency	85.10%	0.851	89.20%	0.892	83.80%	0.84	84.00%	84%	0	0.84	88%	88%	0.00	0.88

O&M Input														
Labour costs per employee	67,087.06	67087.06457	67,087.06	67087.06457	67,087.06	67,087.06	67,087.06	67,087.06	0	67087.06457	67,087.06	67,087.06	0.00	67087.06
Specific number of persons for field maintenance [/m2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0	0.03	0.03	0.03	0.00	0.03
number of persons	30	30	30	30	30	30.00	30	30	0	30	30	30	0.00	30.00
number of persons for field maintenance	13	26.15096914	13	27.83456202	7.5	15.09	4.6	13.7	0.993380049	26.74327068	2.8	14	1.00	25.45
O&M Equipment cost percentage of investment[per a]	1%	0.01	1%	0.01	1%	0.01	1%	1%	0	0.01	1%	1%	0.00	0.01
power block O&M fix [*/kW]	27.00	27	27.00	27	27.00	27.00	27.00	27.00	0	27	27.00	27.00	0.00	27.00
powerblock O&M Variable[*/MWh]	2.50	2.5	2.50	2.5	2.50	2.50	2.50	2.50	0	2.5	2.60	2.60	0.00	2.60
Water Costs		0		0		-				0	1.3	1.3	0.00	1.30
Investment														
Specific Investment cost for Solar Field (*/m2)	287.92	277.9502128	265.55	255.5570116	167.72	161.91	209.65	198.47	-0.049888607	191.9097236	209.65	192.88	-0.05	186.99
Specific Investment cost for Power Block [*/kWel]	978.35	931.8099781	607.98	576.5393333	978.35	931.81	1,048.24	969.97	-0.070635698	924.9133283	888.90	793.86	-0.07	761.21
Specific Land Cost [*/m2]	2.80	2.795294357	2.80	2.795294357	2.80	2.80	2.80	2.80	0	2.795294357	2.80	2.80	0.00	2.80
Specific Investment Storage[*/kWhth]	43.33	41.31959751	0.00	0	0.00	-	19.57	18.17	-0.067455983	17.36260012	139.76	124.39	-0.07	119.12
Total investment cost for tower	0.00	0	0.00	0	0.00	-	2,795,294.36	7,765,158.61	0.930000034	14524797.19	2,795,294.36	12,487,331.83	0.93	21773705.84
Specific investment cost for receiver [*/kWh]	0.00	0	0.00	0	0.00	-	174.71	162.13	-0.068016303	154.8693751	153.74	136.97	-0.07	131.22
Surcharge for Construction, engineering and Contingencies %	20%	0.2	20%	0.2	20%	0.20	20%	20%	0	0.2	20%	20%	0.00	0.20
	PT with Thermal Oil		**PTwith DSG**		**CLFR**		**CRS Salt**				**CRS Steam**			
Financial Parameters		0		0		-			#DIV/0!	#DIV/0!			#DIV/0!	#DIV/0!
Annual Insurance	1%	0.01	1%	0.01	1%	0.01	1%	1%	0	0.01	1%	1%	0.00	0.01
Lifetime	30	30	30	30	30	30.00	30	30	0	30	30	30	0.00	30.00
Debt Interest Rate	8%	0.08	8%	0.08	8%	0.08	8%	8%	0	0.08	8%	8%	0.00	0.08
Economic Results														
Fixed Charge Rate	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%
Investment Solar Field	88,385,881.70	170653552.6	119018448.5	243698745.4	63,095,384.23	121,823,205.99	32017301.57	90929136.45	0.950111393	172402664.7	19498436.02	89693191.46	0.95	158105222.66
Investment Power Block, BOP	54,623,839.36	104073489.9	31,884,551.64	64347148.53	53,698,177.63	102,309,848.87	20,956,186.22	58,215,012.72	0.92999996	108891685.7	10,203,653.21	45,582,465.35	0.93	79480486.27
Investment receiver	0	0	0	0	0	-	12,926,985.51	35,910,382.09	0.929999994	67170682.45	6,927,829.58	30,948,480.24	0.93	53963739.39
