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Robust Design of Thermal Solar Power Station Using System Advisor Model (SAM) Software as the First Pilot Project in Palestine

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أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Robust Design of Thermal Solar Power Station Using System Advisor Model (SAM) Software as the First Pilot Project in Palestine

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **نادر سليمان داود طالب** لنيل درجة الماجستير في **كلية *الهندسة*** **قسم الهندسة الكهربائية – أنظمة التحكم** وموضوعها:

تصميم متين لمحطة توليد الكهرباء بالطاقة الشمسية الحرارية باستخدام برنامج (SAM) كأول مشروع تجريبي في فلسطين

Robust Design of Thermal Solar Power Station Using System Advisor Model (SAM) Software as the First Pilot Project in Palestine

وبعد المناقشة التي تمت اليوم الثلاثاء 28 رجب 1435هـ، الموافق 2014/05/27م الساعة الحادية عشر صباحاً بمبنى طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم **الهندسة الكهربائية – أنظمة التحكم**.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

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ABSTRACT

Concentrating solar power (CSP) imposes itself as a new and efficient renewable energy technology. This technology will be extremely helpful in improving the quality of life for many people around the world who lack the energy needed to live a healthy life. However, the cost of electricity from contemporary solar thermal power plants remains high, despite several decades of development, and a step-change in technology is needed to drive down costs.

Construction of the first thermal solar power plant in Palestine is complicated by the lack of an established, standardized and power plant configuration, which presents the designer with a large number of choices. To assist decision making, thermo-economic studies have been performed on a variety of different power plant configurations until reaching good results and performance.

In this thesis, a robust design of thermal solar power plant as a pilot project is designed. The design starts with modeling the solar radiation for Gaza Strip location, reviewing different parts of the system which are solar collectors, receivers, thermal storage system and power generation system, and ends with designing a solar power plant for the Turkish-Palestinian friendship hospital in Al-Zahra town with net output power of 5.40 MW. The technology of parabolic trough collector (PTC) is chosen, then modeling of the proposed system is done using system advisor model (SAM) software.

This thesis evaluated the designed method and shows good results in the presence of uncertainty and the project achieved better price for electricity than the present price in Gaza Strip by a percentage of 3.5% in addition to environmentally friendly power.

ملخص

فرضت الطاقة الشمسية المركزة نفسها كتكنولوجيا طاقة متجددة جديدة وفعالة. هذه التكنولوجيا سوف تكون مفيدة للغاية في تحسين نوعية الحياة بالنسبة لكثير من الناس في جميع أنحاء العالم الذين يفتقرون إلى الطاقة اللازمة للعيش حياة رغيدة. ومع ذلك ، فإن تكلفة الكهرباء من محطات الطاقة الحرارية الشمسية المعاصرة ما زالت عالية، على الرغم من عدة عقود من التطوير، ويلزم خطوة تغيير في التكنولوجيا لخفض التكاليف.

بناء أول محطة للطاقة الشمسية الحرارية في فلسطين معقد بسبب عدم وجود المعايير المعمول بها و الإعدادات اللازمة لمحطة توليد الكهرباء، والتي تضع المصمم مع كبير عدد من الخيارات . للمساعدة في اتخاذ القرار أجريت دراسات الحرارية الاقتصادية على أشكال متنوعة من تكوينات محطة الطاقة لحين التوصل إلى نتائج وأداء جيد.

في هذه الأطروحة ، تم تصميم نظام متين من محطة للطاقة الحرارية الشمسية كمشروع تجريبي. التصميم بدأ بنمذجة الإشعاع الشمسي لموقع قطاع غزة ، ثم عرض مختلف أجزاء النظام التي هي مجمعات الطاقة الشمسية ، وأجهزة الاستقبال ، ونظام التخزين الحراري و نظام توليد الكهرباء ، وينتهي بتصميم محطة الطاقة الشمسية الحرارية لمستشفى الصداقة التركي الفلسطيني في مدينة الزهراء مع صافي انتاج 5.40 ميغاواط من الطاقة الكهربية.

تم اختيار تكنولوجيا المجمع المكافئ (PTC)، وتم بعد ذلك نمذجة النظام المقترح باستخدام برنامج (SAM). هذه الأطروحة تقيم طريقة تصميمها و تظهر نتائج جيدة في ظل وجود عدم اليقين، والمشروع حقق أفضل سعر أفضل للكهرباء من الأسعار الحالية في قطاع غزة من قبل بنسبة تحسين 3.5 ٪ بالإضافة إلى الطاقة الصديقة للبيئة.

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At the beginning, I thank ALLAH the compassionate for giving me the strength and health to let this work see the light.

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DEDICATION

To my first teacher who gave me strength … My father.

To her who planted love in my heart … My mother.

To noble spirit, for my dear life partner … My wife.

To my lovely kids … Zaina, Nada and Haya.

To the symbols of love … My brothers and sister.

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LIST OF ABBREVIATION

International Energy Agency	IEA
Photovoltaic cell	PV
Concentrated Solar Power	CSP
Heat Transfer Fluid	HTF
Gaza Power Generation Company	GPGC
Concentrating Solar Thermal Electric System	CSTES
Parabolic Trough Collectors	PTC
System Advisor Model	SAM
Direct Steam Generation	DSG
Central Receiver Solar Power Plant	CRSPP
Solar Thermal Electric Component	STEC
Solar Electric Generating System	SEGS
Incidence Angle Modifier	IAM
National Renewable Energy Laboratory	NREL
Solar Collector Assemblies	SCA
Direct Normal Insolation	DNI
Heat Collection Element	HCE
Power of Hydrogen	PH
Chlorofluorocarbon	CFC
Thermal Energy Storage	TES
High Pressure	HP
Low Pressure	LP
Power Purchase Agreement	PPA
Time-Of-Delivery	TOD
Levelized cost of energy	LCOE
Internal Rate of Return	IRR
Net Present Value	NPV
Independent Power Producer	IPP

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In our life today, problems of energy that caused by global warming and pollution effect become important issues for researches. Renewable energy sources are considered as a technological option for generating clean energy.

One of the most used kinds of green energy is solar energy. Solar energy shows great promise as a renewable energy resource; it is clean, abundant, reliable, renewable, freely available and inexhaustible. Solar energy systems are now widely used for a variety of industrial and domestic applications especially in generating electricity. International energy agency (IEA) stated in 2010, that the net consumption of electricity power generated from renewable energy sources increases over time to become by 2015 the major portion [1].

Solar system is based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. In the space of ninety minutes, enough sunlight strikes the earth's surface will fuel the world's energy needs for a full year. The only problem on the way of using solar power plants is the high cost of setting up and operating them. So among some ways of controlling and monitoring of these systems, those will lower costs and hold good reliability for these systems.

Because the sun radiation to the ground affected by the climate, latitude, longitude and other natural conditions, it put higher requirements for collection and utilization of solar energy. The use of automatic sun tracking device to improve the utilization of solar energy is an important way. Theoretical analysis shows that there is difference of about 37% between the solar panel tracking energy and non-tracking [2].

The use of a tracking mechanism increases the amount of solar energy received by the solar collectors resulting to a higher output power. The available amount of solar energy also depends upon the location. In general, the amount of usable solar energy is contingent upon the available solar energy, other weather conditions, the technology utilized, and the intended application.

Solar power plant work to convert sunlight into electricity, either directly using photovoltaic cells (PVs), or indirectly using concentrated solar power (CSP). CSP systems use either lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam, while PVs convert light into electric current using the photoelectric effect.

CSP is one of such renewable energy sources which came into light in the late 20^{th} and early 21^{st} century [3]. Initially, CSP was used for small scale solar thermal-mechanical applications, with outputs reaching up to 100 Kilowatt (KW), mainly for water pumping. Only after the energy crises of 1973 did the idea of large-scale solar power plants took hold.

In CSP technology, the incident solar radiations are reflected onto the receiver placed at the focal point (or along the focal line, in case of line-focusing CSP) to increase the temperature of the surface up to even 1400 $^{\circ}$C. The gained heat energy by heat transfer fluid (HTF) or working fluid is then transformed into the usable form of energy such as electricity using turbines and generators. Today, CSP represents a reliable technology for electricity generation with a global installed capacity that exceeds the 2 Giga watt electrical (GWe).

In September 2013, the biggest solar thermal power plant was fired up in California, which is once fully operational. The project is expected to produce 377 Megawatt (MW) of net power and during some days it could provide enough power for more than 200,000 homes. India will also build the largest solar plant in the world to generate 4000 MW from sunlight near the Sambhar lake in Rajasthan with the intention to finish the first part of the project in 2016 with net power reaching up to 1000 MW. These projects reflect the world moving towards CSP technology to generate electricity and use renewable energy rather than fossil fuels.

1.2 Motivation

In recent years, Gaza Strip suffers from limited electric sources that due to problems in Israeli feeders or lack of fuel for Gaza power generation company (GPGC), which lead people to find alternative solution to this problem using small generators, inverters and solar cells.

The provision of a sustainable energy supply is one of the most important issues facing humanity at the current time, and solar thermal power has established itself as one of the more viable sources of renewable energy. Also, it achieves better efficiency than PV cells.

In addition to the electrical problem presented, Gaza Strip is 360 km^2 and has an excellent solar location with 2135 kWh/m^2/year irradiation [4]. These reasons motivated me to investigate the theoretical performance of a concentrating solar thermal electric system (CSTES) using a field of Parabolic Trough Collector (PTC). This thesis presents a design of thermal solar power station with self-tracking mechanism for the Turkish-Palestinian Friendship Hospital at the Islamic University land located in Al-Zahra town with net power of 5.40 MWe. The design is made using System Advisor Model (SAM) software which presents economic feasibility study for the project in addition to the technical design.

1.3 Problem statement

As it is well known in our country, there is a big problem in electrical power generation, since sources of electricity are limited and are not enough to meet all people requirements. Also, we see that a lot of countries moving toward using thermal solar power plants in producing electricity.

For this reasons, this thesis seeks to find alternative solution for electric power problem that we face in Gaza Strip, so that, it presents theoretical performance of PTC, and then apply this technique on the Turkish-Palestinian Friendship Hospital at the Islamic University land as a case study. This work can be applied practically (if the funding available) so that we can get electricity for the hospital with efficient and clean method. Note that, this project can apply to any location in our country if area and fund are available.

