Khi Solar One Project Overview and Economic Analysis

by

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Submitted to the Department of Electrical Engineering, Electronics,
Computers and Systems
in partial fulfillment of the requirements for the degree of
Master of Science in Electrical Energy Conversion and Power Systems
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Abstract

With one of the largest coal reserves in the world, South Africa had, in 2009, an energy mix of 95% based on coal. There was no energy plan adjusted to the economic growth, so the reserve margin of the electrical system began to evolve unfavorably by the growth of the country getting to be 11.6% since 2009, far below of the 15% recommended by the best international practices. The Integrated Resources Plan for Electricity 2010 - 2030 (IRP 2010) recognizes the need for new generation capacity to ensure the continued uninterrupted supply of electricity to South Africa. Being one of the countries with the highest energy intensity and criticized of being one of the most polluting members of BRICS (Ranked # 12 in countries with more CO2 emissions), renewable technologies play a key role by contributing a total of 18.2 GW by 2030 (about 42% of the new build) about a 17% of the total generation mix. Even when solar thermal energy is a technology that requires more initial investment, it is one of the few renewable technologies able to work at peak demand thanks to its storage capacity with a capacity factor of 43%. The IRP 2010-2030 had 3 first installation steps of this technology for the following 3 years, 50, 100 and 250, within which Abengoa was awarded for the first 150MW (50MW Tower and 100MW Parabolic Through). Khi-Solar-One is a CSP Tower With 2hs of storage object of this Thesis.

Keywords: Renewable Energy, CSP, Khi Solar One, South-African Power System.

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Acronyms

AC	Alternating Current.
BOP	Balance Of Plant.
CAPEX	Capital Expenses.
CFE	Electricity Federal Commission.
CO_2	Carbon Dioxide.
COD	Commercial Operation Date.
CPV	Concentrated Photovoltaic
CSP	Concentrated Solar Power
D&A	Depreciation and Amortization.
DHI	Direct Horizontal Irradiance
DIF	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
DOE	Department Of Energy.
DSCR	Debt Service Coverage Ratio.
DSR	Debt Service Reserve.
EBIT	Earnings Before Interests and Taxes.
EBITDA	Earnings Before Interests, Taxes, Depreciation & Amortization.
EBT	Earnings Before Taxes.
GHI	Global Horizontal Irradiance
IDC	Industrial Development Corporation
IPP	Independent Power Producer
IRP	Integrated Resource Plan for Electricity
IRR	Internal Rate of Return.
Km/h, m/s	Kilometers / hour, meters / second.
KV, V, A	Volts, Kilo Volts, Ampere.
LFR	Linear Fresnel Reflector
LCOE	Levelized Cost of Electricity
NEH	Net Equivalent Hours.
NERSA	National Energy Regulator of South Africa
NPV	Net Present Value.
NREL	National Renewable Energy Laboratory.
OPEX	Operational Expenses.
PPA	Power Purchase Agreement (PPA
PS10	Planta Solar 10 MW
PS20	Planta Solar 20 MW

PV	Photovoltaic
R&D	Research and Development.
REFIT	Renewable Energy Feed-in Tariff
REIPPPP	Renewable Energy Independent Power Procurement Program
SOC	Start Of Construction.
TV	Terminal Value.
TW, MW, MWt, KW, h	Tera Watts, Mega Watts, Thermal Mega Watts Kilo Watts, hour.
VAT	Value-Added Tax.
WACC	Weighted Average Cost of Capital.
WWII	Second World War
ZAR	South African Rand.

Chapter 1

Introduction

Renewable energy has historically been the first and most widely used until the industrial revolution. Wind energy has been used by the Egyptians for navigation and for drying the land, the Romans used hydro power in their grain mills including biomass that has a universal use till today. Even the inventor Rudolph Diesel had envisioned biodiesel as the main fuel for his diesel engine [1], but the industrial revolution put aside renewable sources due to the appearance of energies with greater concentration and even cheaper at that time, obtained from fossil fuels such as coal, oil and later on nuclear energy At present and taking into account the awareness of global warming, the probable depletion of fossil resources and the irrational rise of consumerism, we must prepare a better future for our energy supply by reducing dependence created since the industrial revolution, in respect of fossil fuels.

Renewable technologies are an inexhaustible source of energy, almost all of them based on the energy provided by the sun, which is transformed into different types when entering our planet (wind, radiation, etc.).

In this thesis we will focus on concentrating solar technologies that are intended to be one of the main renewable energy of the future thanks to its storage potential to operate at peak demands of electrical systems.

1.2 Objectives of the Master Thesis

Make a project overview and economic analysis of the Khi Solar One Project in South Africa.

- Analyze the irradiance available at the selected location.
- Search and analyze the background of the renewable energy plan in South Africa.
- Design a tool to ease the economic analysis process.
- Research for future developments in the field.

1.3 State of The Art

The Solar Radiation

The Sun emits a huge amount of Energy, in the form of Electromagnetic Radiation, to the space. The Earth receives some of that tremendous energy into its surface, because this energy decreases by the distance. Approximately the Earth receives between 1,413 – 1,321 W/m^2 but, not all of this energy reaches the surface, some of this energy is reflected by the atmosphere and the clouds and some energy, is also, absorbed by the atmosphere and the clouds. See Figure 1.1

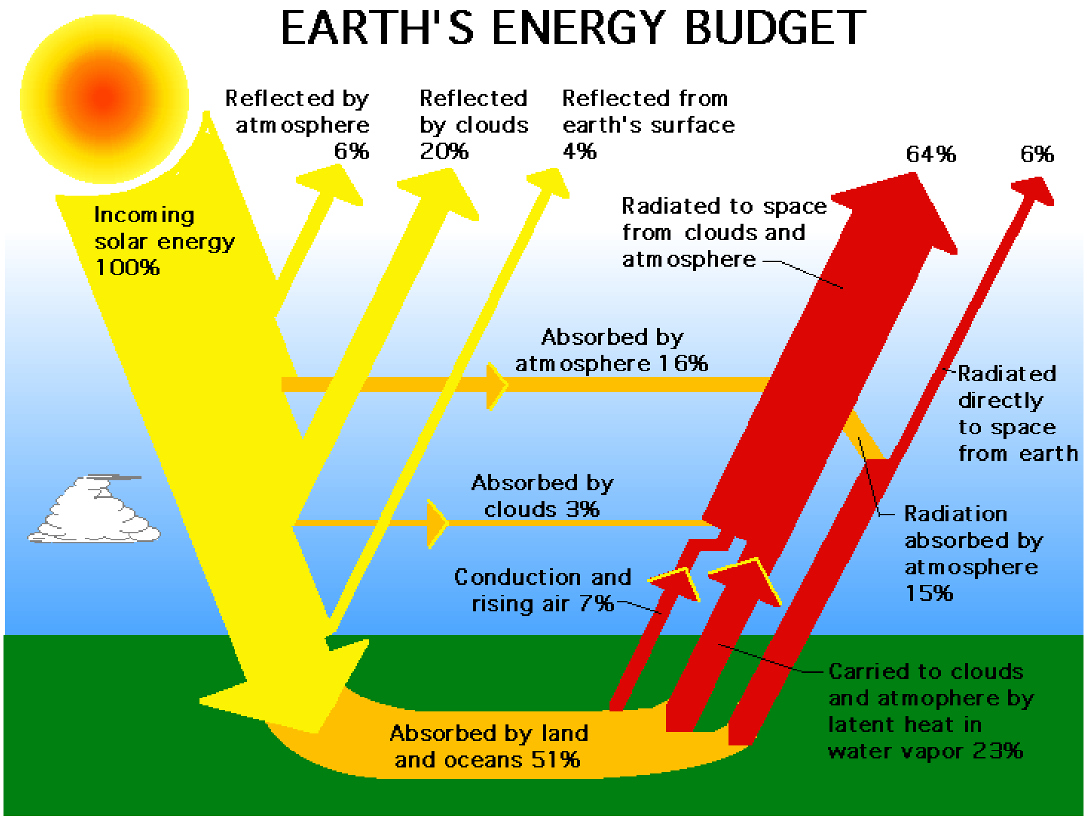

Fig. 1.1. Earth's Energy Budget (Source: NASA).

Furthermore, the received radiation varies by the Angle of Incidence. See Figure 1.2.

Direct Normal Irradiance (DNI)

Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation.

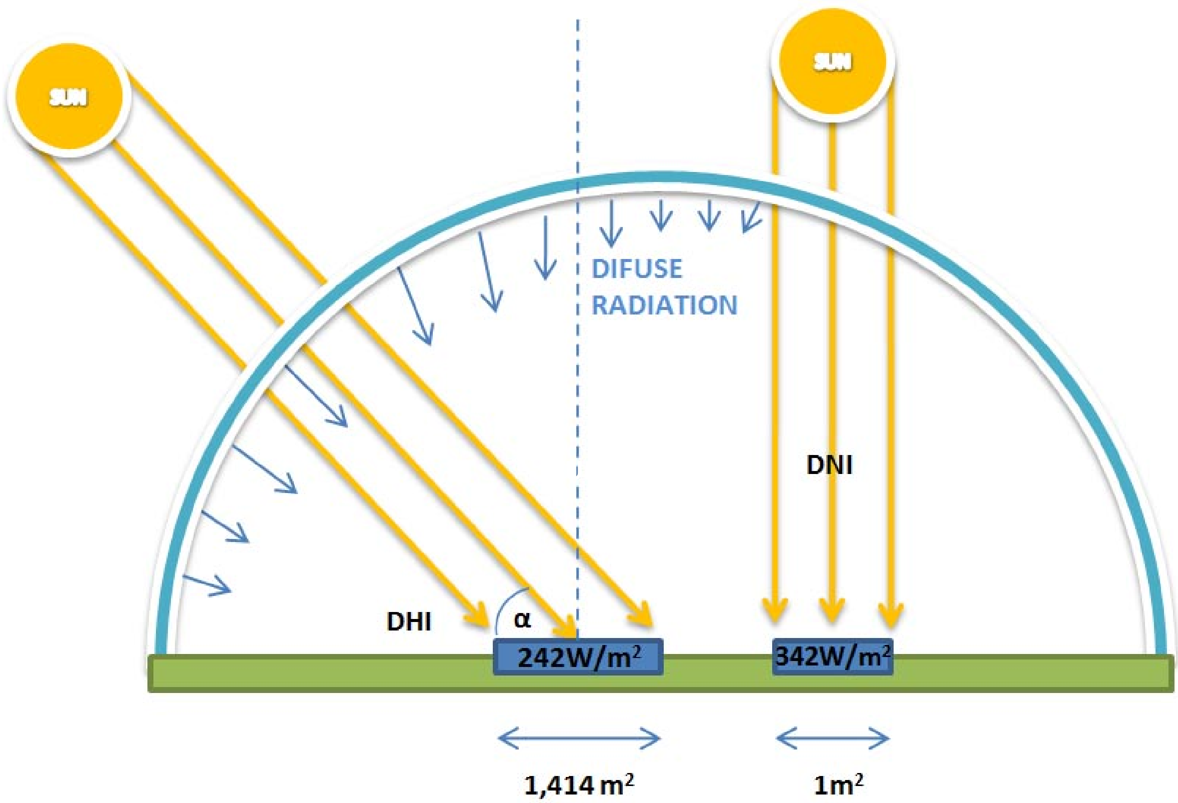

Fig. 1.2. Angle of Incidence of the Solar Radiation (Source: Windows to the Universe).

Direct Horizontal Irradiance (DHI)

Unlike the DNI, the direct horizontal irradiance is measured directly by striking a horizontal plane (relative to the earth's surface). In this case the DNI is modified by the cosine of the angle of incidence.

Diffuse Horizontal irradiance (DIF)

It can be defined as the total irradiance from the celestial dome falling on a horizontal surface, minus the effect of direct radiation incident on that surface. In this case the radiation from the lower parts of the sky (near the horizon) reaches the horizontal surface almost flush, contributing much less than the radiation from the upper reaches of the sky, which affect almost perpendicular.

DIF values are given assuming there are no elements in their surroundings that obstruct a portion of the sky, so they are usually taken in an open field or on the roof of a tall building. They are usually obtained by a pyranometer which includes a shaded band, which prevents the thermoelectric sensor receives direct radiation (the band is placed along the path of the sun throughout the day). The horizontal diffuse irradiance may also be obtained by subtracting the cosine of the DNI to the global horizontal irradiance (GHI).

Global horizontal irradiation (GHI)

Another commonly used value is the global horizontal irradiance, which is the sum of the DNI and DIF.

GHI is usually measured with a pyranometer, a device that uses a 180 ° lens (fisheye) to drive all available radiation to a thermoelectric sensor that measures the energy received.

Turning Solar Heat into electricity.

The solar radiation can be concentrated and collected by a range of Concentrating Solar Power technologies (See Item 2: Concentrating Solar Power Technologies) to provide medium- to high temperature heat. The radiation is concentrated to increase the temperature of the collector in order to transform that heat into Steam to drive a Steam Turbine (Conventional Power Cycle). See figure 1.3. Solar heat collected during the day can also be stored in liquid or solid media such as molten salts, ceramics, and concrete or, in the future, phase-changing salt mixtures. At night, it can be extracted from the storage medium thereby continuing turbine operation.

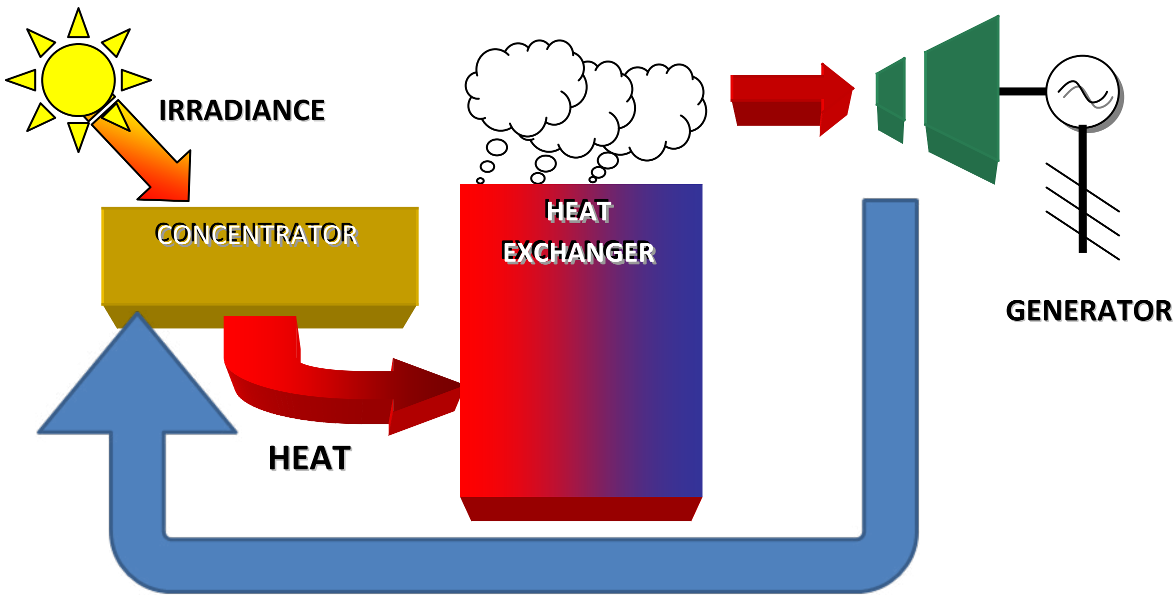

Figure 1.3. Turning Solar heat to Electricity

Solar thermal power plants designed for solar-only generation are ideally suited to satisfying summer noon peak loads in wealthy countries with significant cooling demands, such as Spain and California. Thermal energy storage systems are capable of expanding the operation time of solar thermal plants even up to base-load operation. For example, in Spain the 50 MWe AndaSol plants are designed with six to 12 hours thermal storage, making the CSP one of the few renewable plants which can operate in the peak loads.