Investment Tower	0	0	0	0	0	-	2,795,294.36	7,765,158.61	0.930000034	14,524,797.19	2,795,294.36	12,487,331.83	0.93	21,773,705.84
Investment Storage	18,832,367.69	35919632.89	0	0	0	-	3009472.606	8383530.831	0.932544017	15708352.86	2057057.117	9153904.172	0.93	15938382.14
Investment Land	3,339,008.03	6,703,501.59	3,106,053.98	6,636,102.27	1,095,466.41	2,199,294.16	1,186,124.36	3,558,373.09	1	6,977,202.13	722,157.55	3,610,787.75	1.00	6,565,068.64
Contingencies	33,036,219.36	63356045.75	30801810.81	62606376.93	23577805.65	45,216,933.50	14578272.92	40952318.76	0.940164405	77127740.43	8440885.567	38295232.16	0.94	67158592.71
Sum Total Equipment Costs	165,181,096.78	316780228.8	154009054.1	313031884.7	117889028.3	226,084,667.51	72891364.62	204761593.8	0.940164405	385638702.1	42204427.84	191476160.8	0.94	335792963.57
Total Including indirect Costs	198,217,316.14	380136274.5	184810864.9	375638261.6	141466833.9	271,301,601.01	87469637.55	245713912.5	0.940164405	462766442.6	50645313.4	229771393	0.94	402951556.28
Specific Investment	3964.346323	3801.362745	3932.146061	3756.382616	2829.336679	2,713.02	5145.272797	4817.919854	-0.059835595	4627.664426	4604.1194	4177.66169	-0.06	4029.52
Actual O&M Costs	5,595,466.50	16,186,704.95	4,912,908.73	15,995,173.62	4,083,448.46	11,552,380.72	3,959,377.92	7,713,438.67	0.607017758	19,705,206.71	3,040,029.37	6,957,192.75	0.51	17,158,209.80
O&M %	0.028	0.02	0.027	0.019984997	0.029	0.02	0.045	0.031	-0.333146647	0.02508397	0.060	0.030	-0.43	0.02
Annual Financing & insurance Costs	19589308.61	37567892.35	18264383.44	37123365.28	13980804.11	26,812,040.90	8,644,399.78	24283275.32	0.940164405	45734019.78	5005146.337	22707717.03	0.94	39822668.09
Annual Fuel Costs	0.00	0	0.00	0	0.00	-	0.00	0.00	#DIV/0!	0	0.00	0.00	#DIV/0!	0.00
O&M Cost/ kWh	0.04	0.033110923	0.06	0.039499858	0.05	0.04	0.08	0.05	-0.393408136	0.0397111	0.12	0.05	-0.48	0.04
Actual Net Elec	124,670,469.84	249407794.7	89,299,577.41	190054593.1	80,034,878.80	160,112,676.63	49,655,503.38	149,036,226.66	1.000425893	292311710.5	25,454,157.82	127,065,290.07	1.00	230889164.66
Solar Net Electricity(Adjusted)	124,639,444.16	249,279,003.76	89,450,192.02	190,319,653.49	79,886,327.05	159,772,728.08	41,997,261.61	125,991,784.82	1	247,042,715.34	25,255,572.93	126,278,407.75	1.00	229597471.79
Fossil net Electricity(actual)Seville	0.00	0.00	0.00	0.00	0.00	0.00	7,658,241.78	23,044,441.83	0.00	45,268,995.15	0.00	0.00	-0.00	0.00
Total Calculated Enet	124,639,444.16	249,279,003.76	89,450,192.02	190349720.2	79,886,327.05	159,772,728.08	49,655,503.38	149,036,226.66	1.000425893	292311710.5	25,255,572.93	126,278,407.75	1.00	229597471.79
Calculated LEC Adjusted	0.202	0.216	0.259	0.279	0.226	0.240	0.300	0.254	-0.1519878	0.26489033	0.319	0.235	-0.19	0.248
									#DIV/0!				#DIV/0!	#DIV/0!