1.4 Research methodology

In this thesis, systematic modeling and design procedures for overall PTC solar substation are developed. The procedure of this thesis is as follows:

1. Collecting wanted data about the research subject from related papers, books, journals, previous researches and internet.
2. Modeling the weather data base for Gaza Strip using Meteonorm software with help of Bet Dagan weather database to use it in simulation part.
3. Modeling and design the different parts of our system, which are the parabolic trough collector, receiver, thermal storage and power generation system in the presence of uncertainty affected on the system.
4. Implementing the proposed thermal solar power plant on SAM software with self-tracking.
5. Testing the system and check results obtained from overall system.

1.5 Literature review

Several researches were proposed in this field as shown below:

- R. Desai proposed a study of thermo-economic analysis of a solar thermal power plant with a central tower receiver for Direct Steam Generation (DSG). The goal of his study was to evaluate the thermodynamic and economic performance of one of these plants by establishing a dynamic simulation model and coupling it with in-house cost functions. He proved that these plants had the benefit of working with a single HTF and reached to higher temperatures than conventional parabolic trough CSP plants. This increased the efficiency of the power plant. He used the TRNSYS simulation studio together with MATLAB for post processing calculations and achieved good results [5].
- O. H. Abdulla et. al presented steady state and transient studies to assess the impact of a 200 MW central receiver solar power plant (CRSPP) connection on the main interconnected transmission system of Oman. They proposed the 2015 updated transmission grid model and included the simulation of the proposed 200 MW CRSPP using the DIGSILENT power factory professional software. Their results were shown that the steady state and transient responses for the proposed plant were acceptable [6].
- Y. Usta investigated the theoretical performance of a CSTES in Turkey using a field of PTC. She used the commercial software TRNSYS and the Solar Thermal Electric Component (STEC) library to model and simulate the overall system. The model was constructed using data for solar electric generating system (SEGS) VI. She found good agreement between the model's predictions and published data with errors usually less than 10%. Also, she compared the output results for two systems in terms of absolute monthly outputs and in terms of ratios of minimum to maximum monthly outputs [7].
- M. Dicorato et, al investigated a concentrating solar trough plant, having nominal power equal to 100 KWe and exploiting linear PTC to generate electricity by means of Organic Rankine cycle turbine. They developed a model to estimate solar radiation on a sun tracking surface, in order to minimize the angle of incidence and thus maximize the incident beam radiation. Also, they examined a suitable inclination of the North-South rotation axis on the horizontal plane. They proved that, tracking system with inclined rotation axis on the horizontal plane have yielded better results compared with those from biaxial sun tracking [8].

- M. Jahromi et. al presented modeling for the linear parabolic solar power plant via system identification, and nonlinear model for Shiraz solar power plant. In the proposed model, the input and output were assumed to be the entering oil flow and outgoing oil temperature. The ARX linear model was proposed and evaluated with the use of input-output data, noise and disturbance. In addition, they calculated the input, output, and delay coefficient in optimized state by applying MATLAB software. Their results showed that the method they used it was efficient [9].
- Jones et al. developed a detailed performance model of the 30 MWe SEGS VI parabolic trough plant which was created in the TRNSYS simulation environment using the STEC model library. The power cycle and solar collector performance were modeled, but unlike the actual system natural, gas-fired hybrid operation was not modeled. Good agreement is obtained when comparing the results of their model with plant measurements, and errors percentages were less than 10% [10].

1.6 Contribution

This research of thermal solar power system is very useful and attractive for many researchers and practitioners especially for electrical engineers. According to the issues related to electric power demand, design and evaluation process of the system has been developed here step by step using SAM software, which is a great program for this field.

Developing thermal solar power plant in Gaza Strip for the first time with feasibility study for building real system for the Turkish-Palestinian Hospital at the Islamic University of Gaza is considered main contribution to this research.

1.7 Thesis outline

There are six chapters in this thesis; Chapter 2 presents the study of solar radiation fundamentals and solar data for Gaza Strip obtained by Meteonorm software. Chapter 3 covers briefly the parabolic trough collector solar power plant components. Chapter 4 presents input parameters for each section of the system in SAM software. Chapter 5 demonstrates results for the design of a thermal solar power plant for the Turkish-Palestinian hospital with the presence of uncertainty in system parameters. Finally chapter 6 ends up with conclusion, recommendations, and future work.

CHAPTER TWO

SOLAR RADIATION

2.1 Introduction

Detailed information about solar radiation availability at any location is essential for the design and economic evaluation of parabolic trough solar power plants. Therefore, precise knowledge of historical global solar radiation at a location of study is required for the design of any funded solar energy project. Long term measured data of solar radiation are available for a large number of locations in different parts of the world.

Unfortunately, no meteorological stations are available in Gaza Strip to measure the amount of intercepted solar radiation in Gaza Strip. So an alternative method for estimation of solar radiation is required, and different satellite models can be used to estimate the solar energy availability.

Note that, according to [11] the solar radiation level for both areas Gaza Strip and Bet Dagan are similar, so, the weather database available for Bet Dagan can be slightly changed by data obtained from Meteonorm software and used it in this thesis to represent weather data for Gaza Strip.

The energy contained in the direct normal radiation is harvested by the concentrating collectors of a solar field. By reflecting the received normal direct radiation to the absorber, thermal energy is produced and transported to the power block. Conventional technology is used to convert this energy into electrical energy. Therefore the incoming radiation can be seen as the *fuel* of a CSP plant. For a precise calculation of the CSP plant performance, it is essential to understand the geometrical relations between the sun and earth at any time of the day.

2.2 Solar radiation fundamentals

As a study of solar radiation that strikes the earth's surface, some definitions must be known.

It is important to introduce some definitions for beam radiation angles. These angles describe the relationship between the oncoming sun radiation from the sun and any plane on the earth with a specific position. Figure (2.1) shows some of these angles.

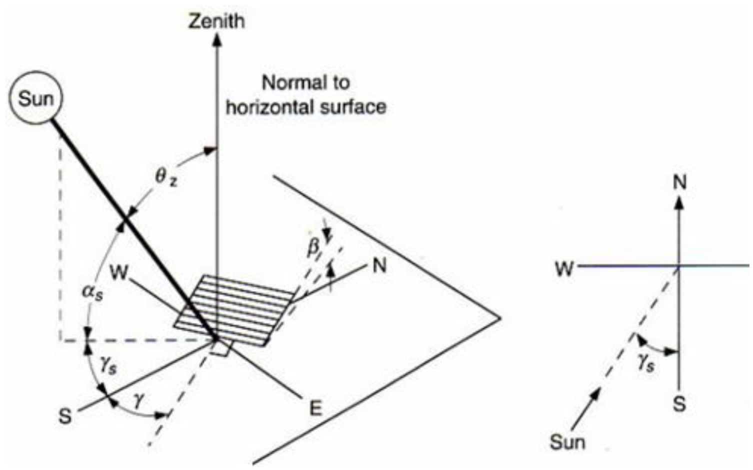


Figure (2.1): Solar angles [3].

The variation in seasonal solar radiation availability at the surface of the earth can be understood from the geometry of the relative movement of the earth around the sun. The distance between the earth and the sun changes throughout the year, the minimum being 1.471×10^{11} m at winter solstice (December 21), and the maximum being 1.521×10^{11} m at summer solstice (June 21). The year round average earth-sun distance is 1.496×10^{11} m. The amount of solar radiation intercepted by the earth, therefore varies throughout the year, the maximum being on December 21, and the minimum on June 21 as shown in figure (2.2) [12].

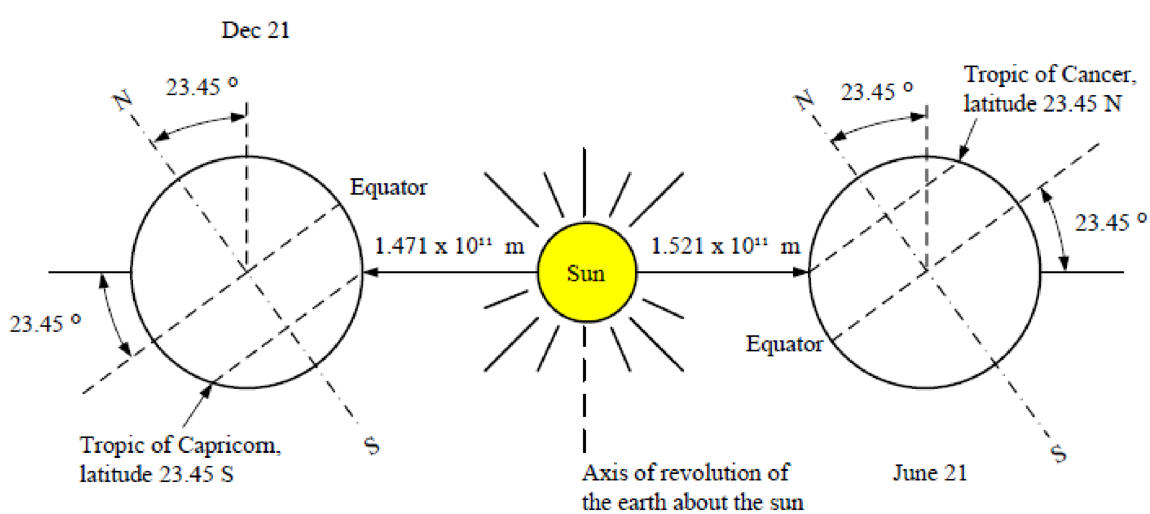


Figure (2.2): Motion of the earth about the sun.

The axis of the earth's daily rotation around itself is at an angle of 23.45 ° to the axis of its ecliptic orbital plane around the sun. This tilt is the major cause of the seasonal variation of the solar radiation available at any location on the earth. In this regards, important information about this angles should be known.

- **Latitude (ϕ)** is the location of site we interested in with respect to the equator, where ϕ varies from -90 in South to +90 in North.
- **Declination angle (δ)** is the angle between the earth-sun line (through their center) and the plane through the equator. The declination angle varies between -23.45° on December 21 to +23.45° on June 21. The solar declination angle is given by equation (2.1).

$$\delta = 23.45° \sin\left(\frac{360(284+n)}{365}\right) \tag{2.1}$$

Where n is the day number with January 1 being n = 1 to 31st December being n = 365.