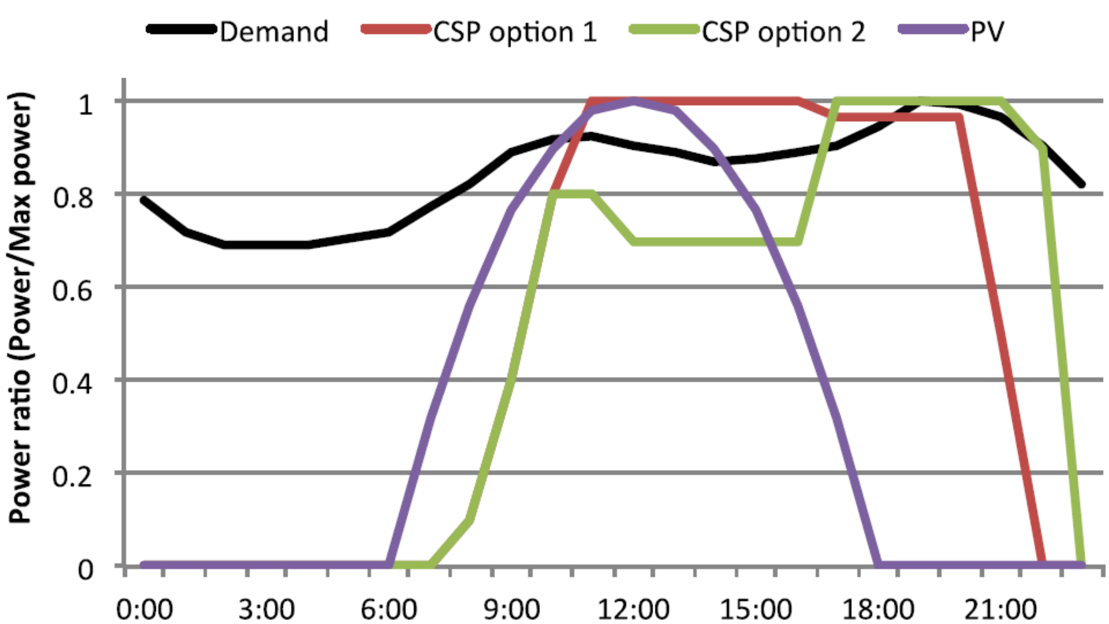

Fig. 1.4: CSP alternatives of production during the day vs PV production over a typical demand profile.

As the Fig. 1.4 shows the CSP with storage, (depending in the amount of hours they can storage) can follow the peaks during a typical day. The maximum power that can be delivered to the grid is limited by the hour of the day and it also changes with the seasons. See figure 5.

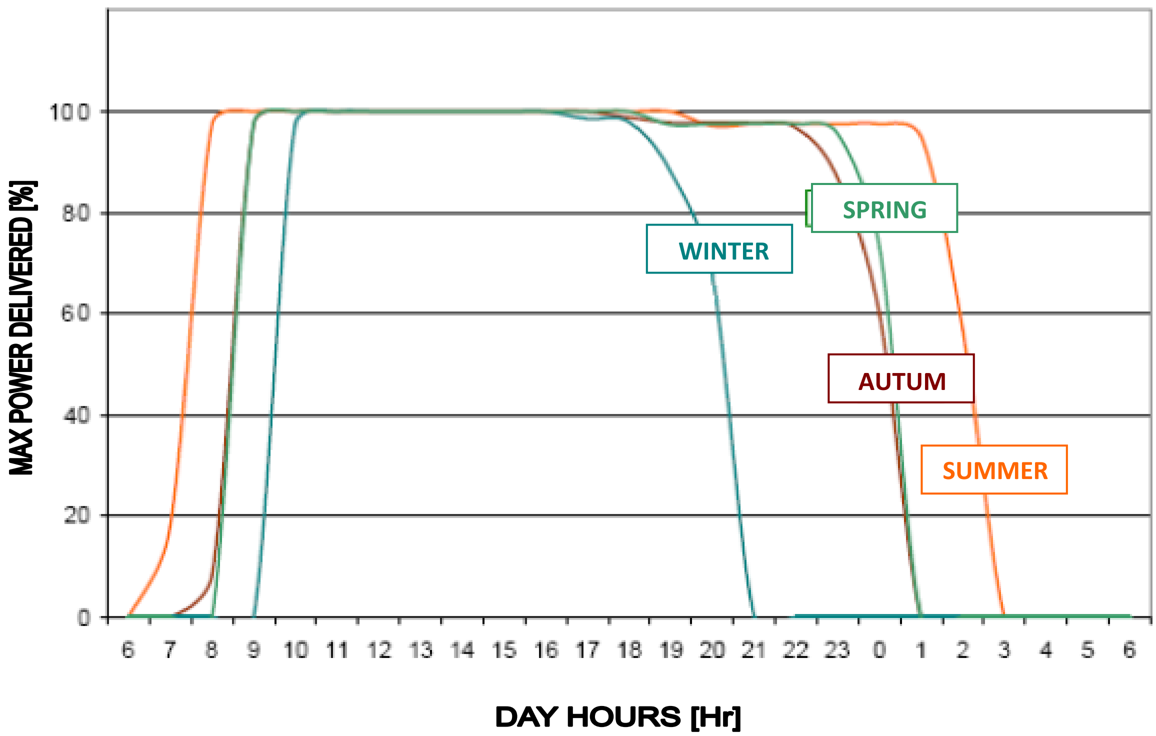

Figure 1.5. % Max Power delivered vs. Day hours. Source: IRENA.

Main Elements of a Solar Power Plant.

Four main elements are required: a concentrator, a receiver, some form of transport media or storage, and power conversion.

Concentrator and Receiver

- **Parabolic trough**

Parabolic trough-shaped mirror reflectors are use to concentrate sunlight on to a thermally efficient receiver tubes placed in the trough's focal line. These tubes are capable to absorb the sunlight creating a mini green-house due to the exterior Glass tube. Inside the Glass tube there's an efficient thermal steel tube in which a thermal fluid circulates trough the entire line. See figure 1.6.

Every Sun Collector has a sun position sensor to correct the alignment of the mirrors using a motor in order to follow the sun path. See figure 1.7.

The concentration ratio raise up to 82:1 and the accuracy of the sun rays hitting the target of 70mm of diameter is around 98%. The Reflection ratio is 93%.

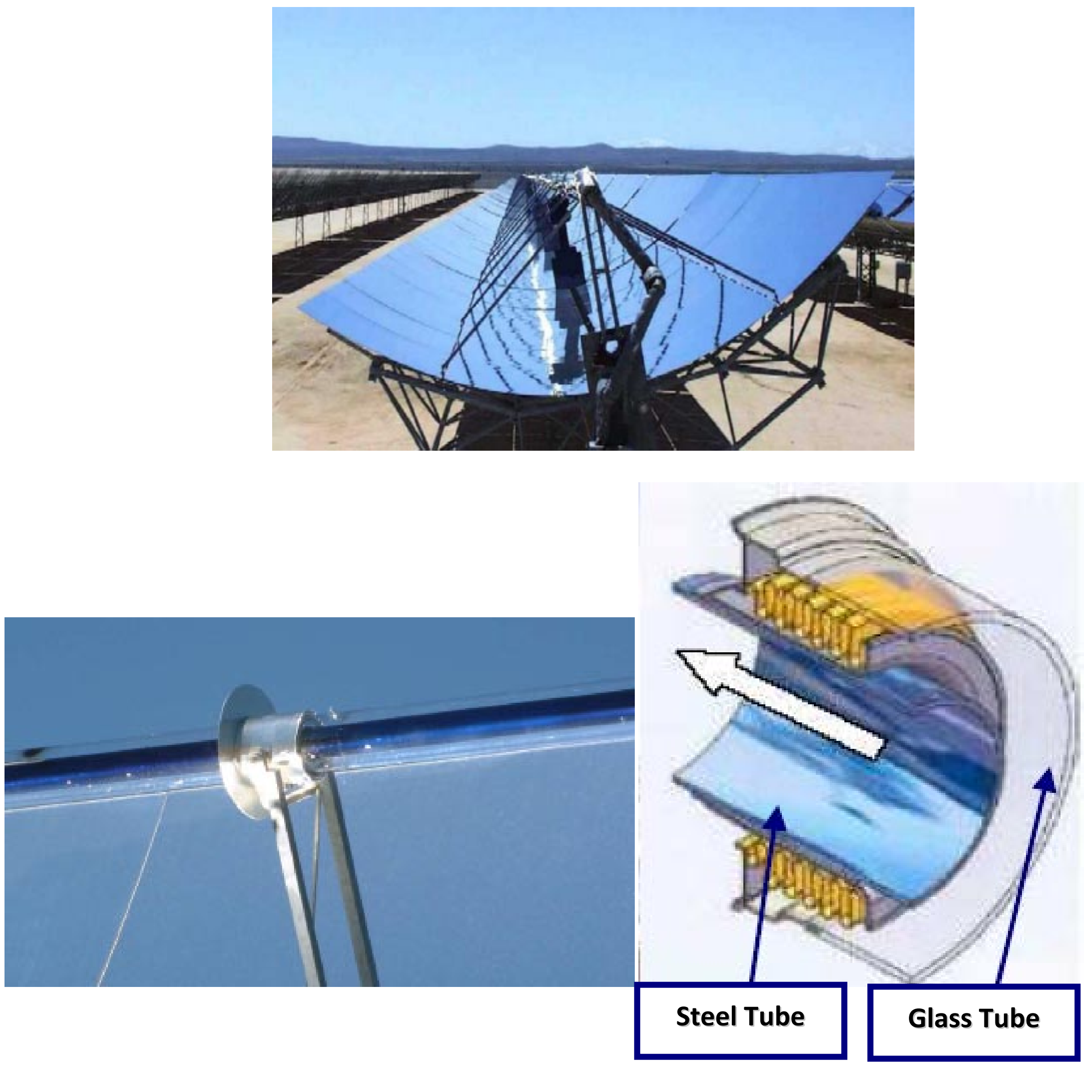

Fig. 1.6. Parabolic trough receptor.

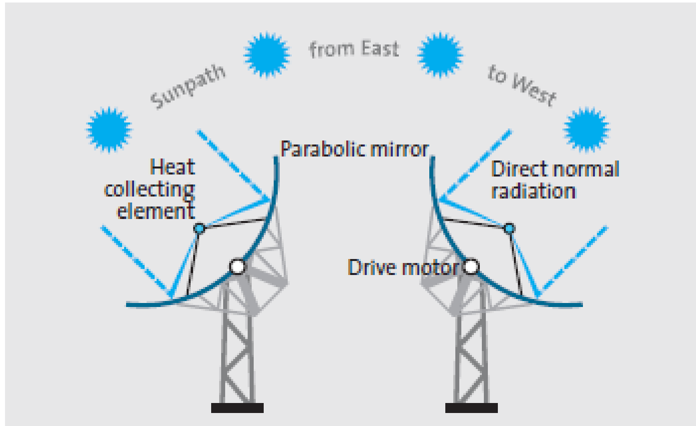

Fig. 1.7. Parabolic through daily tracking. Source: NREL

Heated to approximately 400ºC by the concentrated sun's rays, the thermal fluid (such as synthetic thermal oil) is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combine steam and gas turbine cycle. See figure 1.8.

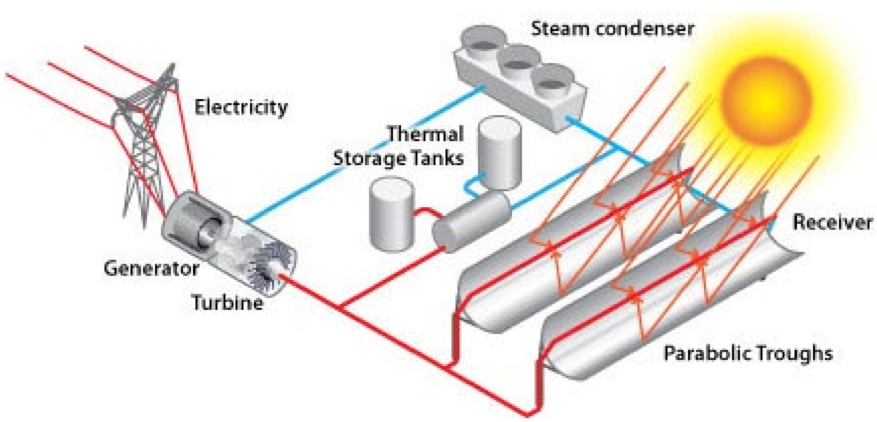

Fig. 1.8. Parabolic trough power plant with hot and cold tank thermal storage system and oil steam generator. Source: NREL

The main research is focused in reducing the cost of the mirrors. One solution seems to be replacing the parabolic trough with Linear Fresnel Reflector.

- **Fresnel principle solar collectors**

A Linear Fresnel Reflector (LFR) array is a line focus system similar to parabolic troughs in which solar radiation is concentrated on an elevated inverted linear absorber using an array of nearly flat reflectors. With the advantages of low structural support and reflector costs, fixed fluid joints, a receiver separated from the reflector system, and long focal lengths allowing the use of conventional glass, LFR collectors have attracted increasing attention. The technology is seen as a lower-cost alternative to trough technology for the production of solar process heat and steam. For power generation, where higher steam temperatures are needed, LFR must still prove its cost effectiveness and system reliability.

An LFR can be designed to have similar thermal performance to that of a parabolic trough per aperture area, although recent designs tend to use less expensive reflector materials and absorber components which reduce optical performance and thus, thermal output. However, this lower performance seems to be outweighed by lower investment and operation and maintenance costs.

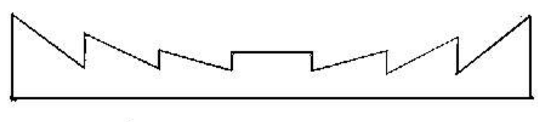

Fig. 1.9. Cross Section of Fresnel Reflector.

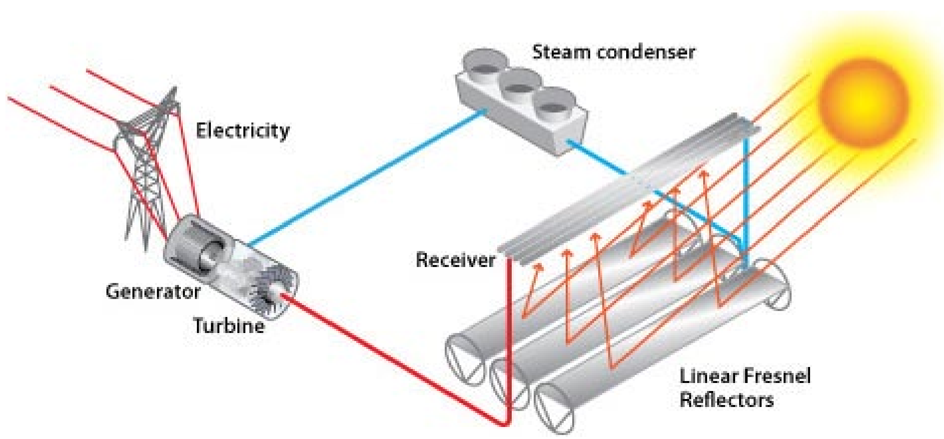

Fig. 1.10. Linear Fresnel Reflector Power Plant. Source: NREL

- **Solar Tower**

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 converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. See Figure 1.11.

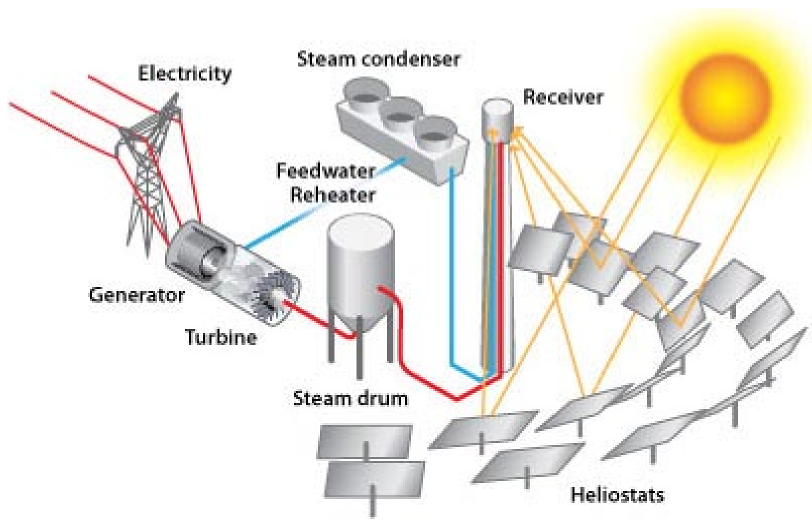

Fig. 1.11. Solar Tower Power Plant

To date, the heat transfer media demonstrated include 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 in a gas turbine, thus making use of the excellent cycle (60% and more) of modern gas and steam combined cycles.

For gas turbine operation, the air to be heated must first pass through a pressurised solar receiver with a sealing window. Integrated Solar Combined Cycle power plants using this method will require 30% less collector area than equivalent steam cycles. See figure 1.12.