Actual Capacity Factor	29.00%	29.00%	22.00%	22.00%	18.30%	18.30%	33.00%	33.00%	0	33.00%	26.00%	26.00%	0.00	26.00%
total capacity	28.46%	28.46%	21.73%	21.73%	18.24%	18.24%	33.34%	33.36%	0.01%	33.37%	26.21%	26.21%	0.01%	26.21%
solar capacity factor for joburg	28.46%	28.46%	21.73%	21.73%	18.24%	18.24%	28.20%	28.20%	0.01%	28.20%	26.21%	26.21%	0.01%	26.21%
Specific Investment Rand	51,904.39	49,770.48	51,482.80	49,181.57	37,043.94	35,520.98	67,366.03	63,080.06	-0.78	60,589.08	60,280.81	54,697.29	-0.79	52,757.64
LEC Rand	2.65	2.82	3.39	3.65	2.96	3.14	3.93	3.33		3.47	4.17	3.08		3.25

	CRS Air Given		sf	Scaled Plant	CRS Hybrid Given		sf	Scaled Plant	Dish stirling given	Scaled Plant	MTPP given	Scaled Plant	Average Scaling Factor	
Design Electrical Output	10	50		100	14.683	58.732		100	50	100	1	100		
Solar Field														
Aperture Area of Solar Field [m2]	104580	522900	1.00	1,045,800.00	38000	152000	1.00	258,802.70	350000	700,000.32	27182.52234	2,718,260.60	1.00	
Total Area of Plant[km2]	0.418	2.092	1.00	4.19	0.432	1.78	1.02	3.07	1.4	2.81		-	1.01	
	0.250191388	0.249952199	9.99406E-07	0.249849256	0.087962963	0.085393258		0.084426835	0.25	0.249049659				
Area solar field for Adjusted	72,629.01	363,145.03	0.69	726,290.07	26,390.34	105,561.38	0.69	179,734.01	243,068.97	486,138.16	18,877.79	1,887,785.12		0.69
Total Area of Plant[km2] Adjusted	290,293.79	1,452,857.93	694,895.49	2,906,913.07	300,016.55	1,236,179.31	709,335.67	2,128,873.02	972,275.86	1,951,972.78	-	-		698,299.17
Lenght of Single Collector [m]	121.34	121.34	0.00	121.34	121.34	121.34	0.00	121.34	120.4	120.40		-	0.00	
Focal Length [m]				0.00				0.00		-		-	0.00	
Collector Row Spacing/Aperature Width	862	4309	1.00	8,617.14	313	1253	1.00	2,134.07	2907	5,805.31		-	1.00	
Average Reflectivity	0.88	0.88	0.00	0.88	0.88	0.88	0.00	0.88	0.88	0.88	0.9	0.90	0.00	
Optical Peak Efficiency	0.75	0.75	0.00	0.75	0.75	0.75	0.00	0.75	0.75	0.75	0.78	0.78	0.00	
HTF Temp at entrance [C]	0	0		0.00	0	0	0	0	0	-		-	0.00	
HTF Temp at exit [C]	0	0		0.00	0	0	0	0	0	-		-	0.00	
Factor for Solar field Parasitics [kW/m]	0.0065	0.0065	0.00	0.01	0	0	0	0	0	-		-	0.00	
design parasitics for pumping and Tracking [kW]	680	3399	1.00	6,797.14	0	0	0	0	0	-		-	0.00	
Factor for Power Block Parasitics	0.03	0.03	0.00	0.03	0	0	0	0	0	-		-	0.00	
Operataing Mode	0	0			0	0	0	0	0	-		-	0.00	
Heat Loss factor piping [W/m2]	-	-			-	-			-			-	0.00	
Concentrator efficiency	61.00%	61.00%	0.00	0.61	50.90%	50.90%	0.00	0.51	88.00%	0.88	44.00%	0.44	0.00	
Efficiency loss due to parasitics	93.00%	93.00%	0.00	0.93	100.00%	100.00%	0.00	1.00	100.00%	1.00	100.00%	1.00	0.00	
												-		
Power Block Design														
Design net Electrical Otput [kW]	10000	50000	1.00	100,000.00	14683	58732	1.00	100,000.00	50000	100,000.00	1000	100,000.00	1.00	
Design Efficiency of Power Block	34%	34%	0.00	0.34	45%	45%	0.00	0.45	21%	0.21		-	0.00	
Storage Capacity [h]	3	3	0.00	3.00	0	0	0.00	0.00	0	-	12	12.00	0.00	
Thermal Capacity of the Storage [kWh]	94233	471166	1.00	942,332.86	0	0	0.00	0.00	0	-		-	1.00	
HTF temp in Storage Discharging [C]	650	650	0.00	650.00	0	0	0.00	0.00	0	-		-	0.00	
Efficiency Factor dur to lower storage fluid Temp	0.985	0.985	0.00	0.99	0	0	0.00	0.00	0	-		-	0.00	
overall Plant Availibility	0.96	0.96	0.00	0.96	0.96	0.96	0.00	0.96	0.96	0.96	0.99	0.99	0.00	