In general, the declination is assumed to remain constant during a specific day. The analysis of the sun motion is based on the Ptolemaic theory, which assumes that the earth is fixed and the sun rotates around the earth. The Ptolemaic view describes the relative sun motion with a coordinate system fixed to the earth with its origin at the location of interest.

- **Hour angle (ω)** is the angular presentation of hour for solar time. It is based on the nominal time of 24 hours required for the sun to move 360° around the earth (or 15° per hour). $\omega = 0$ at 12:00 solar noon, and in the range of $-180 \leq \omega \leq 180$ before and after 12:00. The solar hour angle can be calculated from equation (2.2).

$$\omega = 15° \, (t_s - 12) \tag{2.2}$$

Where t_s is the solar time in hours. The solar time is calculated from the local time by equation (2.3) [12].

$$t_s = t + EOT + (l_{st} - l_{local}) \, 4 \, min/degree \tag{2.3}$$

Where l_{st} is the standard time meridian, l_{local} is the local time meridian and EOT is the equation of time, which accounts for the variation of the rotational speed of the earth. An approximation for calculating EOT in minutes is given by Woolf [13], and is accurate to within about 30 seconds during daylight hours.

$$EOT = 0.258\cos(x) - 7.416\sin(x) - 3.648\cos(2x) - 9.228\sin(2x) \tag{2.4}$$

Where x can be calculated as:

$$x = \frac{360(n-1)}{365.242} \tag{2.5}$$

- **Slope (β)** is the angle between the horizontal surface and the inclined plane. By another expression, it is the tilt angle.

- **Surface azimuth angle (γ)** is the angle between the projection of the plane on horizontal and the south direction. This angle has a range of -180 ≤ γ ≤ 180 from East to West.
- **Solar azimuth angle (γ_s)** is the angle between a due south line and the horizontal projection of the line joining the site to the sun. The sign convention used for azimuth angle is positive for West of South and negative for East of South. Solar azimuth angle can be calculated using equation (2.6).

$$\gamma_s = sin^{-1}\left(\frac{\sin(\omega)\cos(\delta)}{\cos(\boldsymbol{\alpha_s})}\right) \tag{2.6}$$

- **Solar altitude angle (α_s)** is the angle between a line collinear with the sun rays and the horizontal plane. Equation (2.7) is used to calculate the solar altitude angle.

$$\alpha_s = sin^{-1}(sin(\delta)\,sin(\varphi) + cos(\delta)\,cos(\varphi)\,cos(\omega)) \tag{2.7}$$

- **Zenith angle (θ_z)** is the angle between the oncoming beam radiation and the normal on the horizontal surface. It is the complement of altitude angle.

$$\theta_z = \ 90 \ - \ \alpha_s \tag{2.8}$$

- **Angle of incidence (θ)** is the angle between the oncoming beam radiation and the normal on an inclined surface. Figure (2.3) illustrates the angle of incidence between the collector normal and the beam radiation on a parabolic trough. The angle of incidence results from the relationship between the sun's position in the sky and the orientation of the collectors for a given location.

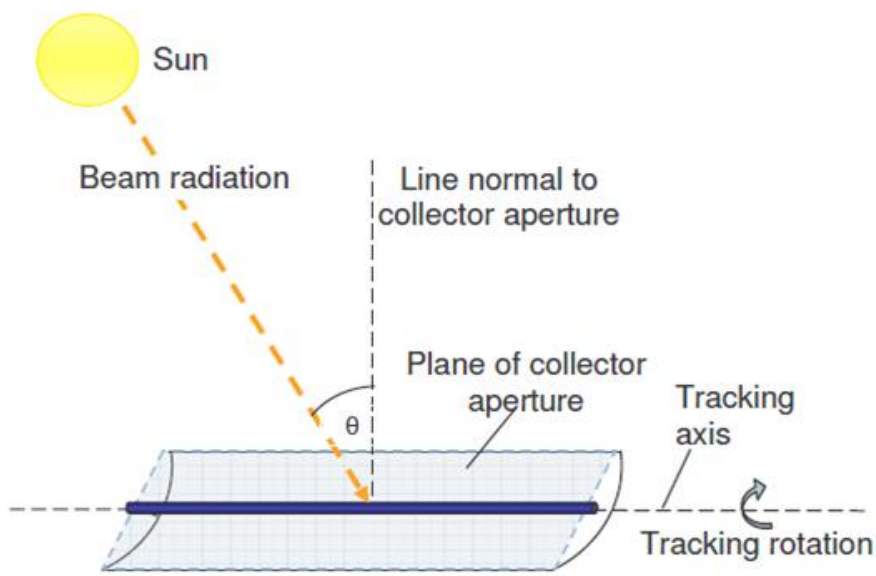


Figure (2.3): Angle of incidence on a parabolic trough collector [14].

The relation between the angle of incidence and the solar position angles for the plane of collector aperture is given by equation (2.9) [15].

$$\cos(\theta) = \sin(\delta)\sin(\varphi)\cos(\beta) - \sin(\delta)\cos(\varphi)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\varphi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\varphi)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega) \quad (2.9)$$

For horizontal surface ($\beta = 0$), the incidence angle = zenith angle as in equation (2.10).

$$\cos(\theta_z) = cos(\delta)\cos(\varphi)\cos(\omega) + \sin(\delta)\sin(\varphi) \quad (2.10)$$

2.3 Sun collector geometry

For the operation of a CSP plant, temperatures of around 400°C are necessary. These high temperatures cannot be reached with a flat plate collector, therefore concentrating collectors are used. The direct normal radiation reaching the collector is concentrated on the absorber tube located in the focal point of the parabolic collector. The most important characteristic factor therefore is the concentration ratio. It is defined as the aperture area in relation to the absorber area as shown in equation (2.11) [16].

$$C = \frac{A_a}{A_{abs}} \quad (2.11)$$

Where A_a is the aperture area of parabolic collector, and A_{abs} is the area of the absorber.

The PTC is a two dimensional system, so a maximum concentration ratio can be reached to 200. The main effect on the concentration ratio is losses, and the most significant losses under some circumstances occurring in a solar field are the *shading losses*. This reduction is happened when one collector row reflects their shadow onto the next row.

Another loss factor occurs because the incoming radiation to the collector is not exact perpendicular, and the absorber tube has a finite length. At the end of each collector, a certain part of the absorber tube will not be irradiated. This displacement of sun image is shown in figure (2.4). In the northern hemisphere, these effects can be noticed especially during winter time. Normally these losses are under two percent in feasible areas for CSP plants.

Further losses that occur depend on the finite earth-sun distance, where the beams reaching the collectors are also not exactly parallel. As a result, the sun image on the absorbers is not precisely circular. The image can be seen in the form of an ellipse, which changes the frame, depending on the angle of incidence.

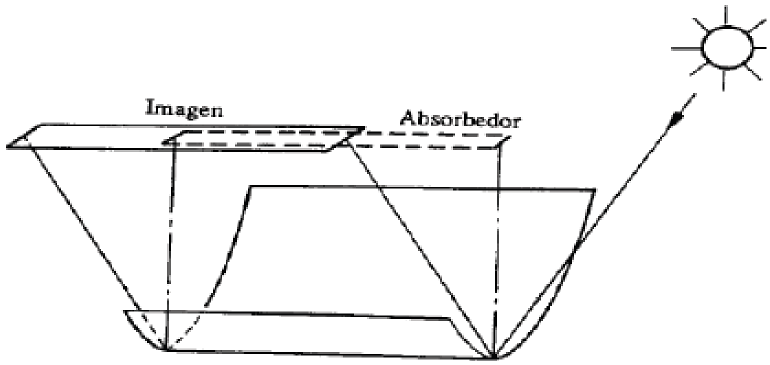


Figure (2.4): Displacement of the sun image.

By increasing the incidence angle, the performance characteristic of the sun image becomes worse. This happens because the absorber is designed for a perfect circular sun image. This effect is called Incidence Angle Modifier (IAM), and can be predicted in general according to [16].

$$\xi_{IAM} = \cos\theta\,(1 + sin^3\,\theta) \tag{2.12}$$

The irradiation reaching the collector can be separated in two parts. One is exactly perpendicular to the other, and one is horizontal to the collector. The collector however only can reflect the perpendicular part of the radiation. This leads to the so called *cosin-effect*. The amount of useful irradiation can be calculated according to [17] by equation (2.13).

$$\xi_{cos} = \cos\theta \tag{2.13}$$

2.4 Available solar energy

In every moment, the fraction of the radiant flux that reaches a specific location on the Earth's surface is highly variable, depending upon local atmospheric conditions and cloud cover. Meteorological science has not yet advanced to the point at which it is possible to obtain detailed forecasts of weather conditions more than a few days into the future. As such, it is impossible to predict the available solar radiation on a daily basis.

The design of solar power systems must therefore rely on long-term statistical averages, which permit evaluation of the suitability of a site for the production of solar energy. The variable nature of the solar resource means that at least 10 years of meteorological data should be used when evaluating a potential site, in order to remove statistical anomalies.

In this thesis, **Meteonorm** software is used to determine the location of Gaza Strip and to obtain solar information about the location that intended to design the substation on it.

Meteonorm is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location. The method is based on databases and algorithms coupled according to a predetermined scheme. It commences with the user specifying a particular location for which meteorological data are required, and terminates with the delivery of data of the desired structure and in the required format.

The first step in the software is to determine Gaza Strip location on the map, then the program determine the latitude and longitude as shown in figure (2.5).

According to [18], the optimal values for azimuth and tilt angles are 180° and 31.42° respectively, so it is used in the program as input parameter, and determine the inclination angle to be equal 45°.