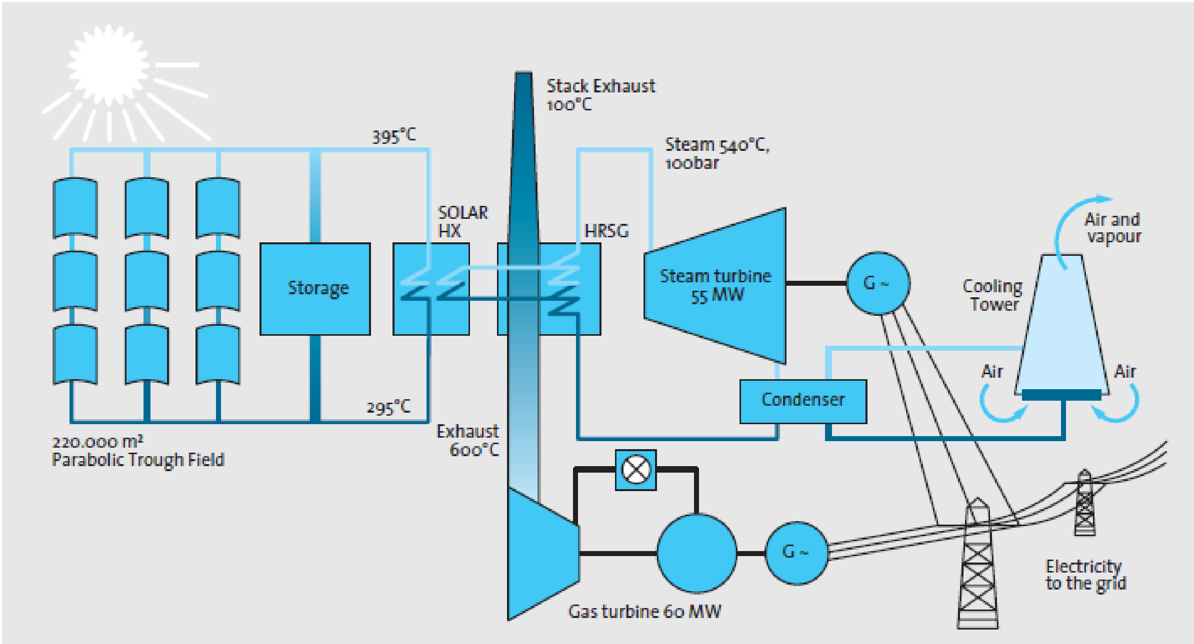

Fig. 1.12. Integrated Solar/Combined Cycle system (ISCC).

Various central receiver heat transfer media have been investigated, including water/steam, liquid sodium, molten salt and ambient air. Those storage systems allows solar energy to be collected during daylight hours and delivered at night or when required by the utility. A plant could meet demand for the whole of the summer peak periods (afternoon, due to air-conditioners, and evening). Today, the most promising storage systems are considered to be the European volumetric air technology and the USA molten salt Technology. The first commercial central receiver plant is Gemasolar, here in Spain. This Solar Tower Power Plant, of 19,9 MWe rated value, has a 16-hour molten-salt storage system to run on a 24-hour basis in summertime. Molten-salt storage coupled with central receiver/tower technology is unique among all renewable energy technologies in that the addition of storage reduces energy cost and increases its value by enabling dispatch to peak demand periods. See Figure 1.13.

Fig. 1.13. Gemasolar (Solar Tower Power Plant, Spain). [2]

- **Parabolic Dish**

Parabolic dish concentrators are comparatively small units with a motor generator at the focal point of the reflector. Overall size typically ranges from 5 to 15 metres in diameter and 5 to 50 kW of power output. Like all concentrating systems, they can be additionally powered by natural gas or biogas, providing reliable capacity at any time. As a result of their ideal point focusing parabolic optics and their dual axis tracking control, dish collectors achieve the highest solar flux concentration, and therefore the highest performance of all concentrator types. For economic reasons, systems are currently restricted to unit capacities of about 25 kWe, but multiple dish arrays can be used in order to accumulate the power output upwards to the MWe range. Because of its size, the future for dish technology lies primarily in decentralised power supply and remote, stand-alone power systems.

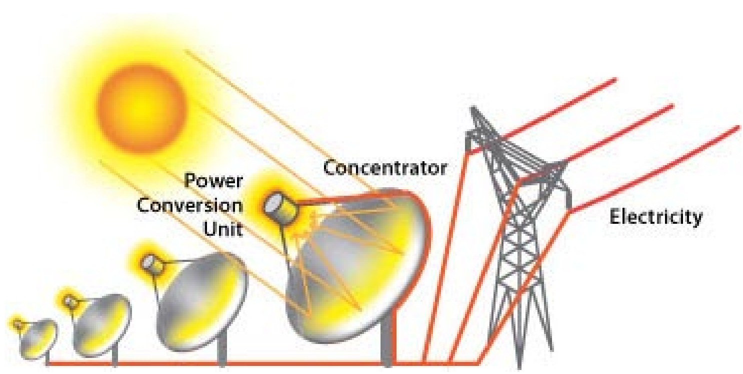

Fig. 1.14. Parabolic Dish Power Plant.

Chapter 2

Background

2.1.1 South African Electricity Sector before IRP 2010-2030

2.1.1.1. History of South African Electricity Sector.

Historically, mining and agriculture were the main sectors of the South African economy (South Africa currently has the ninth position regarding global coal reserves [3]). After WWII, industry became the economic sector with the highest contribution to the growth of the country. In the 60's, the economic growth was very strong, about 6.5%, so power supply shortage was expected. ESKOM [4], a public entity that owned the 95% of electricity generation, mainly coal-based, and virtually all interconnections (except a line with Mozambique), embarks to build 6 large new coal power stations to meet such economic growth. This unprecedented growth resulted in reserve margins as low as 11% in 1975, see Fig. 2.1. In the late 70's, during the oil crisis [4], the price of crude oil imports soared, but the price of electricity remained relatively low and stable. Other sources of energy in the country were shifting toward electricity, such as diesel genset and other petroleum products, further increasing electricity demand.

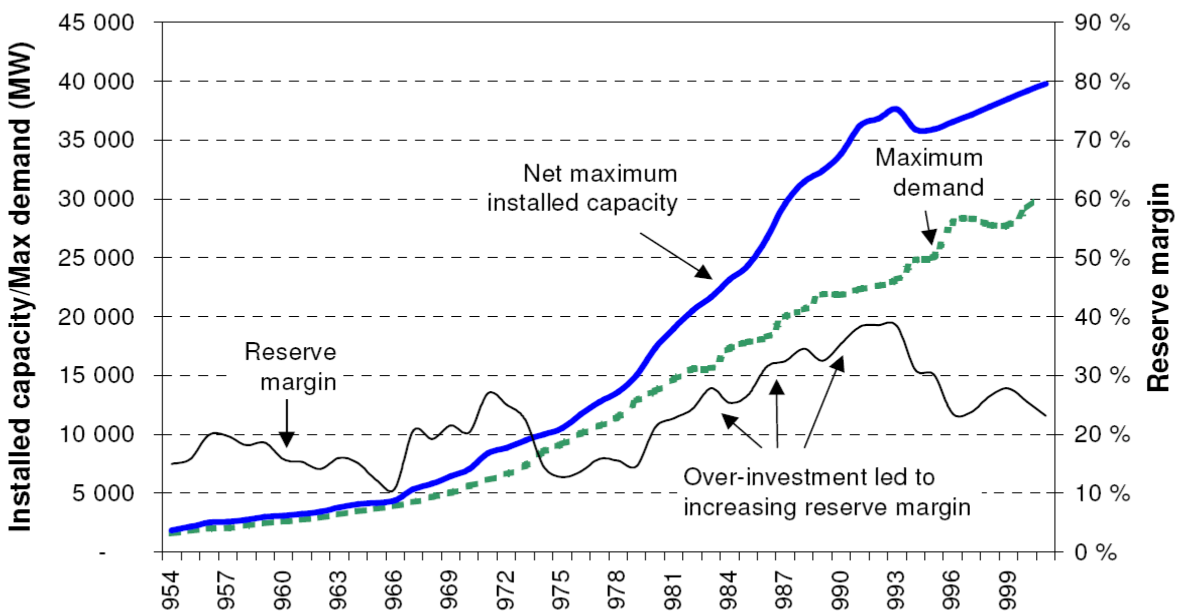

Fig. 2.1: Reserve Margin Evolution since 1954 to 1999. Source: Eskom

As the time went by, initial technical problems were detected in the boiler designs and the use of low-quality coal, which caused various load shedding [5] in 1981.

ESKOM was concerned about power shortages and ordered further power plants. Afterwards they realized that the economic growth forecasts were wrong. The demand had been overestimated, but it was too late: the construction of new power plants was irreversible, due to long lead times and cancellation penalties. By the end of 1983, ESKOM maximum installed capacity was 22,260MW so an increase in the price of electricity was imminent (see Fig. 2.2.).

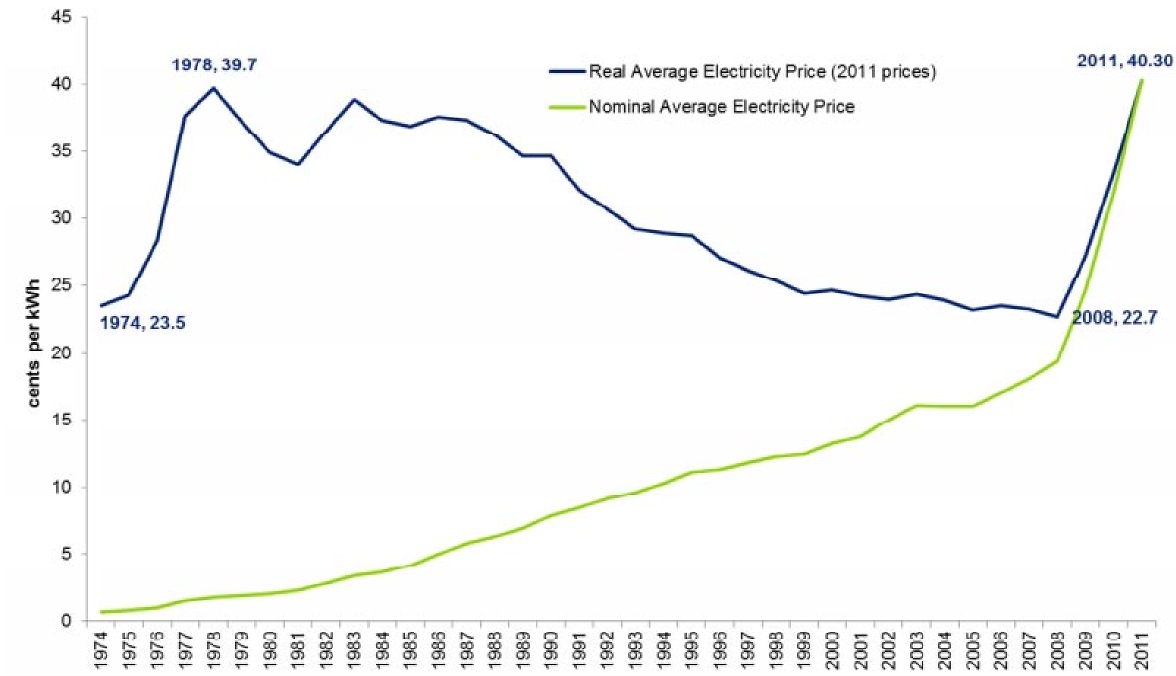

Fig. 2.2: Trend in Average Electricity Prices realized by Eskom per kWh (1974 to 2011). Source: Eskom

2.1.1.2. Generation mix.

South Africa has coal, nuclear, hydro, gas and pumped storage power stations. As mentioned above, most of the plants are coal-fired plants so the Coal is the main source of electricity generation (91.7%), followed by Nuclear (4.2%), then Hydro (2,7%) and finally Pumped Storage (1.7%) for the year 2006. See figure 2.3.

At that time, ESKOM supplied about 95% of electricity and the rest 5% is supplied by both Independent Power Producers (IPP) and local administrations. In 2005, the numbers of operational stations for each energy source are [6]:

- Coal: 20
- Nuclear: 1;
- Bagasse: 4;
- Hydro: 10;
- Pumped storage: 3;
- Gas turbines: 11;

There are 3 mothballed coal stations.

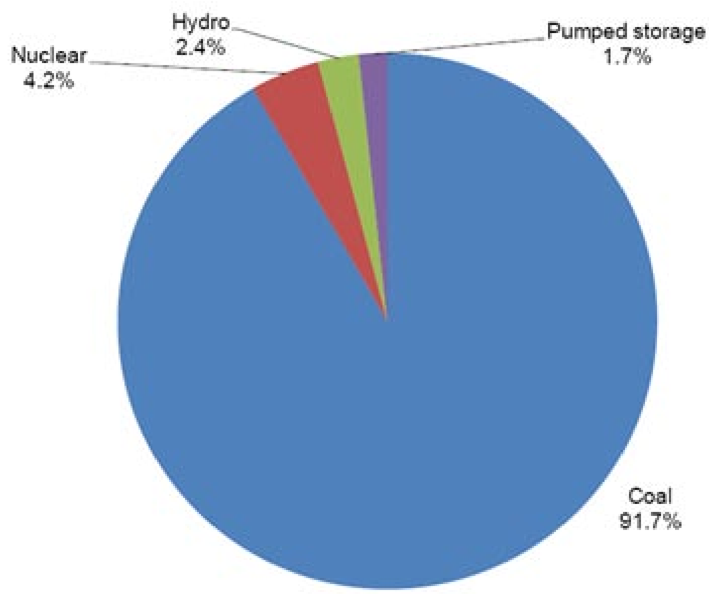

Fig. 2.3: Reserve Margin Evolution since 1954 to 1999. Source: DME 2009 [7]

2.1.1.3. Electricity Crisis (2008)

Between 1983 and 2005 no new plants were planned, and from 2001 to 2005 there was no increase in installed capacity. The demand was continuously increasing so this had affected the reserve margin and in 2004 it fell below the 15% recommended internationally [8] (Fig. 2.4.).

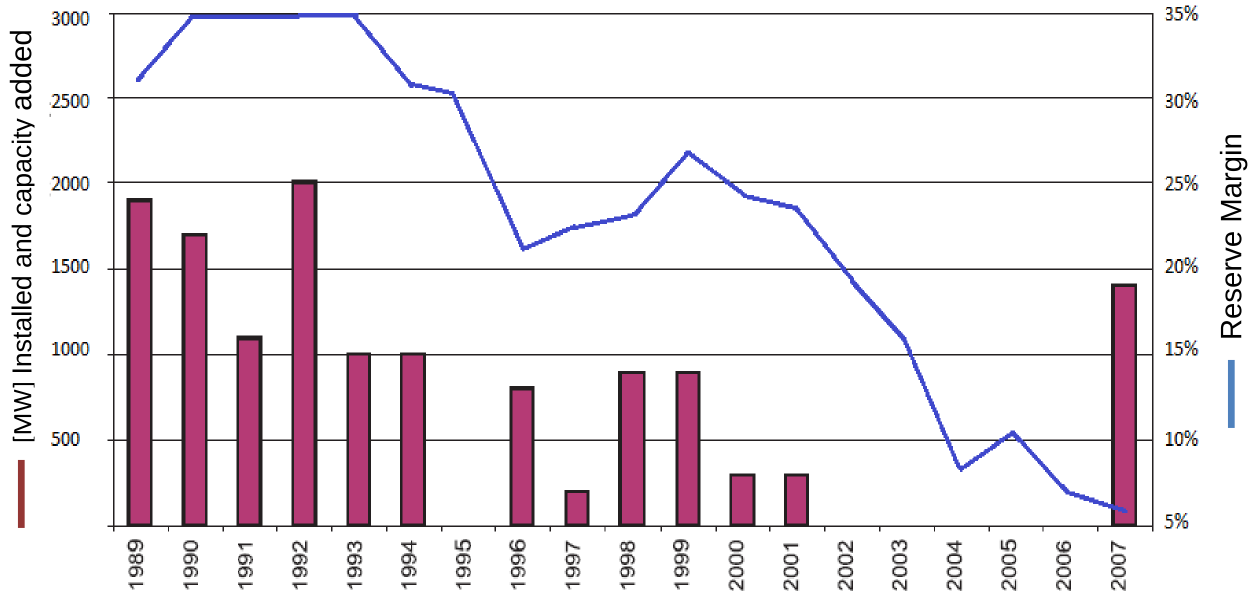

Fig. 2.4: Installed Capacity vs. Reserve Margin. Source: ESKOM.