Power Block Efficiency (incl. availibility and dumping)	31%	31%	0.00	0.31	40%	40%	0.00	0.40	21.30%	0.21	22.50%	0.23	0.00	
Storage Efficiency	100%	100%	0.00	1.00	100%	100%	0.00	1.00	100%	100%	97.00%	0.97	0.00	
									0.5631	0.56		-		
												-		
Receiver														
design solar thermal input tp receiver	50669	253345	1.00	506,690.00	18500	74000	1.00	125,996.05	233125	466,249.55		-	1.00	
Max. Temp at receiver exit	680	680	0.00	680.00	800	800	0.00	800.00	800	800.00		-	0.00	
Receiver/Piping Efficiency	77%	77%	0.00	0.77	93.80%	93.80%	0.00	0.94	89.20%	0.89	88.00%	0.88	0.00	

O&M Input														
Labour costs per employee	67,087.06	67,087.06	0.00	67,087.06	67,087.06	67,087.06	0.00	67,087.06	67,087.06	67,087.06		-	0.00	
Specific number of persons for field maintenance [/m2]	0.03	0.03	0.00	0.03	0.03	0.03	0.00	0.03	0.06	0.06		-	0.00	
number of persons	30	30	0.00	30.00	30	30	0.00	30.00	30	30.00		-	0.00	
number of persons for field maintenance	3.1	15.7	1.01	31.57	1.1	4.6	1.03	7.97	21	42.24		-	1.01	
O&M Equipment cost percentage of investment[per a]	1%	1%	0.00	0.01	1%	1%	0.00	0.01	2%	0.02		-	0.00	
power block O&M fix [*/kW]	27.00	27.00	0.00	27.00	27.00	27.00	0.00	27.00	40.00	40.00		-	0.00	
powerblock O&M Variable[*/MWh]	2.50	2.50	0.00	2.50	2.50	2.50	0.00	2.50	4.50	4.50		-	0.00	
Water Costs	1.30	1.30	0.00	1.30						-		-	1.00	
Investment														
Specific Investment cost for Solar Field (*/m2)	209.65	192.88	-0.05	186.07	209.65	195.67	-0.05	190.56	614.96	593.68	195.62	154.80	-0.05	
Specific Investment cost for Power Block [*/kWel]	838.59	749.14	-0.07	713.62	978.35	887.51	-0.07	854.92	4,192.94	3,993.47	1,662.76	1,202.79	-0.0703	
Specific Land Cost [*/m2]	2.80	2.80	0.00	2.80	2.80	2.80	0.00	2.80	2.80	2.80	0.00	-	0.00	
Specific Investment Storage[*/kWhth]	83.86	75.47	-0.07	72.12	0.00	0.00		0.00	0.00	-	17.21	12.56	-0.07	
Total investment cost for tower	2,795,294.36	12,487,331.83	0.93	23,791,813.60	2,795,294.36	10,147,132.36	0.93	16,645,228.63	0.00	-	0.00	-	0.93	
Specific investment cost for receiver [*/kWh]	160.73	143.96	-0.07	137.28	209.65	190.08	-0.07	183.06	167.72	159.80	0.00	-	-0.07	
Surcharge for Construction, engineering and Contingencies %	20%	20%	0.00	0.20	20%	20%	0.00	0.20	20%	0.20	0.10	0.10	0.00	
	CRS Air				**CRS Hybrid**				**Dish stirling**		0.00	-		
Financial Parameters										-	0.00	-		
Annual Insurance	1%	1%	0.00	0.01	1%	1%	0.00	0.01	1%	0.01	0.00	-	0.00	
Lifetime	30	30	0.00	30.00	30	30	0.00	30.00	30	30.00	0.00	-	0.00	
Debt Interest Rate	8%	8%	0.00	0.08	8%	8%	0.00	0.08	8%	0.08	0.00	-	0.00	
Economic Results											0.00			
Fixed Charge Rate	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	9.88%	
Investment Solar Field	21924891.29	100854499.9	0.95	194,594,043.37	7966588.918	29741931.96	0.95	49,316,447.41	215237665.5	415,576,238.75	5,317,421.61	420,790,865.86	0.95	
Investment Power Block, BOP	9,207,590.60	41,132,784.42	0.93	78,369,307.16	14,365,157.47	52,146,622.95	0.93	85,540,667.68	209,647,076.78	399,435,543.00	0.00	-	0.93	
Investment receiver	8,144,000.66	36,381,442.30	0.93	69,316,689.27	3,878,470.92	14,079,147.14	0.93	23,095,256.99	39,099,179.82	74,494,729.70	0.00	-	0.93	
Investment Tower	2,795,294.36	12,487,331.83	0.93	23,791,813.60	2,795,294.36	10,147,132.36	0.93	16,645,228.63	0.00	0.00	0.00		0.93	