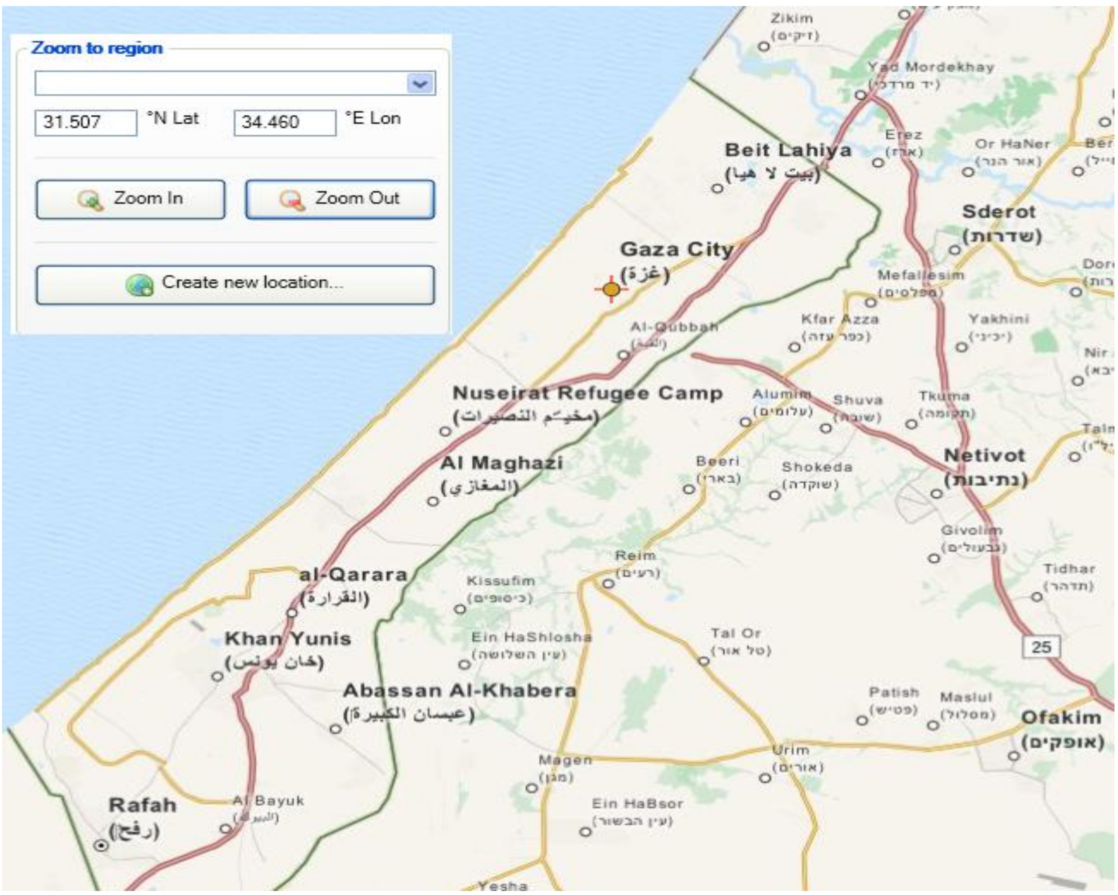


Figure (2.5): Location of Gaza Strip in Meteonorm software.

After that, the program shows the atmospheric turbidity as uncertain parameter that effect on the solar beam radiation as shown in table (2.1). Aeronet results indicate to the nearest station from the chosen location which in our case is **Nes Ziona** with latitude = 31.9°, longitude = 34.8°, and 55 Km far from Gaza Strip.

Table (2.1): Atmospheric turbidity for Gaza Strip.

Month	Interpolated	Aeronet	Custom
January	3.45	3.51	3.45
February	3.45	4.00	3.45
March	3.90	4.38	3.90
April	4.56	5.28	4.56
May	4.32	4.84	4.32
June	3.39	3.63	3.39
July	3.68	4.17	3.68
August	3.51	4.09	3.51
September	3.51	4.07	3.51
October	3.85	4.34	3.85
November	3.51	3.7	3.51
December	3.51	3.61	3.51
Year	**3.72**	**4.14**	**3.72**

Then, the weather monthly values for Gaza Strip for the year 2013 can be downloaded from internal tool in the program. Table (2.2) shows these values.

Table (2.2): Monthly values for Gaza Strip.

Month	T_a	Tad_{min}	Tad_{max}	Ta_{min}	Ta_{max}
January	13.1	8.1	18.9	3.5	28.4
February	15	9.9	20.9	6.2	28.7
March	18	11.6	25	6.5	37.1
April	19.7	13.4	25.7	9.2	37.4
May	23.3	17.4	29.7	13.3	38.4
June	25.8	20.4	31.2	15.7	40.1
July	26.7	22.6	31.3	20.3	35.1
August	27.6	23.1	32.3	20.9	34.2
September	26.2	21.7	30.9	16.9	35.3
October	22	16.5	27.9	11.9	31.8
November	20.3	14.8	27	11.2	35.3
December	13.4	8.7	19.6	1.9	30.2

Where T_a is the temperature, $Tad_{min/max}$ is the mean daily minimum/maximum of temperature and $Ta_{min/max}$ is the minimum/maximum hourly temperature.

Note that the influence of the horizon profile on the monthly and hourly values is taken into account. For hourly values, a relatively little elevated horizon may already have a strong influence on individual values. For these reasons, it is important to consider the effects of a raised horizon. Figure (2.6) is taken from the program, and shows the horizon for Gaza Strip.

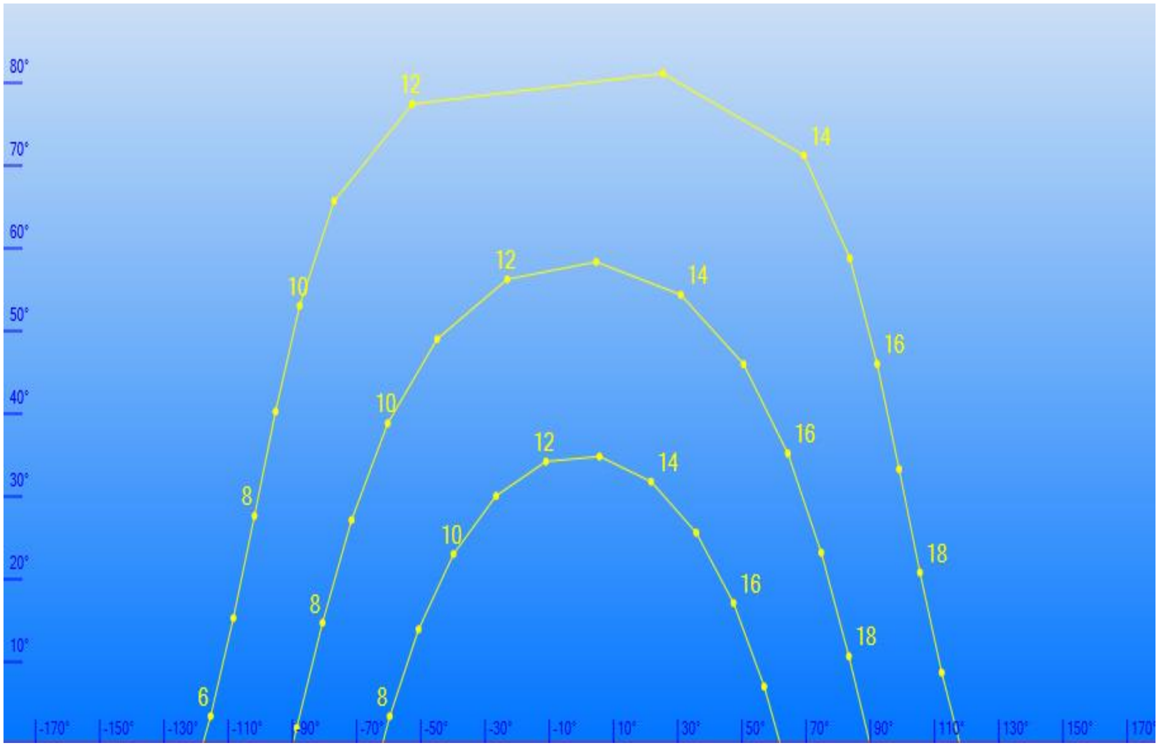


Figure (2.6): Horizon for Gaza Strip.

Where the x-axis represents the azimuth angle, y-axis represent the elevation angle and curves represent the sun path. After the above procedure done, the results are obtained as shown below.

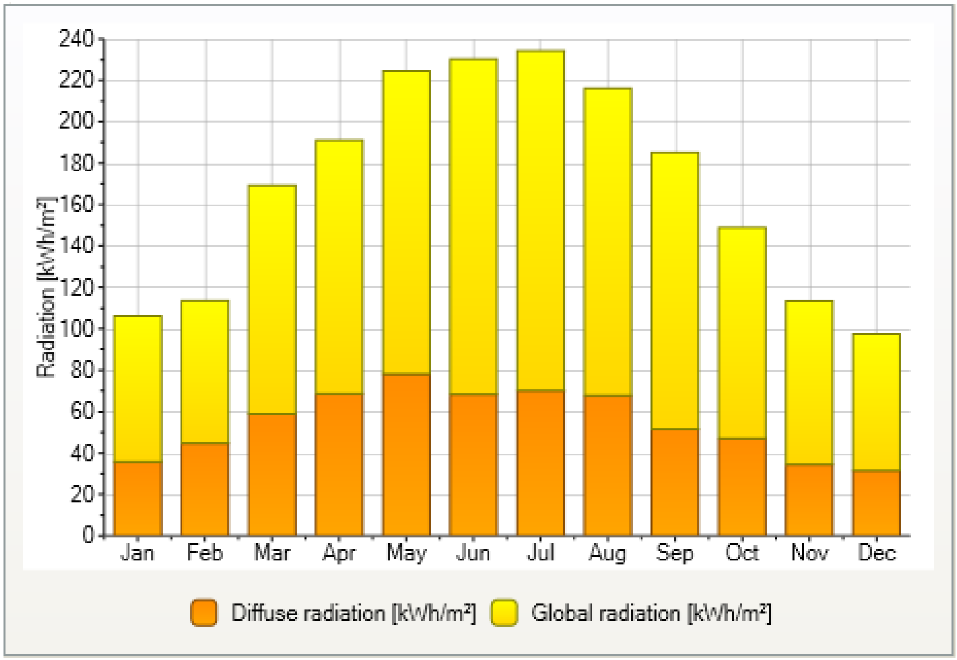


Figure (2.7): Diffuse and global radiations.