ESKOM, as system operator, kept 1.9 GW for reserve system and auxiliary services to maintain system stability. Furthermore, this amount increased by 2.5GW in case of unexpected shutdowns in power plants. If these shutdowns were sufficiently higher than the planned one, the system could be in serious problems so the demand could not be equated. In 2006 there were hundreds of days with less reserve to 1.9 GW and many times they had to apply load-shedding. The biggest problems arose when faults were detected in the nuclear generation plant Koeberg near Cape Town, and several faults in transmission lines. In 2007 ESKOM was forced to implement load shedding in several areas of the country after several faults occur on different power plants. Even ESKOM had to cut the supply to mines and other large consumers to avoid a collapse in the system. Moreover, there began to be shortages of coal, affecting the 92% of system electricity production based on coal.

ESKOM's explanations were based on the fact that due to fixed prices, they could not incur in any new investments since the costs exceeded the tariff. Since 2008 the country had experienced dramatic price rises, including 31.3% in 2009/10 resulting in an average electricity price of R 0.33/kWh, which incorporated a R 0.02/kWh environmental levy, and 24.8% in 2010/2011 resulting in an average electricity price of R 0.42/kWh [9].

2.1.2. Integrated resource plan for electricity IRP 2010-2030

2.1.2.1. Summary

Integrated Resources Plan (IRP) is a plan of the electrical capacity for 20 years which aims to provide indications of South Africa's electricity demand and how it should be met in terms of generation capacity, type, time and cost [10]. Also, this plan includes other input functions of planning, economic development, among other things, financing, formulation of environmental and social policy. IRP proposed policy to achieve a balance between affordable price for electricity to support a globally competitive economy, the shift to a more sustainable and efficient economy, a opportunity to create local jobs, diminish the demand of scarce resources like water and the need to meet an appropriate CO_2 emission national target in line with global commitments. According to the scenarios handled by this plan a number of new power plants were planned, see Fig. 2.5.

Table. 2.1. New build by tech. Source: IRP 2010-2030.

TECH	MW
COAL	6250
NUCLEAR	9600
HYDRO	2609
CCGY	2370
OCGT	3910
WIND	8400
CSP	1000
PV	8400
Total Builds	42539
Current Capacity	46993
Total in 2030	89532

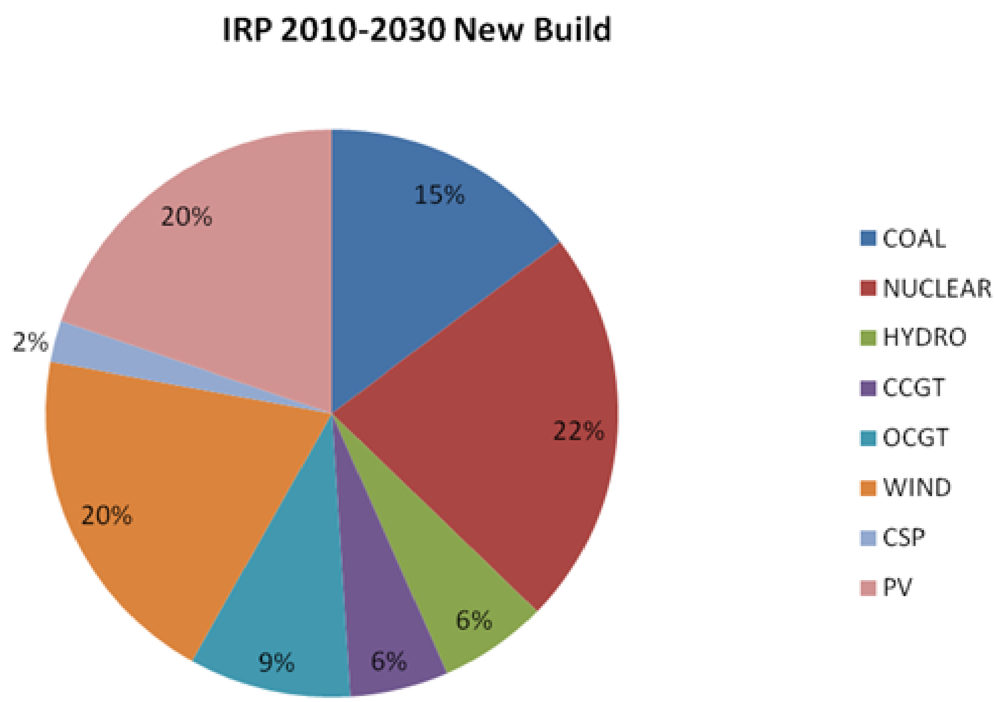

Fig. 2.5: New build proportion: IRP 2010-2030

It was expected that by 2030 at least 46% of the generation was CO_2-free. In Table 2.2 we can see the absolute values by technology and Fig. 2.6 shows the proportional distribution technology.

Table. 2.2. Installed capacity by tech in 2030. Source: IRP 2010-2030

TECH	MW
COAL	41071
NUCLEAR	11400
HYDRO	4759
CCGT	2370
OCGT	7330
WIND	9200
CSP	1200
PV	8400
PUMPED STORAGE	2912
OTHER	890
Total	89532

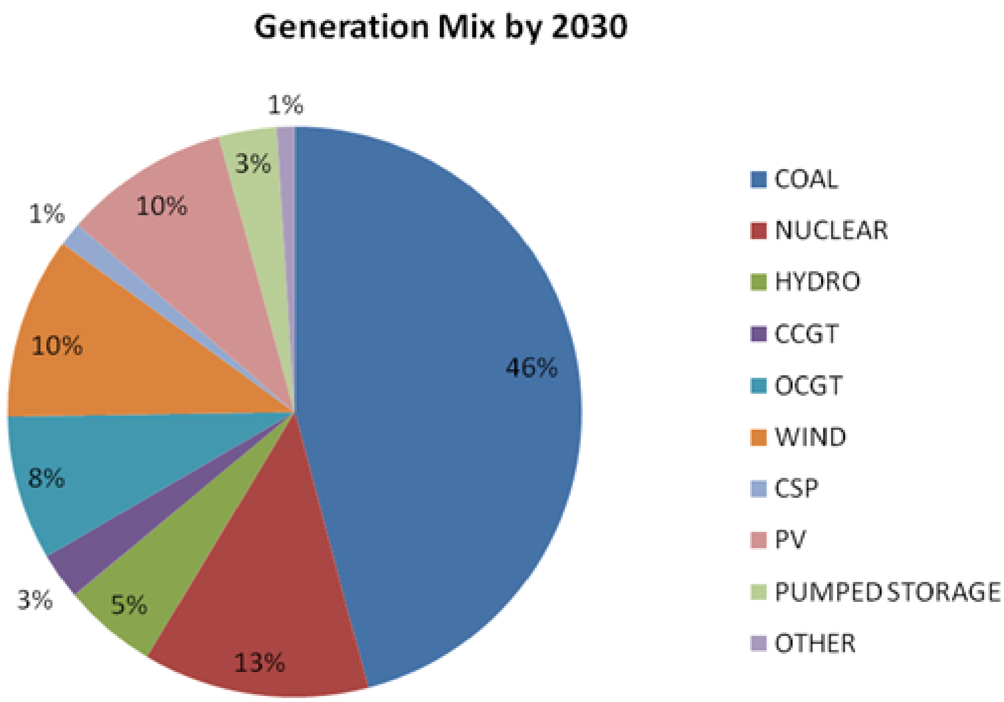

Fig. 2.6: Generation Mix by 2030: IRP 2010-2030

Since the plan became effective in March 2011, the demand expectations were reduced in several updates, such is the case that the last update released required just 6600 MW by 2030 [11], going from 89GW to 61GW at the beginning of the program in March 2014, so the government froze the nuclear program.

In addition to the pause of nuclear plan, this update includes less coal, hydro, wind but more gas. This is due to lower gas import demanded from the United States resulting in gas prices shrank. To keep one of the main pillars of the IRP on environmental policy, new installation of PV and CSP were planned, thus the coal is reduced from 6250 MW to 2450 MW, while the update's projection for closed cycle gas turbine and open cycle gas turbine capacity was increased to 3550 MW (2370 MW) and 7680 MW (7330 MW) respectively. Hydropower Projected imports were at 3000 MW (4109 MW), solar PV and CSP while was Increased to 9770 MW (8400 MW) and 3300 MW (1200 MW) respectively. The allocation for wind falls from 9200 MW in the current IRP to only 4360 MW.

2.1.2.2. REFIT

In late 2007, the National Energy Regulator of South Africa (NERSA) was mandated to develop a renewable energy feed-in tariff (REFIT) for South Africa with the authority to regulate the prices of the country's electricity. Power Purchase Agreement (PPA) would be signed between the Independent Power Producer (IPP) and a single buyer office, so far under ESKOM Holdings, and the Renewable Energy Purchasing Agency (REPA) regulates and controls the process [12].

The main objectives of the REFIT were:

- To encourage the development of renewable energy and play a key role in the South African power system.
- Establish a guaranteed price for electricity generated from renewable sources for a fixed period of time that provides a stable income stream and an adequate return on investment.
- Access to the grid and the purchase of this energy is mandatory.
- Tempting Investment compared with conventional sources of electricity generation.
- To encourage investment and support for the establishment at the energy market.

The REFIT only includes power generation from renewable energy generators connected to the transmission and distribution systems and thus excludes off-grid power generation [12].

The pricing policy was designed in order to cover the costs of generating and adding a 17% real after tax return on equity (ROE), see table 2.3, all corrected by the inflation rate.

Table 2.3: Financial Assumptions, REFIT phase 2. Nersa 2009.

Financial parameter	Unit	Value
Debt,	%	70
Equity	%	30
Nominal cost of debt	%	14.90
Inflation	%	8
Real cost of debt before tax	%	6.39
Tax rate	%	29
Real return on equity after tax	%	17
Real Weighted Average Cost of Capital (WACC)	**%**	**12**

The tariffs set out in the REFIT were generous when compared to international feed-in tariffs and cover the cost of generating renewable energy plus a reasonable profit to encourage developers to invest. The next table shows a quick comparison between Spanish FIT 2007 and South African REFIT 2009.

Tabla 2.4. REFIT price comparison with FIT Spain South Africa 2007. Source: NREL.

	ZAR - EUR	0,10385	in 2007			
Energy Source	**ESP FIT €/kWh**	**ESP FIT In R/kWh (2007)**	**ZA FIT Phase 1 R/kWh**	**Dif. ESP R/kWh**	**ZA FIT Phase 2 R/kWh**	**Dif. ESP R/kWh**
Solar thermoelectric	0,2694	2,59	2,10	-0,49	2,31	-0,28
Wind systems	0,0732	0,70	1,25	0,55	1,25	0,55
Hydroelectric	0,078	0,75	0,94	0,19	0,94	0,19
Biomass and biogas	0,1306	1,26	0,90	-0,36	1,18	-0,08

Many investors were interested but there was no clear mechanism for concession projects. Many had already incurred expenses of assessments for analyzing location viability [13].

In 2011, NERSA published surprisingly, some revisions to the tariffs considerably reducing them between 10-40% (see table 2.5) and even took off indexing for inflation [14] causing disaffection among investors and it generated some uncertainty about it.

Table 2.5: 2009 REFIT and 2011 Revised REFIT with projected CPI adjustments for years 2012-2013. Source: NERSA 2011.

YEAR:	REFIT 2009	REFIT 2011	REFIT 2012	REFIT 2013	Percentage Change 2011/2009
TECHNOLOGY	**R/kWh**	**R/kWh**	**R/kWh**	**R/kWh**	
Wind ≥ 1 MW	1.25	0.938	0.945	0.952	-24.9%
Landfill Gas ≥ 1 MW	0.90	0.539	0.550	0.562	-40.1%
Small Hydro ≥ 1 MW	0.94	0.671	0.675	0.680	-28.6%
CSP trough ≥ 1 MW with 6 storage	2.10	1.836	1.845	1.854	-12.6%
CSP trough ≥ 1 MW without storage	3.14	1.938	1.953	1.967	-38.3%
CSP central receiver (tower) ≥ 1 MW with TES 6 hrs	2.31	1.399	1.408	1.417	-39.4%
Photovoltaic ≥ 1 MW ground mounted	3.94	2.311	2.325	2.338	-41.3%
Biomass solid ≥ 1 MW (direct combustion)	1.18	1.060	1.084	1.108	-10.1%
Biogas ≥ 1 MW	0.96	0.837	0.862	0.887	-12.9%

The National Treasury stepped in to argue that fixed prices are not competitive and in July 2011 the REFIT is removed [13]. No project had been signed in the two years since the launch of the REFIT program.

2.1.2.2. REIPPPP

In August 2011, the DOE announced the Renewable Energy Independent Power Procurement Program (REIPPP). Developers had doubts about this new plan since at the time of removing REFIT had already incurred expenses, but fulfilling certain conditions they could be benefited from the first window REIPPPP.

The program is based on an auction system on 4 levels:

1) Procurement announcement, by the government to pursue a given generation capacity of electricity from renewable energy source.
2) A series of prerequisites set by the government, to participate in the auction (environment, land, commercial and legal, economic development, financial, and technical) [13].
3) Introducing the offer by the IPP with a specific price per unit of electricity which they undertake to carry out the project (less than proposed by the program ceiling price see table 2.6).
4) Evaluation of the offers by the government on the basis of price and other criteria such as local content and signature of the PPA with the winners.

Table. 2.6. Price ceiling for the REIPPPP by technology. Source: DoE South Africa.

Technology	Price Cieling R/kWh
Onshore Wind	1,15
Concentrated Solar Power	2,85
Solar Photovoltaic	2,85
Small Hydro (= 10MW)	1,03
Landfill gas	0,84
Biomass	1,07

Auction systems have become increasingly widespread in the last few years, with 44 countries in 2013 (compared to 9 in 2009), including 30 developing economies, using renewable energy auctions (IRENA, 2013b).

Chapter 3

3.1 KHi Solar One Project Overview

3.1.1. Location Analysis

3.1.1.1. Location

The project is being implemented in Upington, a city founded in 1871 and located in the Northern Cape Province of South Africa, on the banks of the Orange River. Its current population is estimated at 72.198 inhabitants. Upington elevation is 835 meters and its coordinates are 28 ° 27'S 21 ° 14'E. The landscape is arid but the soil is fertile and crops like fruits are grown in irrigated fields. The area is well known for its export quality grapes, raisins and wine, which are grown in the rich plains bathed by the Orange River [15].

Covering 30.5% of the land area of South Africa, the sparsely populated Northern Cape is the largest of the nine provinces in size, however, its contribution to Gross Domestic Product (GDP) is the lowest, a mere 2.2%. Their biggest problem is poverty where a high number of families living below the poverty line.
Unemployment rate in the province grew at an average annual rate of 25.2% in the last decade. The unemployment rate peaked in 2003 with unemployment reaching 28% from 18.4% in 2000. After 2004, the unemployment rate has remained relatively constant at an average rate of 26.3%, the province has not been able to reduce its unemployment rate in line with the government's objective of halving unemployment and poverty by 2014.
Youth unemployment rate in the province has remained consistently high in recent years, higher than the overall unemployment rate in the province. This is an indication of the inability of the labor market to create enough jobs to absorb the young people seeking employment [16].

It has an excellent network of roads, making inside easily accessible from major cities, ports and airports in South Africa.

3.1.1.2 Solar Radiation Availability

Unlike other solar technologies, solar concentration, such as CSP and CPV, needs Direct Normal Irradiance (DNI) for its purposes, where measurements are more complex and expensive. Satellite data received have is more accurate for GHI (3-6% uncertainty) than the DNI that has a 6-12% uncertainty.

Bearing in mind this, we will use an assessment by GeoModel Solar to verify the good numbers of this location to board a draft CSP.

In Fig. 3.1 SolarGis shows that from 2004 to 2010 the average DNI far exceeds the threshold to implement a cost-effective CSP (minimum annual DNI 2000 when in Spain has 2100 annual DNI).