Investment Storage	7902269.194	35560286.85	0.93	67,965,570.96	0	0			0	-	0.00	-	0.93	
Investment Land	811,456.60	4,061,165.58	1.00	8,125,677.70	838,634.57	3,455,485.05	1.02	5,950,826.74	2,717,797.23	5,456,338.50	0.00	0.00	1.00	
Contingencies	10157100.54	46095502.18	0.94	88,422,982.16	5968829.247	21914063.89	0.94	36,104,167.38	93340343.86	179,005,806.71	0.00	-	0.94	
Sum Total Equipment Costs	50785502.7	230477510.9	0.94	442,114,910.78	29844146.23	109570319.5	0.94	180,520,836.92	466701719.3	895,029,033.53	0.00	-	0.94	
Total Including indirect Costs	60942603.24	276573013.1	0.94	530,537,892.94	35812975.48	131484383.3	0.94	216,625,004.31	560042063.2	1,074,034,840.23	7,544,051.77	570,784,354.38	0.94	
Specific Investment	6094.260324	5531.460262	-0.06	5,305.38	2439.077537	2238.717962	-0.06	2,166.25	11200.84126	10,740.35	7,544.05	5,707.84	-0.06	
Actual O&M Costs	3,263,226.63	8,142,225.65	0.57	22,591,004.63	3,352,459.42	7,253,001.98	0.56	9,224,178.97	16,004,790.48	45,733,822.92	113,125.41	8,559,089.32	0.56	
O&M %	0.054	0.029	-0.37	0.023	0.094	0.055	-0.38	0.05	0.029	0.02	0.015	0.015	-0.38	
Annual Financing & insurance Costs	6022801.062	27333001.03	0.94	52,431,698.27	3539304.449	12994264.14	0.94	21,408,493.18	55347519.69	106,144,106.63	745,559.27	56,409,152.76	0.94	
Annual Fuel Costs	0.00	0.00	#DIV/0!	0.00	3,013,613.83	12,054,455.34	1.00	20,524,510.21	13,827,816.63	27,655,633.27	0.00	-	1.00	
O&M Cost/ kWh	0.11	0.06	-0.43	0.04	0.05	0.03	-0.44	0.02	0.07	0.05	0.02	0.00	-0.44	
Actual Net Elec	28,498,432.62	142,885,841.65	1.00	286,111,449.37	70,901,245.14	283,766,613.30	1.00	483,260,721.69	217,171,191.09	434,458,841.14	4,626,353.57	463,460,118.67	1.00	
Solar Net Electricity(Joburg)	28,521,562.00	142,607,810.02	1.00	285,215,620.04	14,615,836.46	58,463,345.83	1.00	99,542,576.16	117,856,798.75	235,713,706.65	4,626,353.57	462,636,780.49	1.00	
Fossil net Electricity(actual)Seville	0.00	0.00	0.00	0.00	56,285,408.69	225,303,267.47	0.00	383,718,145.53	99,314,392.34	198,745,134.49	0.00	0.00	0.00	
Total Calculated Enet	28,521,562.00	142,607,810.02	1.00	285,215,620.04	70,901,245.14	283,766,613.30	1.00	483,260,721.69	217,171,191.09	434,458,841.14	4,626,353.57	462,636,780.49	1.00	
Calculated LEC Joburg	0.326	0.249	-0.17	0.263	0.140	0.114	-0.15	0.106	0.392	0.413	0.186	0.140	-0.16	
													#DIV/0!	
Actual Capacity Factor	33.00%	33.00%	0.00	33.00%	11.00%	11.00%	0.00	0.11	22.00%	22.00%	53.00%	53.00%	0.00	
total capacity	32.56%	32.56%	0.01%	32.56%	55.12%	55.15%	0.01%	55.17%	49.58%	49.60%	52.81%	52.81%	0.01%	
solar capacity factor for joburg	32.56%	32.56%	0.01%	32.56%	11.36%	11.36%	0.01%	11.36%	26.91%	26.91%	52.81%	52.81%	0.01%	
Specific Investment Rand	79,790.93	72,422.30	-0.79	69,462.27	31,934.35	29,311.09	-0.81	28,362.28	146,650.37	140,621.23	98,772.76	74,731.65		-0.79
LEC Rand	4.26	3.26		3.44	1.83	1.49		1.39	5.14	5.41	2.43	1.84		-2.15

Paraboli DISH

ESKOM	sf	PT Only			PT Hybrid			PT with Salt Storage		
Project		**pilot**	**future**	**Scaled**	**pilot**	**future**	**Scaled**	**pilot**	**future**	**Scaled**
Plant Size [Mwe]		100	200	100	100	200	100	100	200	100
Solar Field [m2 x1000]	**1**	589	1086	589	589	1086	589	831	2184	831
Adjusted solar Field	**1**	589.00	1,086.00	589.00	589.00	1,086.00	589.00	831.00	2,184.00	831.00
				0%			0			0
Thermal Storage[hrs]	**1**	0	0	0%	0	0	0	4	10	4