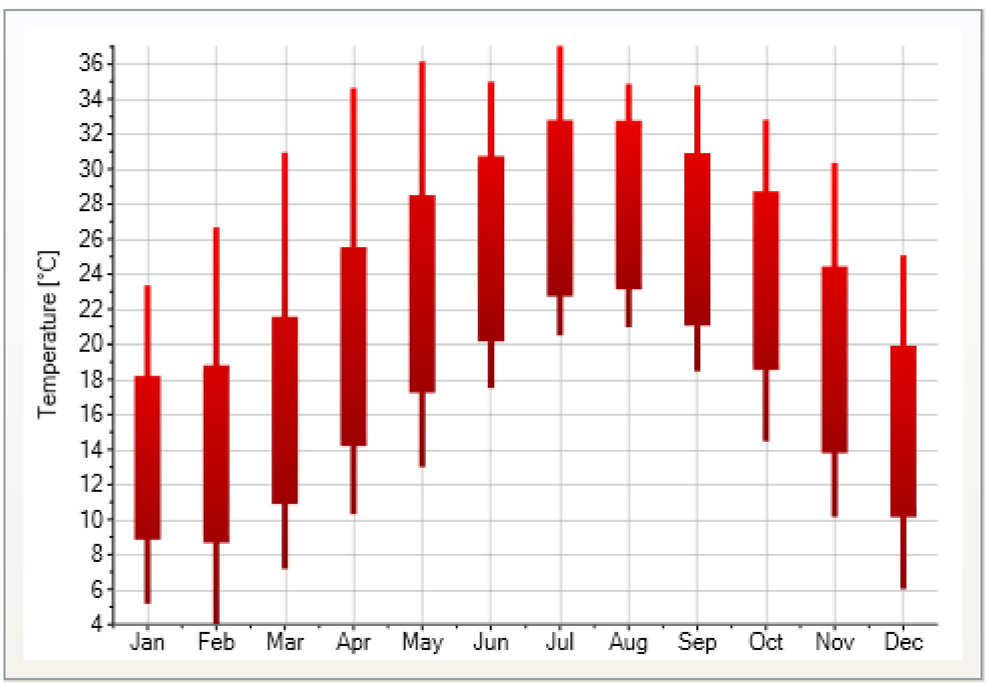


Figure (2.8): Monthly temperatures.

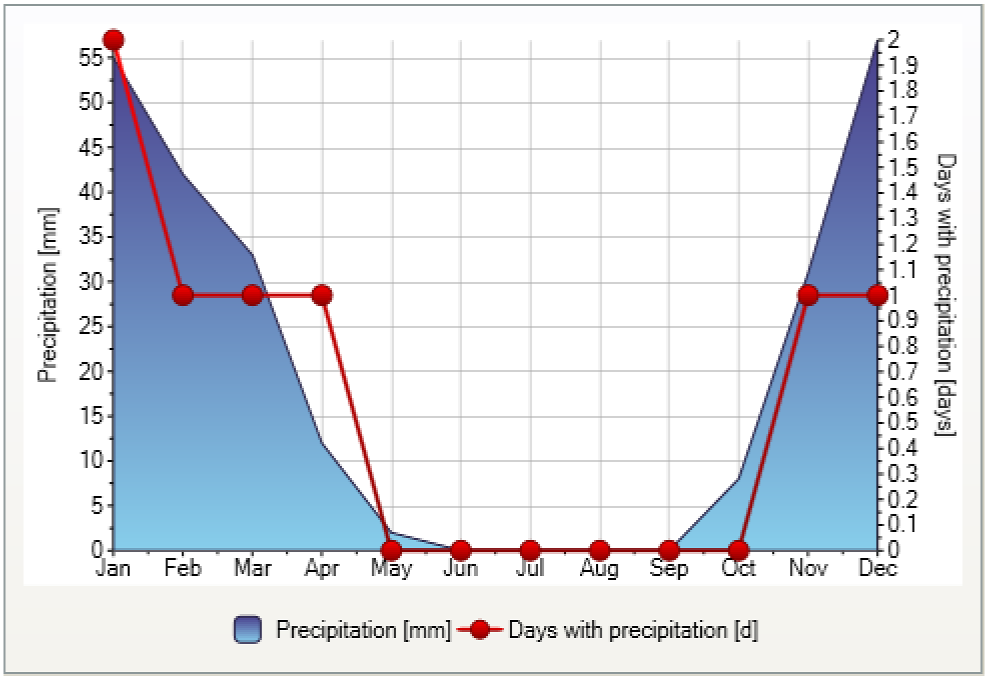


Figure (2.9): Precipitation and days with precipitation over a year.

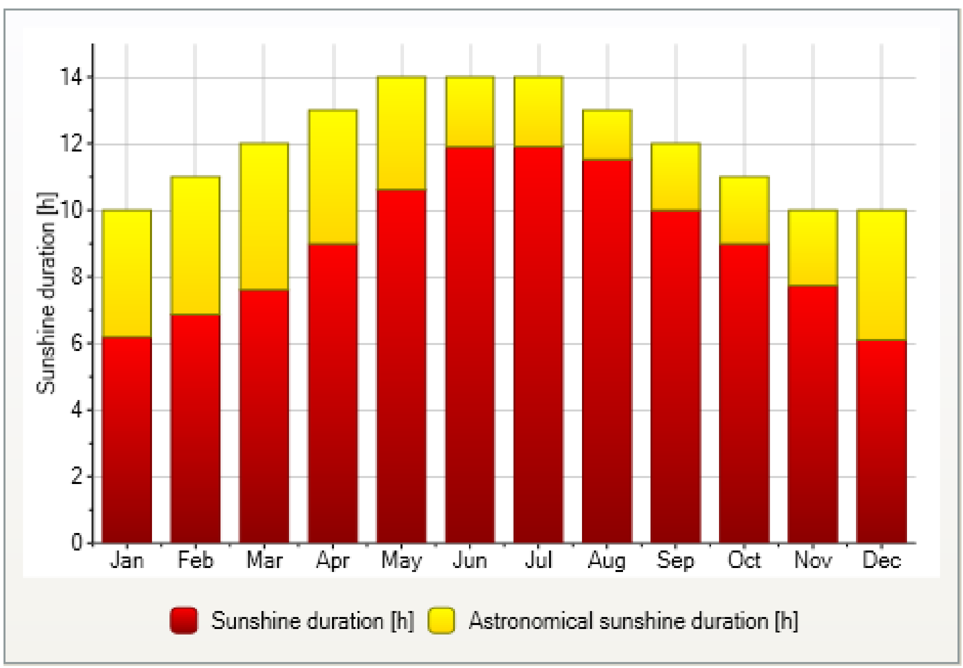


Figure (2.10): Sunshine duration and astronomical sunshine duration.

Note that, the program takes uncertainty range of yearly values as follow:

Gh=6%, B_n=11%, Gk=8%, T_a=0.8°C and variability of Gh/year: 3.4%

Where Gh is the global radiation horizontal, B_n is the beam radiation, Gk is the global radiation on inclined surface.

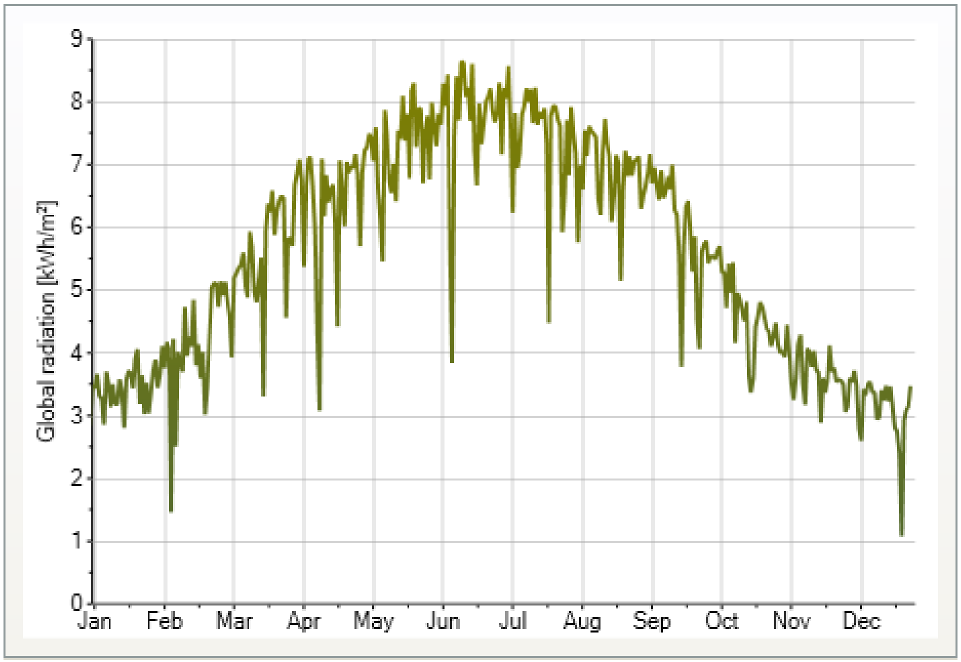


Figure (2.11): Global radiation with uncertainty.

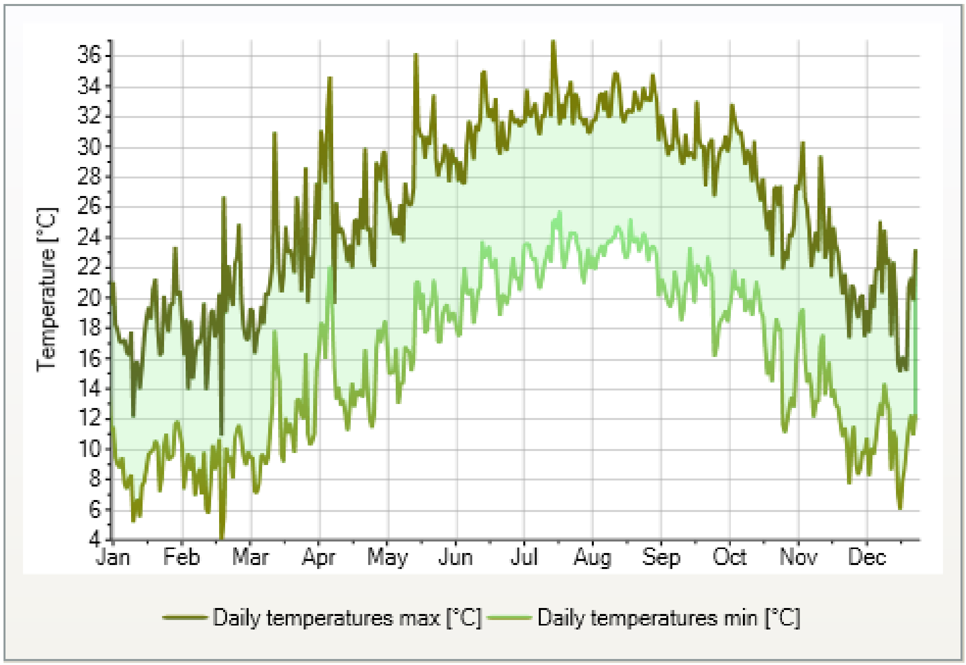


Figure (2.12): Maximum and minimum daily temperature with uncertainty.