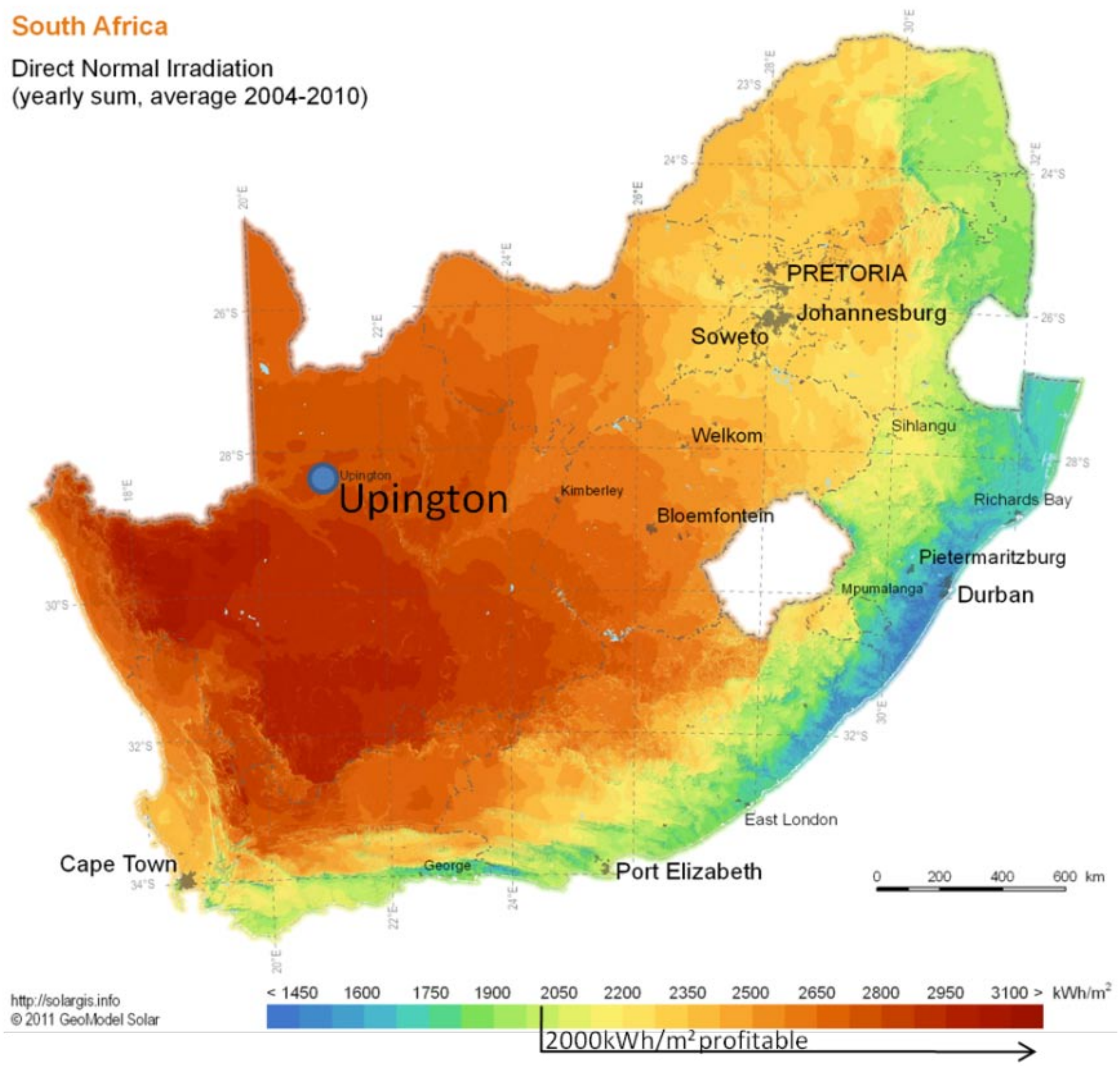

Fig. 3.1. Average DNI for Upington. Source: SolarGIS. GeoModel.

Fig. 3.2.a. Khi Solar One Location. Source: Google Maps.

Fig. 3.2.b. Khi Solar One solar field. Source: IMASA.

Current technology costs and restrictions on financial aid imply that only projects that are in the areas of greatest direct normal irradiation are likely to be feasible in the near future with annual DNI that mean more than 2,0 MWh/m^2/year or 6,0 kWh/m^2/day according to NREL.

In the table below shows DNI statistical values representing 17 years (1994-2010) [17].

Table 3.1: Direct Normal Irradiation, monthly statistics. Source:GeoModel Solar

	Daily sum [kWh/m^2]				Monthly sum		
	Average	Variability			Average [kWh/m^2]	Monthly share [%]	Interannual variability [%]
		Median	P_{75} - P_{25}	P_{90} - P_{10}			
Jan	8.56	9.50	7.04 – 10.54	4.36 – 11.15	263	9.4	11.0
Feb	7.78	8.56	6.13 – 10.04	3.43 – 10.40	220	7.8	12.7
Mar	7.36	8.09	5.97 – 9.18	3.70 – 9.61	228	8.1	9.8
Apr	6.93	7.64	6.11 – 8.35	3.78 – 8.70	208	7.4	11.8
May	6.60	7.36	6.10 – 7.71	3.93 – 8.18	205	7.3	9.4
Jun	6.68	7.21	6.43 – 7.51	4.50 – 7.85	200	7.1	7.4
Jul	6.98	7.33	6.83 – 7.62	5.36 – 7.98	216	7.7	6.0
Aug	7.36	7.82	7.11 – 8.31	5.19 – 8.72	228	8.1	7.9
Sep	7.75	8.41	7.18 – 8.92	4.85 – 9.55	232	8.2	9.5
Oct	8.18	9.06	7.14 – 9.86	4.15 – 10.56	254	9.0	6.1
Nov	8.95	9.98	7.56 – 10.80	5.01 – 11.38	268	9.5	10.2
Dec	9.47	10.52	8.43 – 11.02	6.16 – 11.91	293	10.4	10.9
YEAR	**7.72**	**7.84**	**6.74 - 9.32**	**4.36 -10.60**	**2816**	**100.0**	**3.3**

As we can see the daily average of each month are above the threshold of 6kWh / m^2. The P90 percentile indicates a value of daily sum of DNI exceeded 90% of the days in a month or year in particular; the same applies to P10 but is the value that exceeded 10% of days in a month or year particular. This range is shown in light gray in the graph below Fig. 3.3. and also it refers to the P90-P10 column in the above table. The dark gray range refers to the range P75 and P25, and the black line is the median.

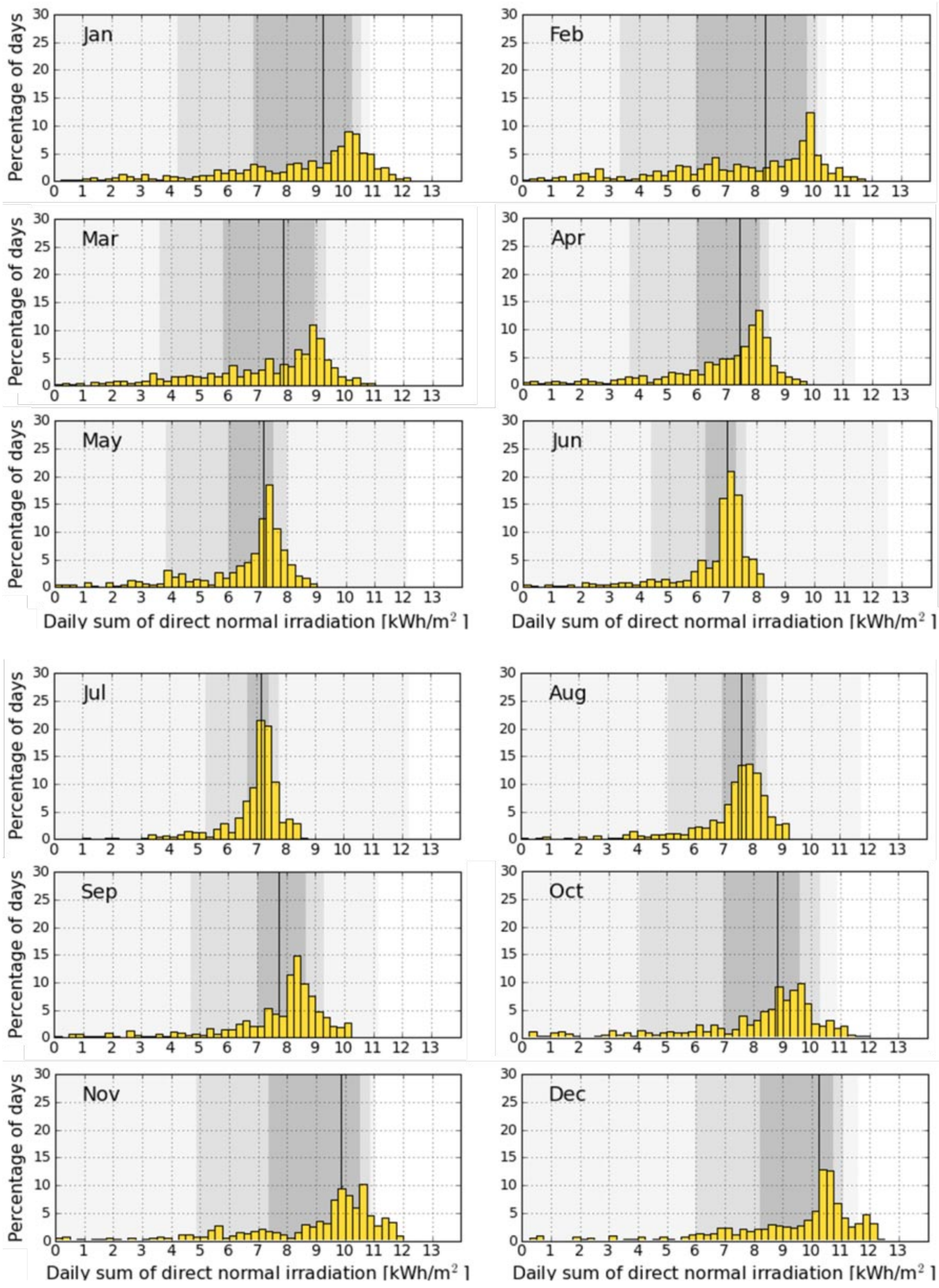

Figure 3.3. DNI: daily amount monthly histograms. Source: GeoModel Solar

Also, throughout a day CSP plants cannot operate below a certain threshold, in particular 300 ID. However, unlike other technologies, the output does not depend on a linear function with respect to the DNI and that is due to the thermal inertia and thermal storage. Fig. 3.4 shows that when the DNI is below 300 W/m^2, the power does not drop immediately but has a delay caused by this phenomenon.

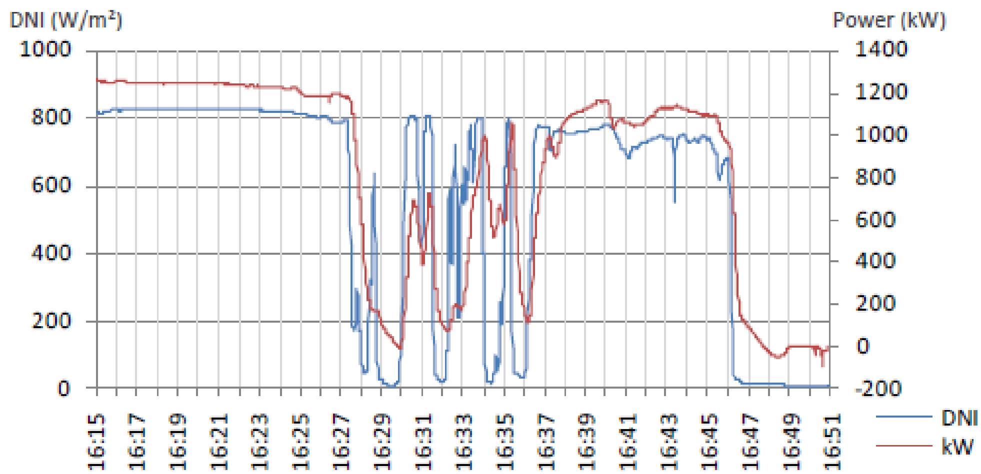

Figure 3.4. DNI vs Power output. Source ESMAP [18]

3.1.2. Tower CSP

Abengoa based on its experience in energy towers like Planta Solar 10 MW (PS10) and Planta Solar 20 MW (PS20), operating since 2007 and 2009 respectively in Spain, to set new standards for CSP projects.

Khi Solar One is a project of a CSP tower with a capacity of 50MW which aims to deliver about 186GWh per year that will prevent approximately 183,000 tons of CO_2 emissions per year, and will supply clean energy to approximately 45,000 households. The plant will create an average of 600 jobs during construction, and approximately 35 permanent, full-time jobs during plant operation.

With a 51% owned by Abengoa Solar together with the Industrial Development Corporation (IDC) and Khi Community Trust, it is a unique structure with a tower of 205 meters high (build completed at the end of August 2013) and 30 meters in diameter at the top and 40 meters in diameter at the base. The solar field covers more than 576.800 m^2 and allocates 4530 mobile heliostats with a curved reflective surface to concentrate solar radiation on a receiver at the top of a tower area. Fig.3.5.

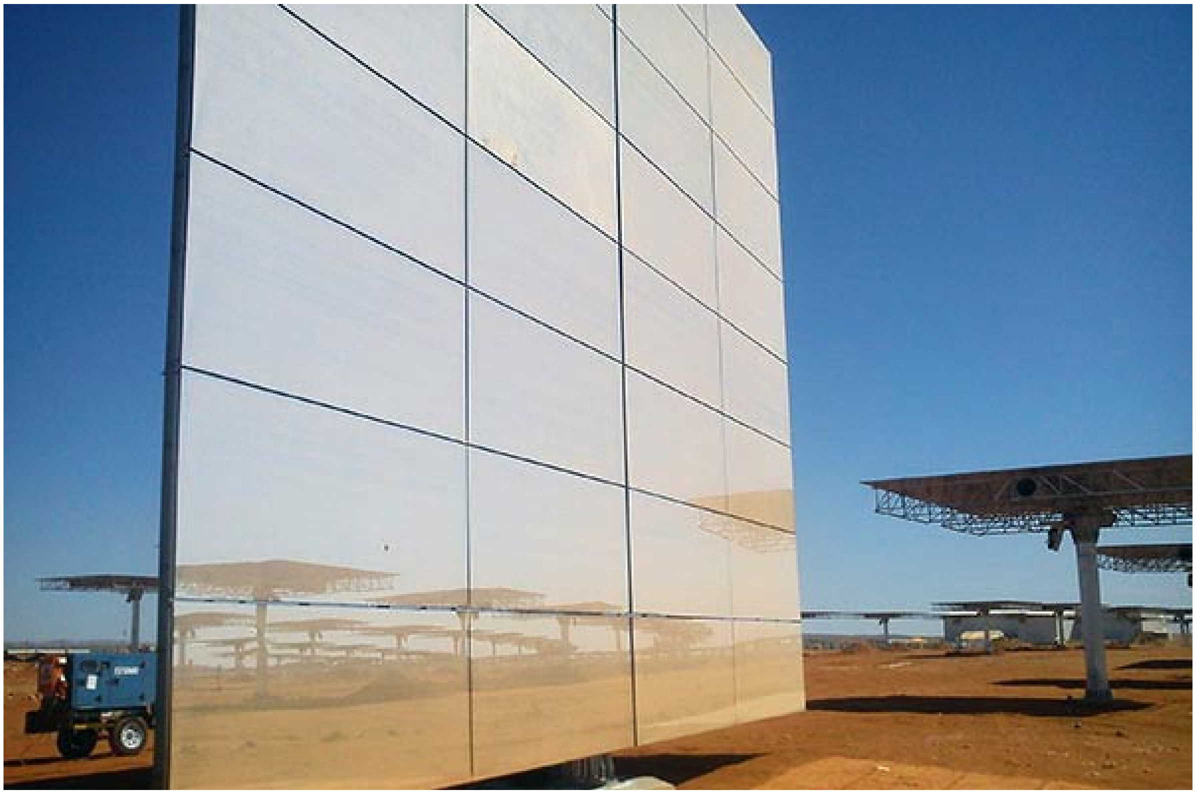

Fig. 3.5 Heliostats used in Khi Solar One. Image: Shamin Chibba.

These heliostats are controlled by the Distributed Control Systems (DCS) of Schneider Electric, which among other things has an advanced algorithm sun tracking to align the mirrors in order to maximize the reflection of solar receivers located 200 meters height.

The solar receiver assembly began in April 2014; it consists of a series of panels of tubes operating at high temperature and by circulating pressurized water. The steam produced is partially stored in a storage tank, located in the top of the tower (Fig, 3.6), to be used when sufficient steam does not occur, the remainder is sent to a steam turbine to generate electricity.