Annual Solar CF	**1**	25%	25%	25%	25%	25%	0.25	35%	50%	0.35
Annual Solar/Elec %	**1**	14%	15%	15%	14%	15%	0.138	14%	15%	0.136
Solar Fraction %	**1**	100%	100%	100%	75%	75%	0.75	100%	100%	1
							0			0
Capital Cost [euroM]							0			0
Infrastructure	**0.94**	9.55	8.19	9.553792528	9.55	8.19	9.553792528	12.28	12.28	12.28344754
Solar Field	**0.95**	165.14	173.33	165.144128	165.14	173.33	165.144128	223.83	323.46	223.8317107
Adjusted Solar Field Cost	**0.95**	165.14	173.33	165.144	165.14	173.33	165.14	223.83	323.46	223.83
Tower/Receiver	**0.93**	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
HTF System	**0.93**	15.01	17.74	15.01310254	34.12	38.22	34.1206876	16.38	20.47	16.37793005
Storage	**0.93**	0.00	0.00	0	0.00	0.00	0	43.67	68.24	43.67448013
Adjusted Storage	**0.93**	-	-	-	-	-	-	43.67	68.24	43.67
Power Block	**0.93**	46.40	45.04	46.40413514	46.40	45.04	46.40413514	46.40	45.04	46.40413514
Balance of Plant	**0.94**	27.30	25.93	27.29655008	27.30	25.93	27.29655008	27.30	25.93	27.29655008
Services	**0.94**	25.93	16.38	25.93172258	28.66	17.74	28.66137758	36.85	30.03	36.85034261
Land	**1.00**	1.36	2.73	1.364827504	1.36	2.73	1.364827504	1.36	5.46	1.364827504
Contingencies	**0.94**	43.67	15.01	43.67448013	46.40	15.01	46.40413514	61.42	25.93	61.41723768
Total	**0.94**	334.38	304.36	334.38	358.95	326.19	358.95	469.50	556.85	469.50
Unit Cost [euro/kW]	-0.06	3343.827385	1521.782667	3343.827385	3589.496336	1630.968867	3589.496336	4695.006614	2784.248108	4695.006614
Solar Field Cost [euro/m2]		280.3805229	159.6068996	280.3805229	280.3805229	159.6068996	280.3805229	269.3522391	148.1062813	269.3522391
O&M Cost [EuroM/year]		6.68765477	6.087130668	6.68765477	7.178992671	6.523875469	7.178992671	9.390013228	11.13699243	9.390013228
Electricity Produced [kWh]		219000000	438000000	219000000	219000000	438000000	219000000	306600000	876000000	306600000
Electricity Produced [kWh] using given LEC	**1**	218,465,414	423,632,933	218465413.8	242,773,537	467,581,199	242773537.3	319,796,180	906,446,327	319796180.1
		218,465,413.75	423,632,932.76	218,465,413.75	242,773,537.26	467,581,198.99	242,773,537.26	319,796,180.13	906,446,326.90	319,796,180.13
O&M [R/kWh]		0.03	0.01	0.03	0.03	0.01	0.03	0.03	0.01	0.03
LEC [Euro/kWh] using given Enet	**-0.16**	0.1819	0.0854	0.1819	0.1757	0.0829	0.1757	0.1745	0.0730	0.1745
LEC Rands		2.381279697	1.117743531	2.381279697	2.300283789	1.085345168	2.300283789	2.284084607	0.955751715	2.284084607
		43780.06319	19924.3961	43780.06319	46996.55762	21353.94919	46996.55762	61470.78259	36453.60363	61470.78259

ESKOM	sf	PT with DSG			ISCCS			CLFR Coal		
Project		**pilot**	**future**	**Scaled**	**pilot**	**future**	**Scaled**	**pilot**	**future**	**Scaled**
Plant Size [Mwe]		100	200	100	30	100	100	30	100	100
Solar Field [m2 x1000]	**1**	536	994	536	170	942	566.6666667	196	667	653.3333333
Adjusted solar Field	**1**	536.00	994.00	536.00	170.00	942.00	566.67	196.00	667.00	653.33
				0			0			0
Thermal Storage[hrs]	**1**	0	0	0	0	10	0	0	0	0
Annual Solar CF	**1**	25%	25%	0.25	27%	52%	25%	25%	26%	25%
Annual Solar/Elec %	**1**	15%	16%	0.151	16%	18%	0.516666667	13%	13%	0.416666667
Solar Fraction %	**1**	100%	100%	1	100%	80%	3.333333333			0
				0			0			
Capital Cost [euroM]				0			0			
Infrastructure	**0.94**	9.55	8.19	9.553792528	6.82	8.19	21.14743431			