The total results obtained from the program are shown in table (2.3).

Table (2.3): Overall output data for Gaza Strip.

Month	Gh KWh/m²	Gk KWh/m²	Dh KWh/m²	B_n KWh/m²	T_a °C	T_d °C	FF m/s
January	106	25	36	152	13.1	8	3
February	114	32	45	128	13.8	8.3	3
March	169	69	59	175	16	9.9	3.4
April	191	115	68	180	20	12.2	4
May	224	167	78	209	22.8	14.7	4
June	230	184	68	228	25.8	18.3	4
July	234	181	70	232	27.7	21	4
August	216	141	68	212	27.9	21.6	3.9
September	185	88	52	202	26.2	20.4	3.1
October	149	42	47	181	23.3	17.4	2.8
November	113	24	34	156	18.9	12.7	2.5
December	98	23	32	147	14.6	9.6	2.9
Year	**2029**	**1091**	**657**	**2202**	**20.84**	**14.51**	**3.38**

Where Dh is the diffuse radiation horizontal, T_d is the dew point temperature and FF is the wind speed.

As mentioned previously, Gaza Strip does not have meteorological station; hence, the program depends on interpolation technique in calculation. The interpolation depends on the following locations:

- **Radiation interpolation locations:** Gilat (27 Km), Bet Dagan (64 Km), El Arish (80 Km), Dead Sea (94 Km), Jerusalem (78 Km).
- **Temperature interpolation locations:** Gilat (27 Km), Bet Dagan (64 Km), Ben-Gurion airport (69 Km), Beer-Sheva/Teyman (43 Km), El Arish (80 Km).

Finally, as it presented before, the output data obtained from Meteonorm will be taken and put in Bet Dagan weather database to represent the weather data for Gaza Strip in simulation part of this thesis in chapter four.

CHAPTER THREE
PARABOLIC TROUGH COLLECTOR SOLAR POWER PLANT

3.1 Introduction

CSP is a large-scale, commercial way to generate electricity through solar energy. CSP systems comprise concentrated solar radiation as a high temperature thermal energy source to produce electrical power. CSP systems produce heat or electricity using hundreds of mirrors/reflectors to concentrate the solar radiation to a temperature typically between 400^{o}C and 1000^{o}C. This thermal power triggers Rankine, Brayton or Sterling cycles, and finally mechanical energy is converted to electricity through an electric generator which is further injected in to the transmission grid. CSP is being widely commercialized with about 1.17 GW of CSP plants online as of 2011 and about 17.54 GW of CSP projects are under development worldwide [5]. At present, there are four main CSP technologies, which can be categorized by the way they focus the sun's rays and the technology used to receive the sun's energy (table 3.1).

Table (3.1): The four CSP technology families.

Focus type (→) / **Receiver type (↓)**		**Line focus**	**Point focus**
		Collectors track the sun along a single axis and focus irradiance on a linear receiver.	Collectors track the sun along two-axis and focus irradiance at a single point receiver.
Fixed	Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of heat to the power block.	Linear Fresnel Collectors	Central Receiver System
Mobile	Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy	Parabolic Trough Collectors	Parabolic Dishes

The main four CSP technologies are parabolic trough collectors, central tower, linear fresnel and parabolic dishes as shown in figure (3.1). One of the most evolved technologies is the parabolic trough collectors. It is being used in several power plants over the world and proposed in plans for new plants. High temperatures can be achieved in central receiver power plants, promising high efficiency conversion ratios from solar to electricity; however, the cost of this technology is still expensive caused by its limited production.

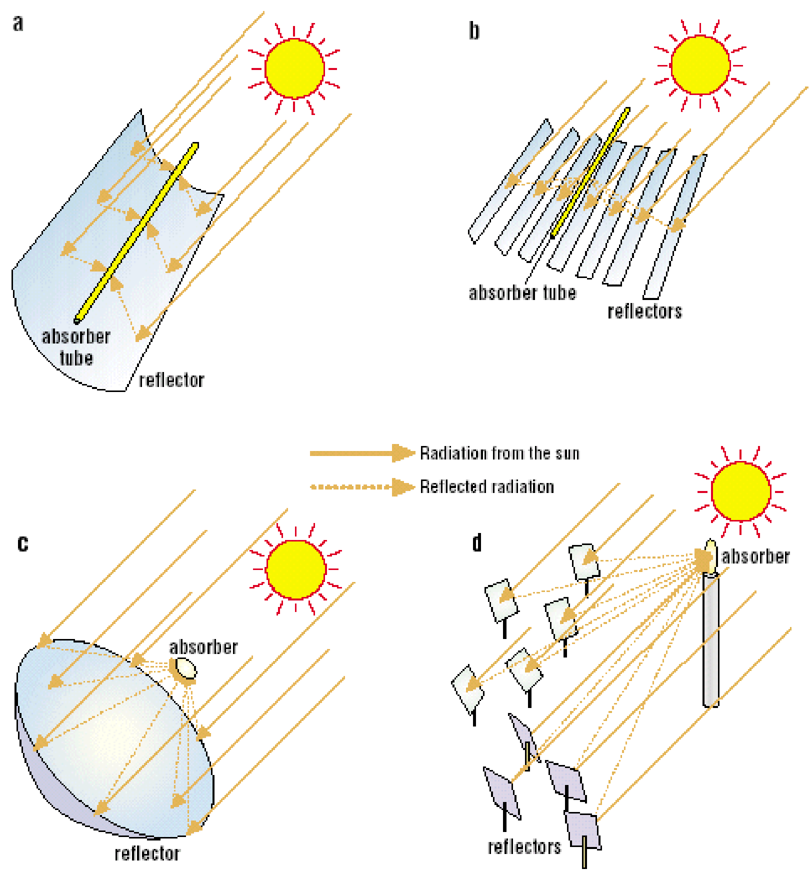


Figure (3.1): Concentration of sunlight using (a) parabolic trough collector (b) linear Fresnel (c) central receiver with dish (d) central receiver with distributed reflectors [19].

In this thesis, the technology of PTC is chosen, and then modeling of the proposed system using the computer software SAM is presented. SAM represents the performance and the cost of renewable energy projects using computer models developed at National Renewable Energy Laboratory (NREL), Sandia National Laboratories, the University of Wisconsin, and other organizations. Each performance model represents a part of the system, and each financial model

represents a project's financial structure [20]. The models require input data to describe the performance characteristics of physical equipment in the system and project costs.
In this chapter, theoretical background for PTC power plant is proposed with detailed information about each part of the system.

3.2 PTC power plant components

PTC systems are the most developed systems among all concentrating solar thermal power technologies. Today, most of the solar thermal power plants use parabolic trough collector systems. The block diagram of the proposed system is shown in figure (3.2), which consists of PTC having parabolic reflective mirrors, receiver (absorber tubes) for concentrated radiation, thermal storage system and power generation equipment. PTC systems use a Rankine cycle to produce electricity.

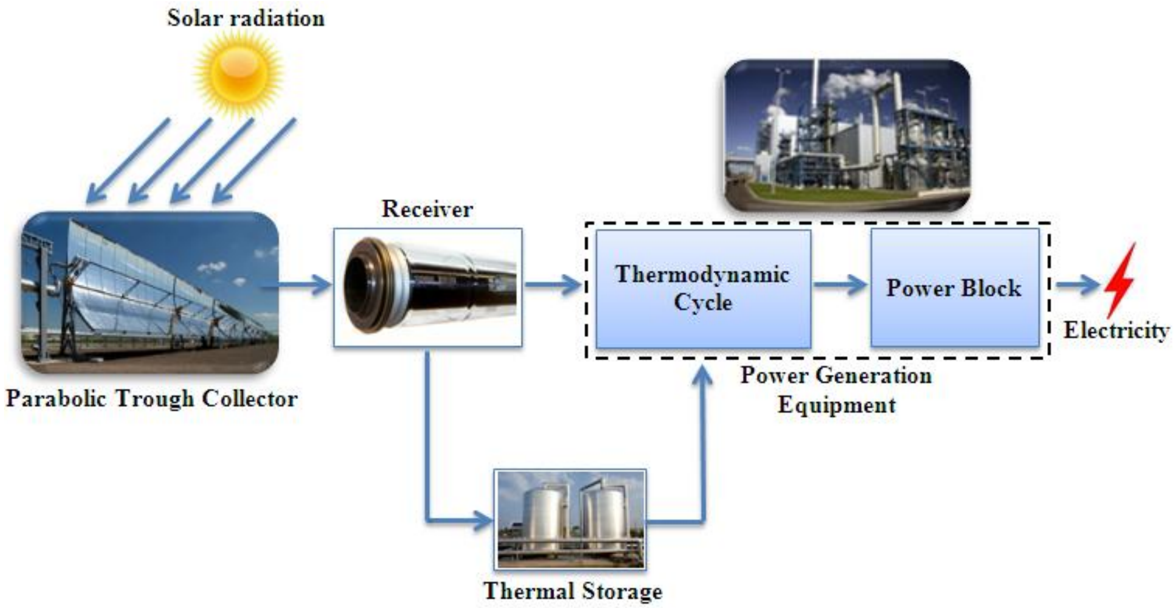


Figure (3.2): PTC solar thermal power plant block diagram.