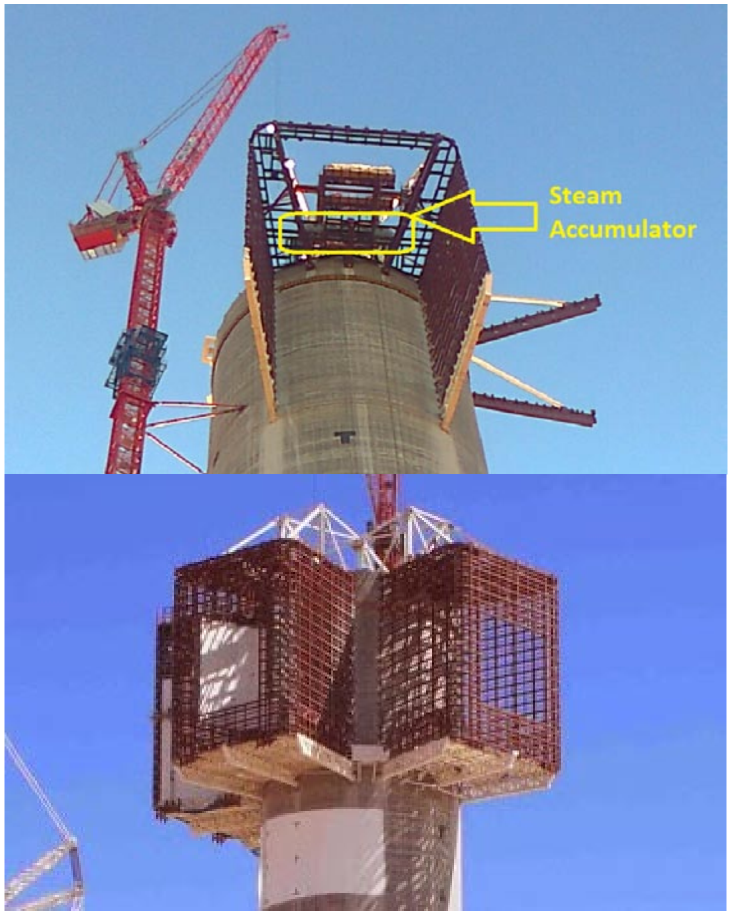

Fig. 3.6 Solar Receiver. Image: IMASA.

Khi Solar One uses a Super Heated Steam Cycle similar to the one that Abengoa has been using since 2009 in a test called plant of 3 MW Solúcar near Seville [19]. It is anticipated that the superheated steam can reach a maximum operating temperature of 530 ° C whereupon the cycle efficiency should be higher. As indicated by Abengoa, Khi Solar One cycle achieves an efficiency of 30% higher than PS20.

3.1.2.1. Storage

Unlike other CSP tower where normally molten salt for thermal storage are used, Khi Solar One uses its innovative super-heated steam storing up to 2 hours in tanks of 247m³. See Fig. 3.7.

Fig. 3.7 Steam Accumulator Tanks. Image: IMASA.

In the following diagram we can understand broadly the change in structure over other CSP tower with storage.

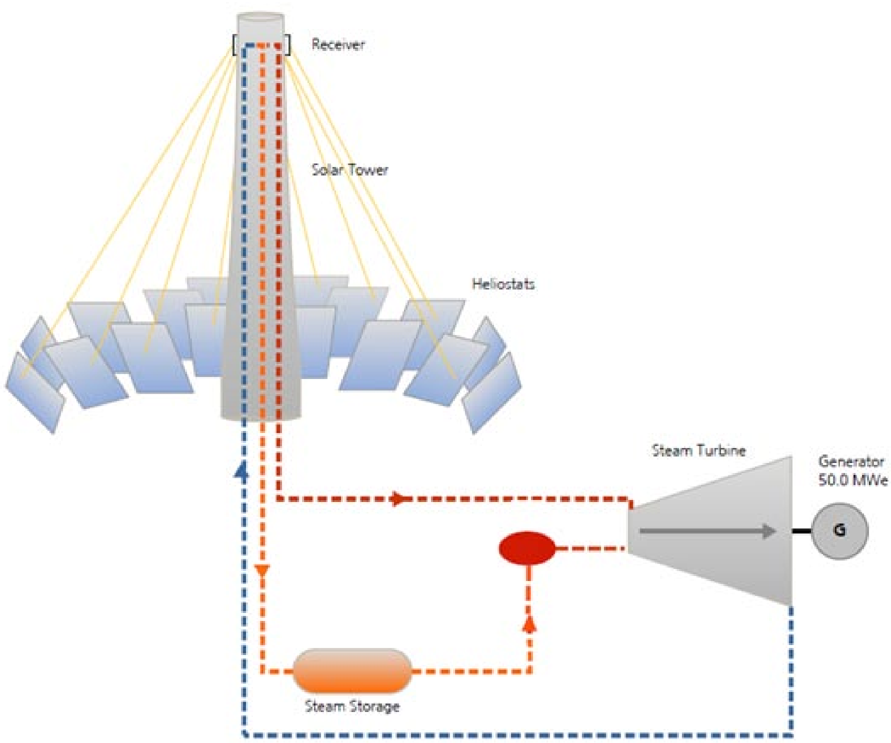

Fig. 3.8. Khi Solar One operation Scheme. Source: Abengoa Solar.

3.1.2.2. Water consumption

Despite of using a steam cycle and having a water extraction point located along the Orange (Gariep) River, water is a scarce resource in this region and that is why Khi Solar One has a dry cooling system developed by SPX [20] to distribute air through stabilizing plates to dissipate heat using the tower instead of using fans as normally occurs in air-cooled condensers. Abengoa estimates that the technology will allow Khi Solar One use 80% less water than a CSP plant with wet cooling.

3.1.3.1 Electric Infrastructure

Using a conventional steam turbine requires a substation to step-up 15 kV of the generator output to the interconnection with a line of 132 kV, 50Hz located 4 km away from the plant (according to an environmental assessment it was decided to install single pole overhead to reduce the visual impact [15], Fig. 3.9). The electric infrastructure must be reliable to handle a maximum power of 50 MW.

Figure 3.9. Single pole overhead interconnection between Khi Solar One and Eskom Grid. Image: IMASA.

The main elements that will constitute the electric infrastructure are mentioned below:

- Conventional Steam Turbine
- Step-up transformer 15kV-132kV
- Distributed Control Systems (DCS)
    - Scheider Electric DCS [21]
        - Solar tracking controller.
        - Comm. Network and concentrators along the solar field.
        - Main Controllers for the plant operation.
- Grounding.

3.1.3.2 IMASA INGENIERIA Y PROYECTO S.A.

IMASA was the first company in Spain in charge of the mechanical erection and insulation of a solar thermal plant.
Over the past seven years, IMASA has accumulated experience in this field than any other company in Spain has after performing the mechanical erection of 12 + 1 solar thermal plants.

IMASA is a pioneer in Spain in the mechanical erection of solar thermal power plants with the agreements reached with several Spanish groups participating in such projects.

UTE Cobra / Sener for the implementation of the Andasol I and II plants in Granada, Extresol I and II in Badajoz, Gemasolar in Seville and Valley I and II in Cadiz, UTE SAMCASOL for the mounting of its two plants SAMCASOL I and II in Badajoz
Moreover IMASA has also made the implementation of ASTESOL, Aste 1B ELECNOR and is currently the Termosolar "The African" in its final stages of implementation and Solar Thermal Villena in full implementation phase for the joint venture between IMASA and FCC (in this case IMASA also participates as a partner in the joint venture and as a company in charge of Mechanical erection). Table 3.1.

Table 3.2: IMASA's CSP Project participation

	Proyecto	Alcance
1	Samcasol 1	Shop frabrication and mechanical erection of piping and equipment in the power block.
2	Samcasol 2	Shop frabrication and mechanical erection of piping and equipment in the power block.
3	Andasol 1	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
4	Andasol 2	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block

5	Extresol 1	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
6	Extresol 2	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
7	Gemasolar	Shop frabrication and mechanical erection of piping and equipment in the power block and supply and installation of thermal insulation of pipes and equipment of the power block
8	Astesol 2	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
9	La Africana	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
10	Aste 1b	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
11	Valle 1	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
12	Valle 2	Shop frabrication and mechanical erection of piping and equipment in the power block, Molten Salts, HTF and BOP and supply and installation of thermal insulation of pipes and equipment of the power block
13	FCC	Shop frabrication and mechanical erection of piping and equipment in the power block, HTP, BOP and solar field.

3.1.3.2.1 IMASA's Scope in Khi-Solar-One Project.

In concordance with previous experiences, Abengoa Solar has selected IMASA to perform the following tasks:

- Mechanical erection of the BOP and HTF of the power block.
- Supply and erection of the insulation for pipes, valves and equipment in the power block and HTF.
- Solar Receiver Erection.

Figure 3.10. Solar field view and erection process of the Solar Receiver. Khi Solar One. Image: IMASA.

Figure 3.11. Khi Solar One Tower. Image: IMASA.

Figure 3.12. Khi Solar One Tower zoomed in. Image: IMASA.

Figure 3.13. Top view of the power block. Image: IMASA.

3.1 Economic Analysis

3.2.1. Spreadsheet Model

During the Master we have developed a calculation model for assessing economic/financial projects. Being a model allows us to input variations to observe different behaviors in certain situations. However, this project has certain variables fixed with the South African Government in accordance to a price between R2,31-R2,85. As we saw before, the price of REFIT 2009 tariff was R2.31 for CSP tower with storage and R2,85 in REIPPP Ceiling Tariff Program, see table 2.3. However the agreed PPA is not a public info but we know that the agreed price will be closer to the ceiling than the REFIT 2009 as discussed below in the simulations.
The model is made in local currency Rand (ZAR) because that's how the REIPPPP required.

3.2.1.1 Project Assumptions

First of all we will make macro assumptions based on previous data and information provided by the South African government [12][14] (Table 3.3). General project data were obtained from various public sources (NREL, Abengoa, IRENA, NERSA, EIA).

Table 3.3. Project Macro Assumptions

Project Assumptions		
Country		South Africa
CSP Technology		Tower + 2hs of storage
Installed Capacity	MW	50
NEH	**Hs/MW**	**3875**
Availabitity	%	96%
SOC		ene-13
COD		nov-14
First year production	%	16,67%
Last year production	%	83,33%
Years of D&A	years	20
Years of PPA	years	20

In Table 3.4 the economic data used by the model were obtained from The South African Revenue Service (SARS) and Trading Economics.

Table 3.4. Economic Input Data.

Macro Assumptions	Data
Growth rate [22]	2,0%
Corporate Tax [23]	28,00%
VAT [23]	14%
Inflation [22]	5,0%
Reveivables	45 days
Payables	30 days
Nominal Interest Rate [22]	9,0%

3.1.4.1 WACC

The Weighted Average Cost of Capital (WACC) is a leading indicator for valuation of projects. It represents the average rate of return a company expects to compensate all its different investors. In other words, it is the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, or they will invest elsewhere.

$$\textbf{WACC} = ((E/V) * R_e) + [((D/V) * R_d)*(1-T)] \qquad (1)$$

E = Market value of the company's equity
D = Market value of the company's debt
V = Total Market Value of the company (E + D)7
Re[1] = Cost of Equity = Risk Free Rate + Beta * Risk Premium (MRP)
Rd = Cost of Debt = Risk Free Rate of debt + Spread
T= Tax Rate

RFR: Risk Free Rate, and it is typically a long-term US Treasury bond yield as of the valuation date.

Beta: It is a measure of the sensitivity of changes in the returns (dividends plus price changes) of a stock relative to changes in returns of a specific market benchmark or index. It measures a specific market risk.

MRP: It is the rate of return added to a risk-free rate to reflect the additional risk of equity instruments over risk-free instruments.

Spread: Banks usually charge a spread over the cost of the debt.

In Table 3.5 we present the values used by REFIT 2009, 2011 and own calculated with data obtained from NERSA [24], IRENA[25], IEA and Fraunhofer [26]. See Table 3.6.

Table 3.5: Financial Assumptions from REFIT 2009, 2011. Source: NERSA.

Financial Assumptions	REFIT (2009) phase I&II	REFIT (2011) Review	Our Assumptions
Debt share(%)	70.00%	70.00%	65,00%
Equity share(%)	30.00%	30.00%	35,00%
Nominal Cost of Debt (%)	14.90%	9.93%	10,64%
Real Cost of Debt (%)	6.39%	3.71%	7,15%
Real Cost of Equity	17.00%	17.00%	9,91%
Inflation (%)	8.00%	6.00%	5,00%
Tax Rate (%)	28.00%	28.00%	28,00%
Real WACC after Tax (%)	**12.00%**	**9.80%**	**6,91%**

[1]Re también es conocida como la tasa de costo de oportunidad de los accionistas.

Table 3.6. Indexes needed for WACC calculation.

Index	Value
RFR	4,15%
BETA	0,84091963
MRP	6,85%
R_E	**9,91%**
RFR	4,15%
SPREAD	2,80%
R_D	**6,95%**

The leverage for our calculations is 65% -35% (Debt - Equity) since for such a large investment banks are demanding a little more to such a risky investment. Knowing the starting dates of Construction (SOC) assign a reasonable capex milestones as it takes to prepare the solar area. See Table 3.7.

Table 3.7. Capex Milestones Debt and Equity.

Investemt		2012	2013	2014	
Capex Milestones		10%	50%	40%	**Total**
Total	'000R	389.800,00	1.949.000,00	1.559.200,00	**3.898.000,00**
Total Debt	'000R	253.370,00	1.266.850,00	1.013.480,00	**2.533.700,00**
Total Equity	'000R	136.430,00	682.150,00	545.720,00	**1.364.300,00**

3.2.1.2 Main Ratios

Before presenting the key ratios for the economic valuation we need to expose a series of preconceptions.

<u>Free Cash Flow (FCF)</u>

The FCF is the cash flow available for distribution among all shareholders of the organization.

FCF = EBITDA – Taxes – Changes in WC – Capex (2)

EBITDA*:* Earnings Before Interests, Taxes, Depreciation and Amortization. It represents the amount of money that is left after subtracting the OPEX (Operational Expenses) from the Revenues.

Taxes: Represents the Taxes that a company pays for its incomes, but only over the EBT (Earnings Before Taxes). This means, after subtracting the Interests, Depreciations and Amortizations (D&A) corresponding for each year.

Capex: Capital Expenses (amount of the money invested in the project).

Change in WC: the Change in Working Capital represents the remaining amount of money that has to be paid to the suppliers for OPEX mainly minus the amount of money received from the energy sold (the revenues). This remaining amount of money will depend on the Receivables and the Payables.

Discounted Free Cash Flow (FCF)

It refers to the FCF but discounted at a real rate, in this case the WACC.

$$\mathbf{DFCF = FCF / (1+WACC)^{N}}$$

N: number of years transcurred till the calculation takes place.

In figure 3.13 we picture the evolution of the FCF and the discounted FCF taken into account that the first year will be negative due to the initial investment. So the difference between FCF and DFCF is like the following: FCF refers to the actual amount of money at disposal and the discounted FCF reflects its purchasing power, in other words how much can you spend.