Solar Field	**0.95**	156.96	165.14	156.955163	55.96	152.86	175.4563262			
Adjusted Solar Field Cost	**0.95**	156.96	165.14	156.96	55.96	152.86	175.46	-	-	-
Tower/Receiver	**0.93**	0.00	0.00	0	0.00	0.00	0			
HTF System	**0.93**	1.36	2.73	1.364827504	0.00	1.36	0			
Storage	**0.93**	0.00	0.00	0	0.00	28.66	0			
Adjusted Storage	**0.93**	-	-	-	-	28.66	-	-	-	-
Power Block	**0.93**	46.40	45.04	46.40413514	5.46	8.19	16.72688189	0.00		
Balance of Plant	**0.94**	27.30	25.93	27.29655008	0.00	0.00	0	0.00		
Services	**0.94**	24.57	15.01	24.56689507	6.82	12.28	21.14743431	0.00		
Land	**1.00**	1.36	2.73	1.364827504	0.00	2.73	0	0.00		
Contingencies	**0.94**	39.58	13.65	39.57999762	12.28	10.92	38.06538175	0.00		
Total	**0.94**	307.09	278.42	307.09	87.35	225.20	272.54	0.00	0.00	0.00
Unit Cost [euro/kW]	-0.06	3070.861884	1392.124054	3070.861884	2911.632009	2251.965382	2725.434584	1,364.83	777.95	1270.173618
Solar Field Cost [euro/m2]		292.8267966	166.1409738	292.8267966	329.1642804	162.2724846	309.6288109	0	0	0
O&M Cost [EuroM/year]		6.141723768	5.568496217	6.141723768	1.746979205	4.503930763	5.450869168	0	0	0
Electricity Produced [kWh]		219000000	438000000	219000000	70956000	455520000	219000000	65700000	227760000	219000000
Electricity Produced [kWh] using given LEC	**1**	216,859,050	417,815,104	216859050.4	71,093,830	480,623,910	236979431.9	66,650,465	226,409,611	19995139.56
		216,859,050.42	417,815,103.81	216,859,050.42	71,093,829.56	480,623,910.26	236,979,431.87	66,650,465.21	226,409,610.62	19,995,139.56
O&M [R/kWh]		0.03	0.01	0.03	0.02	0.01	0.02	-	-	-
LEC [Euro/kWh] using given Enet	**-0.16**	0.1683	0.0792	0.1683	0.1460	0.0557	0.1367	0.0730	0.0408	0.059915316
LEC Rands		2.203088699	1.036747623	2.203088699	1.91150343	0.728963172	1.789263732	0.955751715	0.534572993	0.784459243
		40206.18048	18226.80182	40206.18048	38121.41556	29484.53235	35683.56992	17869.41354	10185.56572	16630.12915

						POWER TOWER							**DISH STIRLING**			**DISH STIRLING**		**SCOT**		**CHIMNEY**	
	Molten Salt							**PHOEBUS**													
ESKOM	**Solar Only**					**Hybrid**		**Solar Only**			**Hybrid**										
Project	**near term**	**mid term**	**Long Term**	**Long Term**	**Scaled**	**Mid Term**	**Scaled**	**near term**	**mid term**	**Scaled**	**Long Term**	**Scaled**	**Short Term**	**Long term**	**Scaled**	**Short Term**	**Scaled**		**Scaled**	**Pilot**	Scaled
Plant Size [Mwe]	30	100	200	200	100	100	100	10	30	100	100	100	1	100	100	1	100	34	100	5	100
Solar Field [m2 x1000]	275	826	1490	2477	916.6666667	1350	1350	80.5		805					0		0		0		0
Adjusted solar Field	275.00	826.00	1,490.00	2,477.00	916.67	1,350.00	1,350.00	80.50	-	805.00	-	-	-	-	-	-	-	-	-	-	-
					0		0			0									0		
Thermal Storage[hrs]	6.5	6.5	6.5	13	6.5	13	13	1	3	10	8								0		0
Annual Solar CF	40%	41%	44%	74%	41%	19%	0.188	22%	40%	22%	38%	38%						24%	0.705882353	32%	6.40
Annual Solar/Elec %					0		0												0		-
Solar Fraction %					0		0												0		-
					0		0												0		-
Capital Cost [euroM]					0		0												0		-
Infrastructure	4.78	8.19	13.65	13.65	14.80320401	10.92	10.91862003											0.00	0	4.09	68.30
Solar Field	45.04	110.41	142.35	236.66	141.2209454	180.16	180.1572305											51.45	143.2620553	20.06	344.60
Adjusted Solar Field Cost	45.04	110.41	142.35	236.66	141.22	180.16	180.16	-	-	-	-	-	-	-	-	-	-	51.45	143.26	20.06	344.60