PTC system consist of parallel rows of mirrors (reflectors) curved in one dimension to focus the sun's rays. Stainless steel pipes (absorber tubes) with a selective coating serve as the heat collectors. The coating is designed to allow pipes to absorb high levels of solar radiation while emitting very little infrared radiation. The pipes are insulated in an evacuated glass envelope.
The dynamics of the distributed solar collector field are described by the following system of partial differential equations describing the energy balance [21].

$$\rho_m C_m A_m \frac{\partial T_m}{\partial t} = In_\circ G - GH_t(T_m - T_a) - LH_t(T_m - T_f) \quad (3.1)$$

$$\rho_f C_f A_f \frac{\partial T_f}{\partial t} + \rho_f C_f \dot{q} \frac{\partial T_f}{\partial x} = LH_t(T_m - T_f) \quad (3.2)$$

Where the sub-index m refers to the metal, and f to the fluid. H_t represents the sum of radiative and conductive thermal losses, ρ_m and C_m are the density of the metal and fluid respectively, ρ_f and C_f are the heat capacities, A_m and A_f are the tube cross section and inner area, I is the solar radiation, $n_\circ$ is the reflectivity coefficient, q is the oil flow and T_m, T_f and T_a are metal, fluid and ambient temperatures respectively.

Now the detailed theoretical background for each part of our system is discussed.

3.2.1 Parabolic trough collector

A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two. The collectors are constructed as long parabolic mirrors, which have a thickness of approximately 4 mm and are typically coated by silver or polished aluminum to maximize the reflectance of the incoming rays. The mirrors used as concentrator consist of a heat-formed glass cake. It is carried by the metal structure of the collector. By using special production techniques, like the float-glass method, absolute evenness of the cake is guaranteed. Glass, which is used in solar applications, must have very low iron content for getting a transmissivity in the solar spectrum of around 91%. The iron content of a so-called “White Glass” is around 0.015% compared to normal glass with an iron content of around 0.13%, so it can be best choice in solar power plant [22].

The energy of sunlight which falls into the mirror parallel to its plane of symmetry is focused along the focal line, where HTF inside the receiver is positioned that is intended to be heated. Figure (3.3) shows the parabolic trough collector.

The group of collectors in solar power plant is called *solar field*. The solar field is the heat collecting portion of the plant. It consists of many parallel rows of solar collectors aligned on a north-south horizontal axis. In order to reach the operational conditions, the solar collector assemblies (SCA) are arranged in a series configuration normally known as a *loop* [23].

A common header pipe provides each loop with an equal flow rate of HTF, and a second header collects the hot HTF to return it either directly to the power cycle for power generation or to the thermal energy storage system for use at a later time.

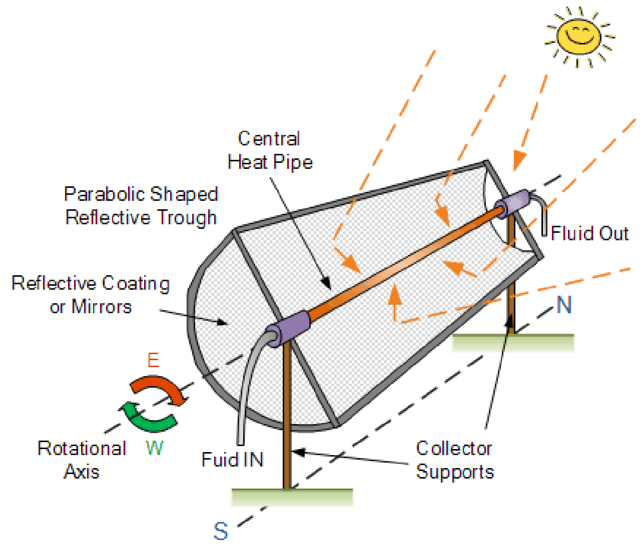


Figure (3.3): Parabolic trough collector.

To minimize pumping pressure losses, the field is typically divided into multiple sections, each section with its own header set, and the power cycle is situated near the middle of the field. Figure (3.4) shows one possible plant layout where two header sections are used for 20 total loops.

The solar field produces thermal energy by using direct normal insolation (DNI), and delivers this energy to a steam power plant. DNI can be evaluated using relation (3.3).

$$DNI = \int_{year} B_n\,(t)dt \qquad (3.3)$$

Where B_n is the beam radiation, which is incident from the direction of the center of the sun's disk. The total irradiation on the field is a function of the equivalent aperture area of all of the collectors in the field, the strength of the solar insolation, and the angle at which the irradiation strikes the aperture plane.

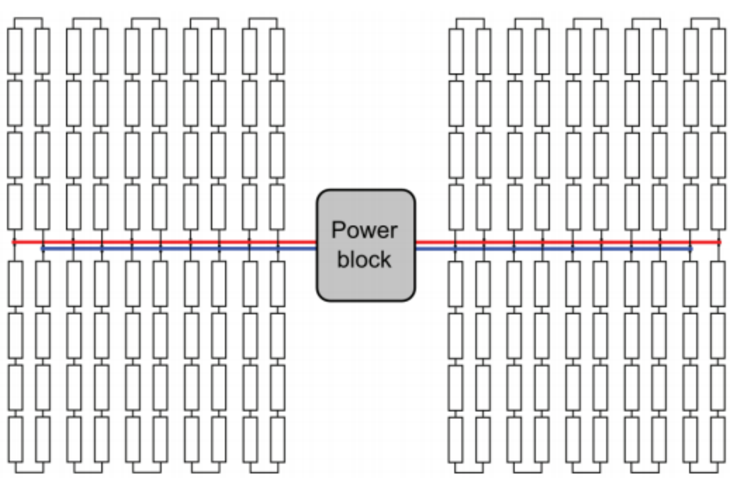


Figure (3.4): One possible field arrangement.

Note that it is commonly accepted that the minimum DNI at which it becomes economically viable to build a concentrating solar power plant is around 2000 kWh/m^2, and particularly in Palestine, DNI reach to average value of 2400 kWh/m^2 [4].

One of the most modern Collectors nowadays is the type LS-3. One LS-3 collector consists of 224 mirror segments, where each segment has an area of 2.68 m^2. Taking into consideration the bending of the mirrors, an area of 545 m^2 is reached with one LS-3 collector. In addition, the collector contains 24 absorber tubes [24].

Traditionally, a steel truss is used as the frame (LS-3 and LS-2 space frame), although other approaches such as torque tubes (Euro Trough) and lighter metals (Duke Solar space frame) are being explored. The support structure with drive controls is shown in Figure (3.5) [25].

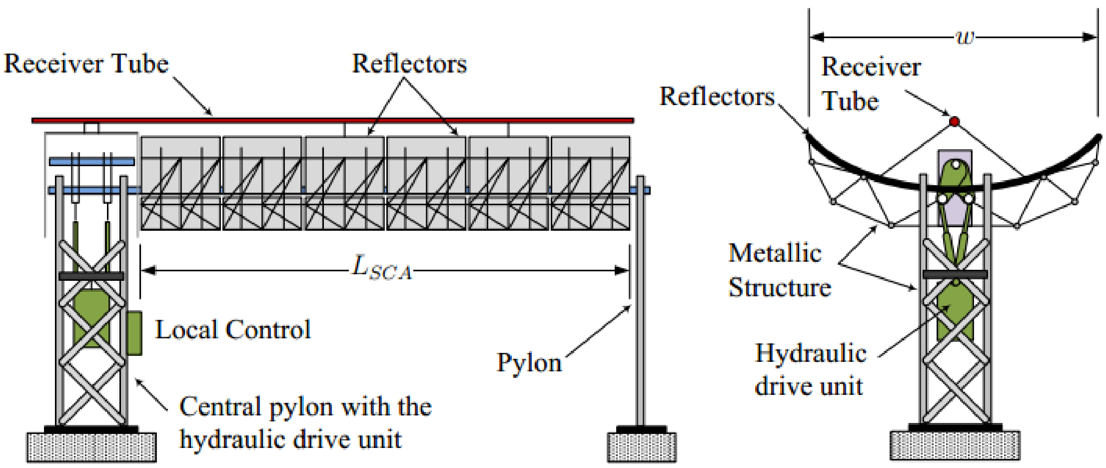


Figure (3.5): Parts of a Solar Collector Assembly (SCA).

When we talk about PTC, a very important definition must be presented, which is the equivalent aperture area. It refers to the total reflective area of the collectors that is projected on the plane of the collector aperture. This area is distinct from the curved reflective surface. Area that is lost due to gaps between mirror modules or non-reflective structural components is not included in the aperture area value. Thus, though the structure of the collector may occupy 100 m lengthwise and 5 m across the aperture, for example, the total reflective aperture area may be somewhat less than 100 × 5 = 500 m^2 after spaces, gaps, and structural area are accounted for.

The parabolic reflector is defined by its aperture diameter (W), rim angle (θ_r), and receiver shape and size. The radius of parabola at an arbitrary location is defined by r, and is called the mirror radius. The maximum mirror radius occurs at its outer rim and is fittingly called rim radius or parabolic radius. The rim angle θ_r corresponds to beam radiation reflected from the outer rim of the concentrator. The focal length f is related to rim angle and aperture width as in equation (3.4) [26]:

$$W = 4.f.\tan\left(\frac{\theta_r}{2}\right) \tag{3.4}$$

The size of a reflected solar image at the focal point depends upon the mirror radius at the point of incident of the beam radiation. A simple equation for the image width W_{im} was developed by Jeter [27].

$$W_{im} = r.\theta_s \tag{3.5}$$

Where θ_s represents the angular width of the incident beam radiation of 0.53^o ($\approx$ 0.00925 rad) with an acceptance half angle θ_a of 0.267^o, and reflected beam path length equal to the parabolic radius r, then for near normal incidence, occurring more frequently in the summer months, equation (3.5) can be rewritten as:

$$W_{im} = 0.00925\, r \tag{3.6}$$

The concentration ratio C which is written in equation (2.13) is related to θ_r, can also defined as:

$$C = \frac{\sin\theta_r}{\pi\sin\theta_a} \tag{3.7}$$

The size of the receiver to intercept the entire solar image can be calculated. The diameter D_r of a cylindrical receiver is given by: [28]

$$D_r = 2\, r\sin\theta_a = \frac{W\sin 0.267}{\sin\theta_r} \tag{3.8}$$

For a flat receiver in the focal plane of the parabola, the width W_f is given by:

$$W_f = \frac{2\, r\sin\theta_a}{\cos(\theta_r + 0.267)} = \frac{W\sin 0.267}{sin\theta_r\cos(\theta_r + 0.267)} \tag{3.9}$$

Now, the optical analysis of solar collectors with parabolic reflector must take into account. There are many different effects such as optical properties of materials, relative size of receiver and concentrator, the type of tracking and the corresponding losses.