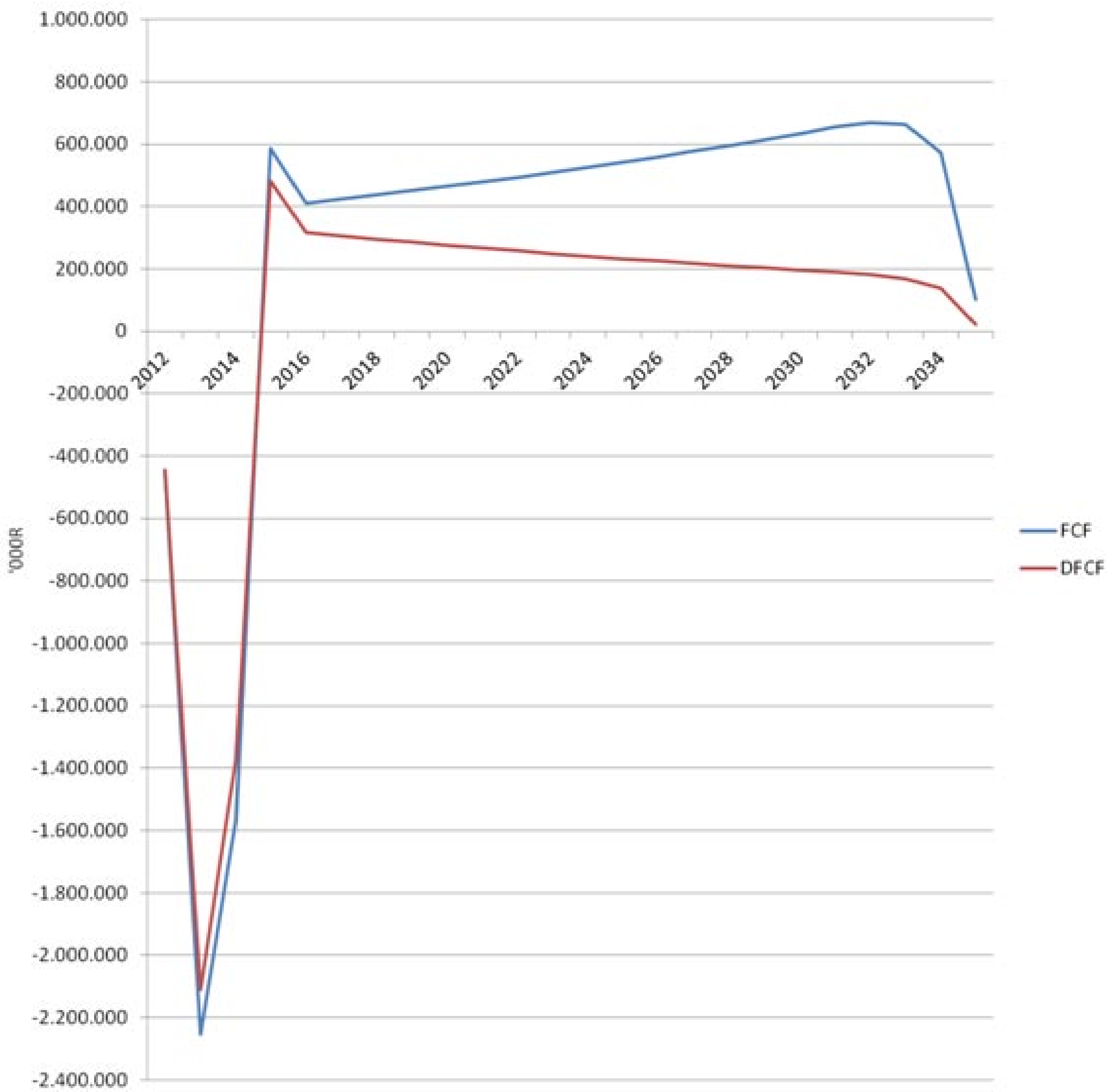

Fig. 3.14: FCF (Normal and Discounted) of the project of analysis.

Net Present Value (NPV)

It represents the present value of a number of future cash flows, resulting from an investment.

$$\mathbf{NPV = - I_0 + \Sigma\ (FCFt/(1+ r)^t)\ (3)}$$

I_0: Initial investment

r: Interest Rate

Therefore an NPV> 0 indicate that the investment would produce earnings above the interest rate.

Internal Rate of Return

The IRR is the discount rate at which the Net Present Value (NPV) = 0, in other words, it represents the maximum return on investment, meaning that, if IRR < WACC, the NPV would be negative and it means we would be destroying value with that investment, therefore projects should only be accepted if IRR is greater than the return demanded by the investors, which in this case is represented by the WACC.

$$\mathbf{0 = - I_0 + \Sigma\ (FCFt/(1+ IRR)^t)\ (4)}$$

In the next table (table 3.8) we can see the IRR and the IRR/WACC using our assumptions.

Table 3.8. IRR and IRR/WACC calculated with our assumptions.

Index		Value
IRR	%	9,39%
IRR/WACC		1.4

Having the WACC by 6,91% the ratio IRR/WACC >1 so that means that the proyect would be profitable. But if we take a look in table 3.5 we also hace the WACC used in REFIT 2009 and 2011 calculations and both values are greater than the 9.39% IRR we obtained in our case.

Enterprise Value

The Enterprise value o Discounted Cash Flow is the net present value (NPV), which is taken as the value or price of the cash flows in question

$$\mathbf{Enterprise\ Value = \Sigma\ (FCF_n/(1+ WACC)^n) + TV_n/(1+WACC)\ \ (5)}$$

TV_n: The Terminal Value (TV) represents the value of the going concern or the residual value of the investment, which is why, it is calculated only for the last year's FCF of the project.

$$\mathbf{TV_n = FCF_n*(1+g)/(WACC-g)\ (6)}$$

The Enterprise Value for this project is **R4.395.124.590**, which is considerably higher than the initial investment.

Equity Value

The Equity Value (EV) is the Enterprise Value minus the net debt.

EV = Enterprise Value – Net Debt (7)

Payback

Normal: Period refers to the time required to recover the initial investment. For that we have to calculate de accumulated FCF and when the first time the value is positive.

Discounted: Refers to the time required to recover the initial investment, factoring in the time value of money. The calculation is similar to the Payback (normal) but using Accumulated Discounted FCF.

We normally use the Payback Discounted in order to negotiate with banks, because this index gives an idea of how long could it take to repay the debt in case the initial investment is fully financed. Next table shows the Payback Period, both normal and discounted of this case.

Table 3.9. Calculated Payback Period (Normal and Discounted).

Payback	Years
Normal	11,05
Discounted	16,32

The following figure represents the accumulated FCF and the accumulated discounted FCF where we can appreciate the payback period. The results are not great but after 16 years the initial investment is fully recovered. Note that the TV is not used in this graph.

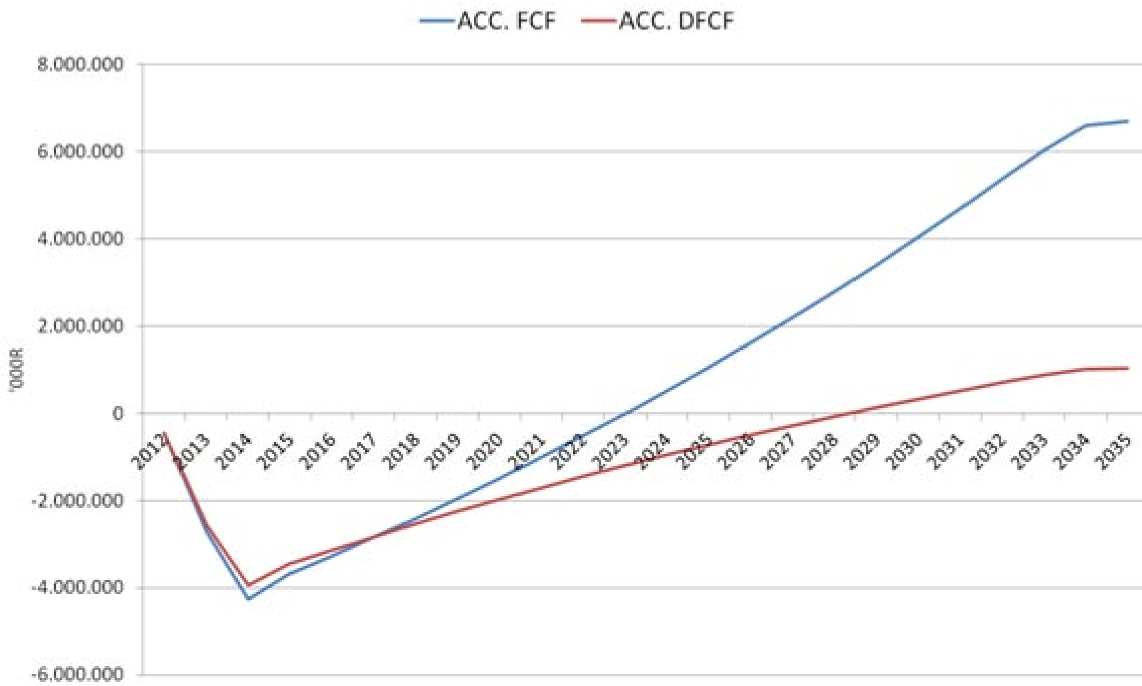

Fig. 3.15: Accumulated FCF (Normal and Discounted) of the project of analysis.

Other Ratios

Table 3.10 show other ratios to be considered in order to compare this project, for instance, to other projects.

Table 3.10. Valuation Ratios.

Ratio		Values
CAPEX/MW	'000R/MW	77.960,00
TOTAL OPEX/MWh	'000R/MWh	5,43
NPV/MW	'000R/MW	87.902,49
NPV/MWh	'000R/MWh	23,63
EQUITY VALUE/MW	'000R/MW	37.228,49
NPV/EBITDA		9,19
NPV/REVENUES		7,59
Terminal Value	'000R	14.333.344,43

Looking at NPV/EBITDA and NPV/Revenues. NPV/EBITDA gives an idea of what is the price of the company compared to its earnings while NPV/Revenues is used to give an idea of how healthy are the finances of an enterprise compared to other. It compares the actual price you would pay for a company (Enterprise Value).

3.2.1.3 Debt Service Coverage Ratio (DSCR) Proposal

The DSCR is the amount of cash flow available for covering the interests and the principal payments derived from a bank loan used to finance a project. The higher this ratio is, the easier it is to obtain a loan.

Table 3.11. DSCR ratios assumptions.

Financial Assumptions			
	Fixed Mid swap	Spread	Total
First 10 years	2,1%	2,5%	4,6%
From 10-20 years	2,1%	3%	5,1%
DSR Letter of Credit Cost.			0,75%

Spread is the difference between the purchase price and the sale of a financial asset. It's kind of margin that is used to measure market liquidity. Usually narrower margins represent a higher level of liquidity.

The mid-swap is the reference rate which is used to calculate the premium that a bond buyer will pay. Adding a spread to a reference rate is one method to value a bond.

The Debt Service Reserve (DSR) Letter of Credit Cost is a promise to pay. Banks usually issue letters of credit as a way to ensure that the 0.75 %, for this specific case, of the one year’s fee is held the year before it should be paid.

In order to calculate the DSCR, we must know first the Operational Cash Flow (OCF) Available.

$$\textbf{OCF = EBITDA – Taxes – Change in WC (8)}$$

Once we’ve calculated the Operational Cash flow for every year and knowing the leverage of the project (the financed amount) we can proceed to calculate the DSCR, see fig. 3.15.

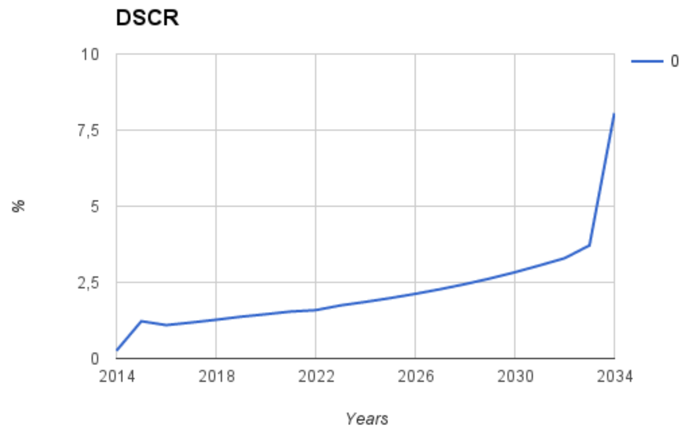

Fig. 3.16: Evolution of DSCR calculated for this case project.

A Sculpted Repayment structure have been chosen to make it more comfortable for the company. By doing so we have to obtain the OCF profile. This is calculated by every year OCF over the the accumulated OCF of the project (Fig. 3.16a) and the repayment is the OCF profile multiplied by the leverage (Fig. 16b).

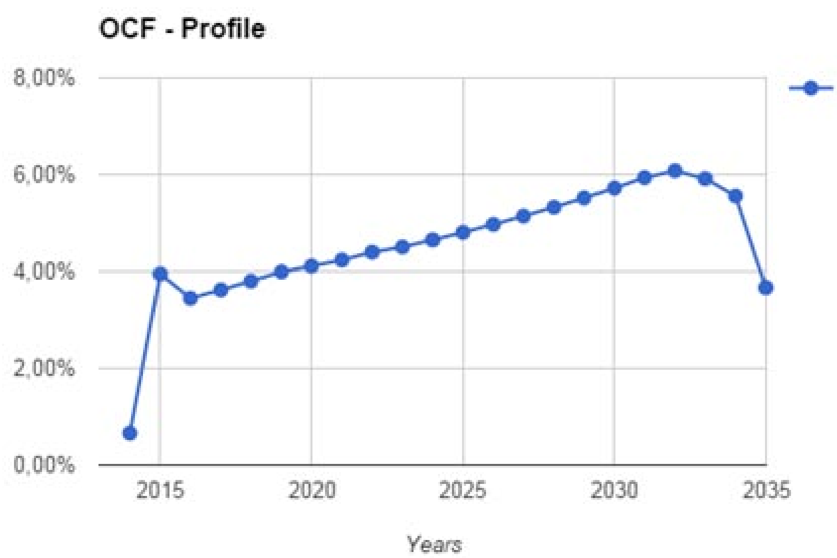

Fig. 3.17a: The proportional of each year variation of the OCF.

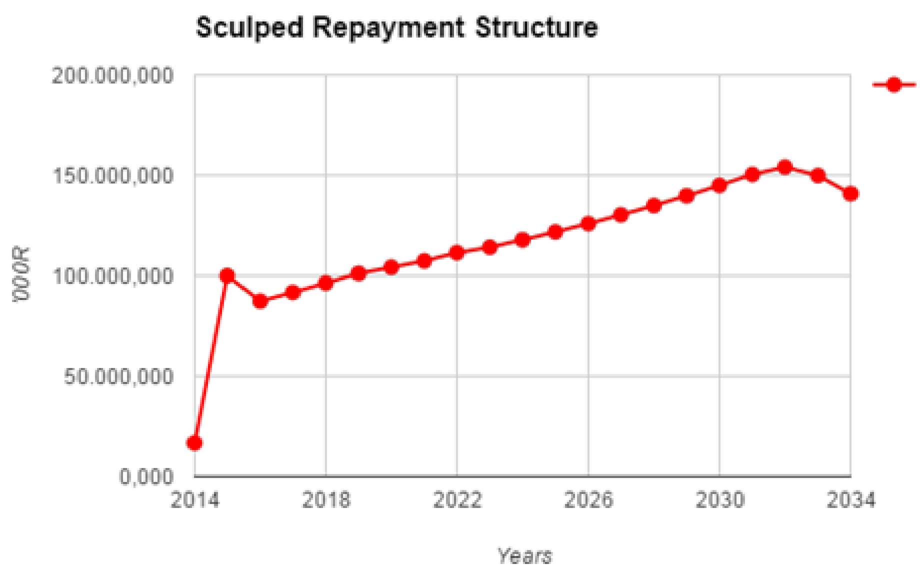

Fig. 3.17b: **Repayment Structure.**

3.2.1.5. Valuation result using REFIT and REIPPPP prices.

In order to appreciate what this project could have been if REIPPPP didn't show up. As we saw before the Accumulated FCF can gives us a simple index to determine the period in which the project recovers from its initial investment.

So we used our spreadsheet model to se different results on the accumulated FCF (Normal and Discounted) using REFIT phase I&II and REFIT phase III in comparison with the PPA.
Next figure shows the different behaviors of each tariff by only changing the energy tariff.

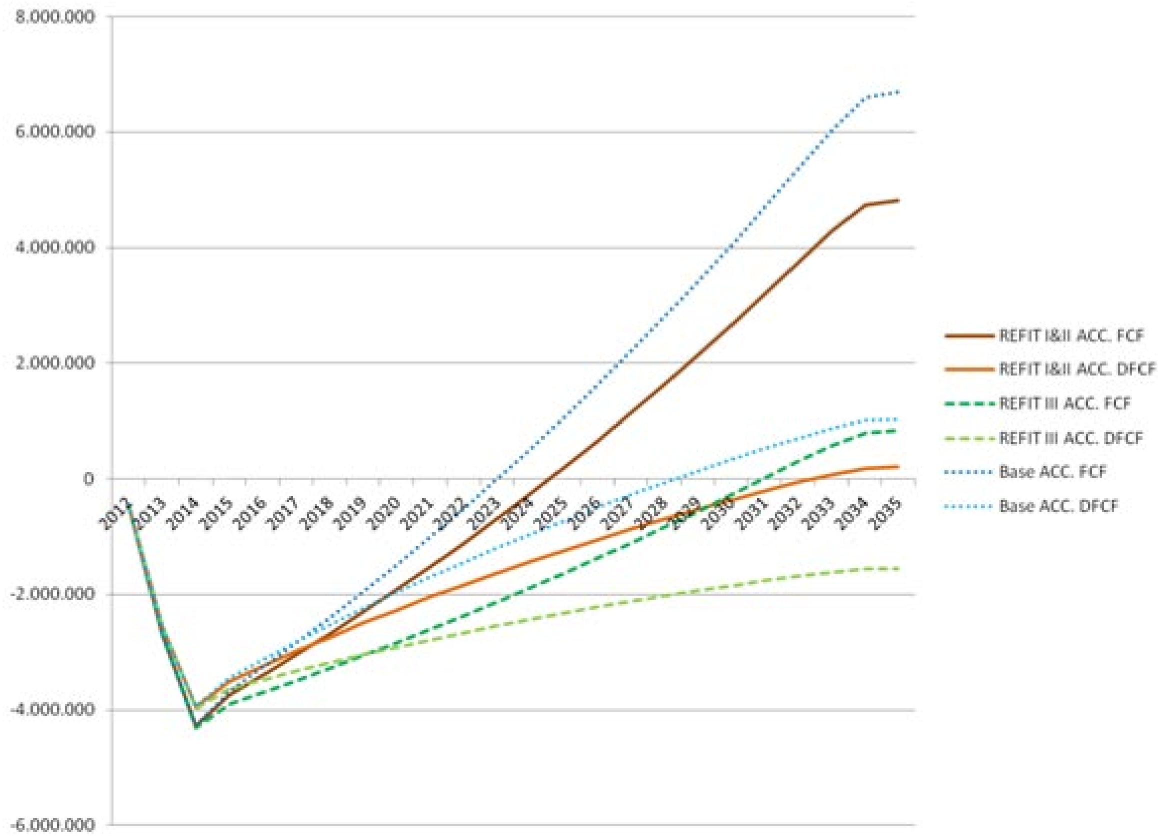

Fig. 3.18: Acc. FCF (Normal and Discounted) for REFIT tariff and REIPPPP PPA tariff.