Tower/Receiver	24.57	34.12	51.86	68.24	75.27097012	47.77	47.76896264											23.88	65.13890146	15.42	250.10
HTF System	7.23	15.01	23.20	23.20	22.1631185	15.01	15.01310254											33.57	91.56668255	0.00	-
Storage	17.20	32.76	51.86	81.89	52.68967813	60.05	60.05241018											0.00	0	0.00	-
Adjusted Storage	17.20	32.76	51.86	81.89	52.69	60.05	60.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Power Block	38.22	77.80	113.28	113.28	117.0881732	38.22	38.21517011											5.60	15.26111376	8.46	137.22
Balance of Plant	4.78	8.19	13.65	12.83	14.80320401	10.92	10.91862003											0.00	0	0.00	-
Services	13.65	27.84	39.58	54.46	42.29486861	35.21	35.2125496											0.00	0	0.00	-
Land	0.00	0.00	0.00	0.00	0	0.00	0											0.00	0	0.00	-
Contingencies	22.66	45.99	65.38	88.58	70.2094819	58.14	58.14165167											12.97	35.72283072	1.50	25.04
Total	178.11	360.31	514.81	692.79	550.54	456.40	456.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.38	0.00	127.47	350.95	49.54	825.26
Unit Cost [euro/kW]	5936.999643	3603.144611	2574.064673	3463.932205	5505.436439	4563.983174	4563.983174	4,599.47	5,627.64	4008.758833	4,546.24	4008.758833	4,094.48	1,637.79	3110.30907	16,377.93	12441.23628	3749.261438	3509.515838	9908.647679	8252.647445
Solar Field Cost [euro/m2]	163.7793005	133.6737834	95.53792528	95.54343529	154.0592132	133.4498004	133.4498004									0.00	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
																0.00	0				
O&M Cost [EuroM/year]	3.562199786	7.206289221	10.29625869	13.85572882	11.01087288	9.127966347	9.127966347	0	0	0	#REF!	0	0	0	0	0.00	0	2.549497778	7.019031676	0.990864768	16.50529489
Electricity Produced [kWh]	105120000	359160000	770880000	1296480000	359160000	164688000	164688000	19272000	105382800	192720000	335508000	335508000	0	0	0	0	0	71481600	618352941.2	14016000	5606400000
Electricity Produced [kWh] using given LEC	97,923,909	352,275,480	789,054,098	1,358,854,874	326,413,029.96	611,203,809	611203809	20,078,958	101,340,644	200789575.7	363,854,147	200789575.7	363854146.6	200789575.7	363854146.6	200789575.7	20078957573	81,618,679	240054937	14,869,302	297,386,044.47
	97,923,908.99	352,275,479.68	789,054,097.68	1,358,854,873.55	326,413,029.96	611,203,809.00	611,203,809.00	20,078,957.57	101,340,643.81	200,789,575.73	363,854,146.61	200,789,575.73	363,854,146.61	200,789,575.73	363,854,146.61	200,789,575.73	200789575.7	81,618,678.58	240,054,937.00	14,869,302.22	297,386,044.47
O&M [R/kWh]	0.04	0.02	0.01	0.01	0.03	0.01	0.01	-	-	-	#REF!	-	-	-	-	-	-	0.03	0.03	0.07	0.06
LEC [Euro/kWh] using given Enet	0.2161	0.1215	0.0775	0.0606	0.2004	0.0887	0.0887	0.2722	0.1980	0.186569232	0.1485	0.148471052	0.2475	0.0990	0.116252993	0.8649	0.406311893	0.1856	0.1737	0.3959	0.3298
LEC Rands	2.829754677	1.591287049	1.015060483	0.793186937	2.624058523	1.161735426	1.161735426	3.563819954	2.591869058	2.442713641	1.943901793	1.943901793	3.239836322	1.295934529	1.522077181	11.32344208	5.319760349	2.429877241	2.27449934	5.183738115	4.317396732
	77731.94892	47175.25176	33701.71395	45352.57158	72081.57821	59755.31889	59755.31889	60219.92365	73681.54852	52485.87765	59523.01652	52485.87765	53608.24063	21443.29625	40722.65459	214432.9625	162890.6184	49088.33015	45949.38897	129731.9423	108050.2625