As we can see with the first REFIT, 2009, the accumulated DFCF was only positive after 20 years having an IRR of 7,28% so the IRR/WACC ratio is 1,08, which is bigger than 1 meaning that the project is slightly profitable. Also the Enterprise Value is lower than the one we calculated with de REIPPPP PPA. See table 3.11 to view all the results.

Table 3.12. Calculated Results, IRR, Enterprise value and IRR/WACC.

Index		REFIT 2009	REFIT 2011	Our Case
IRR	%	7,28%	1,61%	9,39%
Enterprise value	'000R	2.969.872,56	-47.563,96	4.395.124,59
IRR/WACC		1,08	0,24	1,40

Moreover the REFIT 2011 has an IRR/WACC < 1 meaning that the WACC > IRR which means that it would be destroying value with that investment. This is also shown by the enterprise value being negative.

The problem was that the REFIT where based on a LCOE calculated with unaligned O&M values with this project, around 21 % higher than the ones on REFIT and also R808M less capex. See next table.

Table 3.13. REFIT 2011 Macro Assumptions. (Source: NERSA 2011).

PARAMETER	UNITS	CSP power trough without storage	PV Ground/Building-mounted > 1 MW	BIOMASS (solid)	BIOGAS	Concentrating PV without storage	CSP (tower) with storage of 6 hrs per day
Capital cost: enginneering procurement & construction (EPC)	$/kW	4700	4900	3000	2750	6841	5638
Land cost	%	2%	2%	2%	2%	2%	2%
Allowance for funds under construction (AFUC)	%	4.4%	0.0%	4.4%	4.4%	4%	4.4%
Tx/Dx integration cost	%	3%	3%	3%	3%	3%	3%
Storage (CSP)	%						
TOTAL INVESTMENT COST	**$/kW**	**5152**	**5145**	**3289**	**3015**	**7499**	6180
Fixed O&M	2009$/kW/yr	66	16.19	54	170	64	66
Variable O&M	2009$/kWh			0.0032	0.00001		
Economic life	years	20	20	20	20	20	20
Discount rate real after tax	%	12%	12%	12%	12%	12%	12%
Plant lead time	years	2	1	2	2	2	2
Fuel type		renewable	renewable	renewable	renewable	renewable	renewable
Fuel cost	$/10^6BTU			3			
Fuel cost	$/kWh	-	-	-	-	-	
Heat rate	BTU/kWh	-	-	15750	-	-	
Assumed load factor	%	25%	16%	80%	80%	20%	40%
Levelised cost of electricity	**$/kWh**	**0.3132**	**0.4488**	**0.1181**	**0.0962**	**0.5481**	**0.2308**
Exchange Rate R/$	ZAR/$	10	10	10	10	10	10
Levelised cost of electricity	**R/kWh**	**3.132**	**4.488**	**1.181**	**0.962**	**5.481**	**2.308**

Chapter 4

Future Developments: IMASA's Alternative Dry Cooling Technology

4.1 Rankine Cycle

The Rankine cycle is the fundamental operating cycle of all power plants where an operating fluid is continuously evaporated and condensed. The selection of operating fluid depends mainly on the available temperature range. As we can see in Fig. 4.1

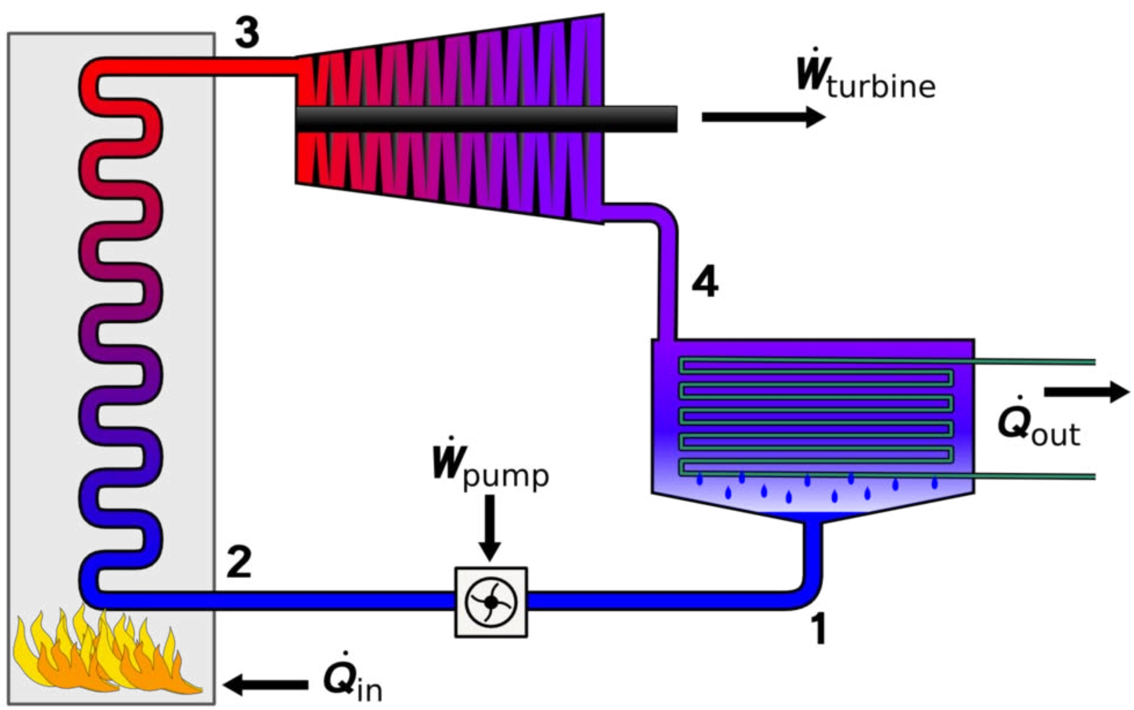

Fig. 4.1. Rankine Cycle scheme. Source: Wikipedia

As is known in the energy industry, its efficiency is limited by the thermodynamic efficiency of a Carnot cycle operating between two heat reservoirs. The main advantage of this cycle is its industrial maturity, thanks to a long and continuous development as well as its high applicability.

To cool the hot reservoir to the turbine outlet was typically using water but at present, water availability is becoming increasingly scarce and in turn is increasingly expensive commodity. This is the case experienced by Khi Solar One which decided to use a dry cooling technology for this process.

4.2 Hygroscopic Cycle

This innovative evolution of the Rankine cycle to work with hygroscopic compounds that contribute to improve the conditions for condensation of steam leaving the turbine. The hygroscopic cycle uses the physical and chemical principles of absorption machines to provide the Rankine cycle a higher performance and better cooling conditions in an efficient and practical system.

Hygroscopic compounds are not volatile, toxic or flammable, but stable, abundant and cheap. They are generally salts (LiBr, NaCl, Na_2SO_4 among others) their solutions with increasing water temperatures allow condensation through absorption with hygroscopic compounds, unlike the Rankine cycle, less pressure could be achieved at the output of the turbine at the same cooling temperature or condense at a higher temperature for the same pressures condensation. A careful choice of these compounds can achieve greater absortion thus consuming less water. The rest of the energy is dissipated through an air cooler condenser. Hygroscopic cycle configuration is simple, just by putting an absorber where they contact the hygroscopic salts with the turbine exhaust steam which is intended to condense [27].

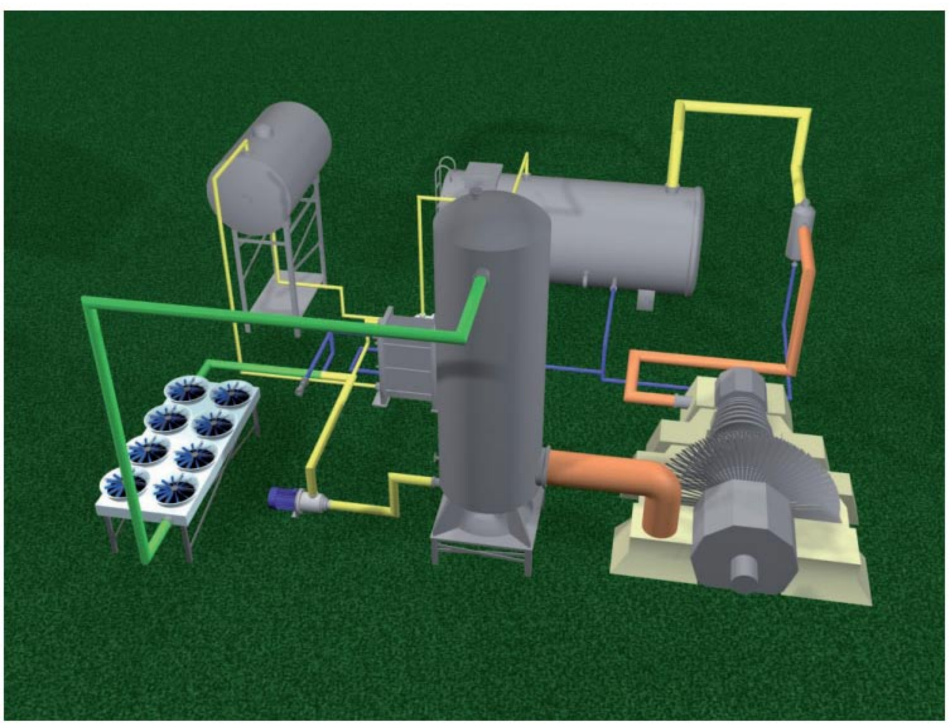

Fig. 4.2. 3D Model of the hygroscopic Cycle. Source: IMASA.

To enumerate the various advantages of this method of dry cooling against existing technologies, we can see the following table below about the investment with approximate values for the different technologies to install dry cooling to a project like Khi Solar One.

Table 4.1. Aproximated investment required by Dry Cooling technologies.

	Technologia		
Inversión	Air Cooled Condenser	Natural Draft Condenser	Hygroscopic Cycle
Montaje y	4 M€	2,5 M€	0,5 M€
Suministros	7 M€	5 M€	3,5 M€
Total[1]	11 M€	7,5 M€	4 M€

As it can be seen the hygroscopic cycle is a considerably lower investment than the other technologies, one of its key features is that they are intended to be modules connected in series easily assembled with what brings in less spending erection cost.

Conclusions

As we have seen, the investment required by CSP today isn’t profitable if there is no mechanism to encourage this kind of projects.

For the time being this technology needs to be improved in order to reach lower LCOE than to other technologies and assuming that they are likely to suffer from higher taxes taking into account that they are not friendly with the environment.

But even through these projects they develop new alternatives that benefit not only the CSP but also to other technologies. As we saw the Dry Cooling can reduce water consumption by 66% compared to wet cooling. Water is a scarce resource and we must begin to treat it as urgent.

The CSP is able to operate at peak demand thanks to its thermal storage, which is why it is expected that in future 20% of the energy comes from a similar technology.

The global warming is a fact that we can perceive every year. The Kyoto Protocol has to regain its strength if we all want to have a sustainable world. If we regain this, CSP technology could be the future Base Load Power Plant powered by a renewable source.

Quality Report

Even if this work is about a project of another company, IMASA has participated in many CSP project in Spain and now Worldwide. The only problem is confidentiality, so we could only use public information. However we believe that the values, ratios, etcetera are very approximate to reality.

Undoubtedly such restrictions limit you when evaluating a project concerning the economic part of it. The complaint expressed by developers REFIT was justified, and we could show that the problem was a bad appreciation of the macro assumptions calculations and trends.

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ANNEXES

Annex 1:

Work Carried Out in the Host Institution

The Institution

IMASA, ENGINEERING PROJECTS, SA, headquartered in Oviedo (Spain), becomes the 70's as a company dedicated to the implementation of projects and the maintenance and erection of industrial facilities.

Thanks to the excellent professionals who have worked throughout our history and the ones are working with us to advance and improve our technological capabilities, and the evolution of our processes, currently IMASA leads a group of companies with multidisciplinary and presence in different sectors and industries employing approximately 1,200 workers.

Throughout its existence IMASA has incorporated new business areas, promoting excellence in its products and services. We are committed to research and development; we can position ourselves internationally as already seen in this thesis. The experience in the industry and know how acquired in the execution part of work has given us an advantage to offer attractive alternatives and solutions for our customers position.

We are constantly being awarded new projects for solar thermal plants due to the confidence generated that gives us our experience with more than 13 solar thermal plants in Spain and 5 out of Spain (3 South Africa, 1 in Morocco, 1 in Chile).

International Tender Department and Economic and Financial Department

This is my sixth year at IMASA and dynamics is very agile as our customers need emergency and we sell this added value .

The International Tender Department are responsible for studying the offer and make a technical-economic assessment to present to the customer our proposal. The proposals submitted by Jorge Quirós managed to have had participation in the 3 solar thermal plants planned by Abengoa in Sudáfirca (Khi, Kaxu and recently Xina).

Alberto Martinez Diaz is responsible for the economic and financial department of our division, Maintenance and Assembly Aviles, and was commissioned to develop a funding plan for the works abroad. South Africa in particular, this has been a challenge because it required a great effort from IMASA. However disposing of the necessary tools and models, our creditors had a continuous evolution of the project achieving almost perfect estimations.

Activities Carried Out

- Thanks to the model of Project Finance learnt in the master, we could adapt it to extrapolate to our works abroad. Thanks to prior knowledge, we could develop a very visible tool for decision making.

- To automatically feed the monitoring of the project mentioned in the previous model, we develop a multiplatform tool to carry cash flows, accounting closures and control of on-site billing.

  At the beginning of each project, equivalences between accounting accounts of the country of the project and budgetary chapters, used in our International Tender Department, are set. With this we have a general view of all international projects.

- Nowadays we have a tool that is used in all international subsidiaries of IMASA such as (Chile, Peru, Bolivia, Morocco and South Africa).

Annex 2:

External Master Thesis Evaluation Form

Student's Information

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Title of the Master Thesis

Khi Solar One Project Overview and Economic Analysis.

Advisors

NIF	Full Name:	Institution:
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11399895Z	Alberto Martínez Díaz	IMASA INGENIERIA Y PROYECTOS S.A.
52614505G	Jorge Quirós Alonso	IMASA INGENIERIA Y PROYECTOS S.A.

Alberto Martínez Díaz

Jorge Quirós Alonso

Evaluation Report of the Master Thesis

(To be completed by the Co-Advisor of the Host Institution)

Report	
The student's Ability to generate all type of calculations making useful dashboard, giving us a great tool in order to compare different types of projects. He was commissioned to keep the department on progress of the work and through the creation of a software tool that it could have daily cost controls and billing to facilitated the task to show progress to our investors and creditors. It is worth mentioning that the student was always predisposed to undermine information establishing informal contacts to achieve objectives.	
Topic	**Grade,** from 0 (min) up to 10 (max)
Integration of the student	8,5
Ability to adapt to the institution	9
Technical quality of the work	8
Degree of accomplishment of the objectives of the Master Thesis	9
Student's ability to solve problems autonomously	9
Average Grade	**8.5**

Alberto Martínez Díaz

Jorge Quirós Alonso