- **Optical Efficiency of PTC**

The optical efficiency η_o is the fraction of solar radiation incident on the aperture of the collector which is absorbed at the surface of the receiver tube [29].

$$\eta_{\circ} = \frac{S}{I_b} \tag{3.10}$$

With all of the modifiers taken into account, the absorbed radiation S or the actual amount of radiation on the receiver is calculated by: [30]

$$S = I_b\left(\rho_a.\tau_g.\alpha_r.\gamma_i\right)\xi_{IAM}X_{END} \tag{3.11}$$

Optical efficiency of PTC embodies many important concentrators optical properties including insolation I_b, mirror surface reflectance ρ_a, receiver (glass) transmittance τ_g, receiver surface absorption α_r, end losses X_{END} and intercept factor γ_i which represents the fraction of reflected radiation which intercept the receiver.

3.2.2 Heat Collection Element (HCE) or receiver

Parabolic trough systems concentrate sunlight onto a receiver tube located along the focal line of a trough collector. This receiver tube is a vacuum tube designed specifically to maximize the amount of thermal energy adsorbed based on cost constraints. Figure (3.6) shows a diagram of a typical vacuum tube.

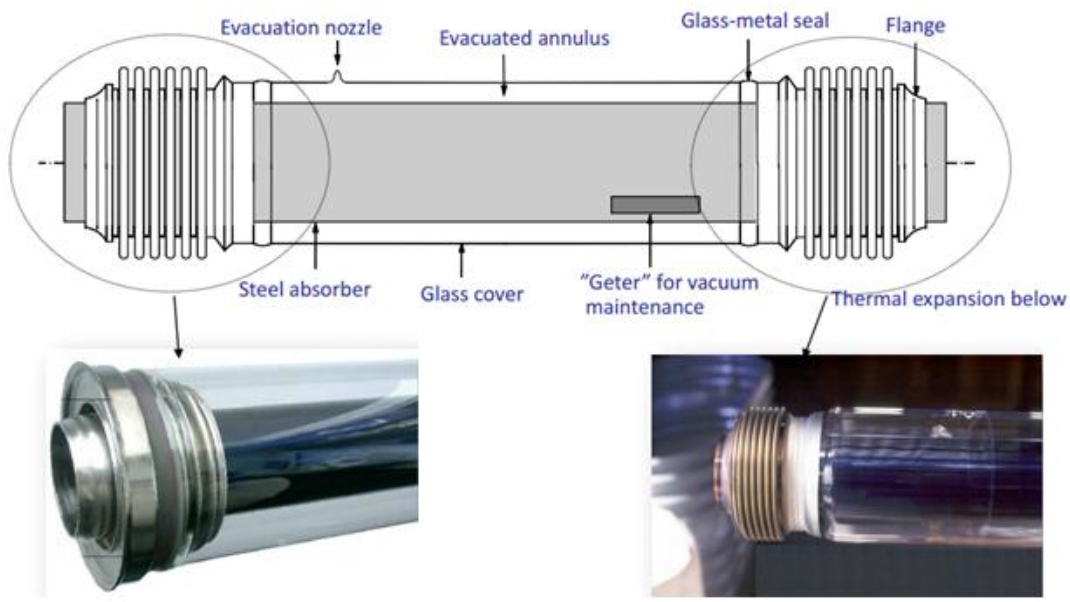


Figure (3.6): Vacuum tube collector.

Vacuum tubes should be designed using the most suitable material and geometry to absorb the maximum amount of solar energy. Vacuum tubes are usually formed using a cermet coated stainless steel absorber tube surrounded by a glass envelope [31]. The outer glass tube is transparent to shortwave radiation and allows light rays to pass through with minimal reflection.

The inner tube is coated with a special selective coating. The coated absorber layer should have high radiative absorptivity at short wavelengths and low radiative emissivity at long wavelengths. The glass envelope is typically made from Pyrex, which maintains good strength and transmittance under high temperatures. The air between the two tubes is removed making a vacuum. A good vacuum effectively eliminates convective and conductive heat transfer from the absorber tube to the outer tube, thereby minimizing heat transfer losses to the surroundings.

Receiver uses conventional glass to metal seals and metal bellows at either end to achieve the necessary vacuum enclosure and for thermal expansion difference between the steel tubing and the glass envelope. The bellows also allow the absorber to extend beyond the glass envelope, so that the HCEs can form a continuous receiver. The space between bellows provides a place to attach the HCE support brackets [32]. Chemical getters are placed in the annulus to absorb hydrogen, which comes from the HTF and decreases the PTC performance. The heat transfer model is based on an energy balance between HTF and the surroundings.

Nowadays, selective coatings remain stable in temperatures of 450°C upwards to 500°C. On average, the solar absorption is currently above 95%, and at an operational temperature of around 400°C, the emissivity is below 14%. This leads to an optical efficiency of around 80% for upcoming perpendicular radiation. The receiver thermal efficiency is obtained by equation (3.12).

$$\eta_r = \eta_o \, \alpha - \frac{\varepsilon_r \sigma (T_r^4 - T_a^4) - U_{loss}(T_r - T_a)}{C.B_n} \tag{3.12}$$

Where η_r is the receiver thermal efficiency, η_o is the optical efficiency, α is the material absorptivity, ε_r is the receiver material emissivity, σ is the Stefan-Boltzmann constant, T_r is the receiver temperature, U_{loss} is the convection loss coefficient and C is the geometric concentration ratio.

3.2.3 Heat Transfer Fluid (HTF)

Heat transfer fluid is the component in the system which carries heat from the receiver to the heat exchangers in the power block or to the heat storage tanks in solar heating and cooling system. The fluids most commonly used are water, hydrocarbons oil, glycol and air. When selecting a HTF, the following criteria should be considered: the coefficient of expansion, viscosity, thermal capacity, freezing point and boiling point. The most commonly used HTF and their properties are [33]:

- **Air** will not freeze or boil, and is non-corrosive. However, it has a very low heat capacity and tends to leak out of collectors, ducts and dampers.
- **Water** is non-toxic and inexpensive. It has a high specific heat and a very low viscosity, making it easy to pump. Unfortunately, water has a relatively low boiling point and high freezing point. It can also be corrosive if the power of hydrogen (PH) (acidity / alkalinity level) is not maintained at a neutral level.
- **Hydrocarbon oils** have a high viscosity and lower specific heat than water. They require more energy to pump. These oils are relatively inexpensive and have a low freezing point.
- **Refrigerants/phase change fluids** are commonly used as the HTF in refrigerators, air conditioners, and heat pumps. They generally have a low boiling point and a high heat capacity. Heat absorption occurs when the refrigerant boils (changes phase from liquid to gas) in the solar collector.
- **Chlorofluorocarbon (CFC) refrigerants**, such as Freon, are the primary fluids used by refrigerators, air conditioners and heat pump manufactures because they are nonflammable, low in toxicity, stable, non-corrosive, and do not freeze.

The heat transfer from the receiver tube to the HTF must be characterized by turbulent or laminar flow conditions. Equation evaluates the Reynolds number Re_f of the fluid is given by: [34]

$$Re_f = \frac{4\,\dot{m}}{\pi\, D_{r,i}\, \mu_f} \tag{3.13}$$

Where $\dot{m}$ is the mass flow rate, μ_f is the viscosity, and $D_{r,i}$ is the receiver inner diameter.

Nusselt number of the fluid Nu_f for laminar flow is given by equations (3.14) and for turbulent flow by equation (3.15).

If $Re_f < 2200$

$$Nu_f = 3.7 \tag{3.14}$$

If $Re_f > 2200$

$$Nu_f = \frac{\left(\frac{f_f}{8}\right) Re_f\, Pr_f}{1.07 + 12.7\sqrt{\left(\frac{f_f}{8}\right)}\,(Pr_f^{\frac{2}{3}} - 1)} \tag{3.15}$$

Where Pr_f is Prandlt number of the fluid and f_f is the fraction factor.

Fraction factor for smooth pipe is given by:

$$f_f = (0.79 \ln(Re_f - 1.64))^{-2} \quad (3.16)$$

The heat transfer coefficient h_f to the fluid is then evaluated by:

$$h_f = \frac{Nu_f\ K_f}{D_{r,i}} \quad (3.17)$$

Where k_f is the thermal conductivity for the fluid.

The overall heat transfer coefficient (U_o) is the coefficient for heat transfer from the surroundings to the fluid. Based on the outer diameter of the receiver tube $D_{r,o}$, this is given by equation (3.18) [35]:

$$U_o = \left(\frac{1}{U_L} + \frac{D_{r,o}}{h_f\ D_{r,i}} + \frac{D_{r,o} \ln\left(\frac{D_{r,o}}{D_{r,i}}\right)}{2K} \right)^{-1} \quad (3.18)$$

Where K is the thermal conductivity of receiver tube material.

3.2.4 Tracking control

We know previously that the efficiency of solar power plants is low, so in order to increase the efficiency, we must use tracking technique for collectors system. The selection of tracking configuration is based on load profile, site latitude and solar irradiation.

Solar fields in a PTC plant use single axel tracking systems. The tracking is according to the position of the sun and/or the requirement of the power block. Therefore a solar sensor is used to evaluate the sun position. Sensors consisting of a convex lens focus the sun light to a small photovoltaic cell, reaching a resolution of around 0.05%. Figure (3.7) show the PTC tracking sun path from East to West.

The tracking system must have sufficient torque to operate collectors even at higher wind speeds. For LS-3 collector's, normally electrohydraulic drives are used. In the design specs, the movement can take place with a speed of 9 m/s. For emergency reasons or for operation conditions, which are not requiring a high optical efficiency, the speed can be increased up to 20 m/s.

In existing plants, the controlling of the field takes place in two separate stages. The overall control is located in the central control room, and the second stage is placed on each collector unit. The local units take care of the incoming irradiation, wind speed and mass flow of heat transport medium. In case of emergency, the local units can shut down parts of the solar field. The overall unit operates the solar field according to the overall plant requirements, mainly the electrical output in relation to the actual solar radiation.

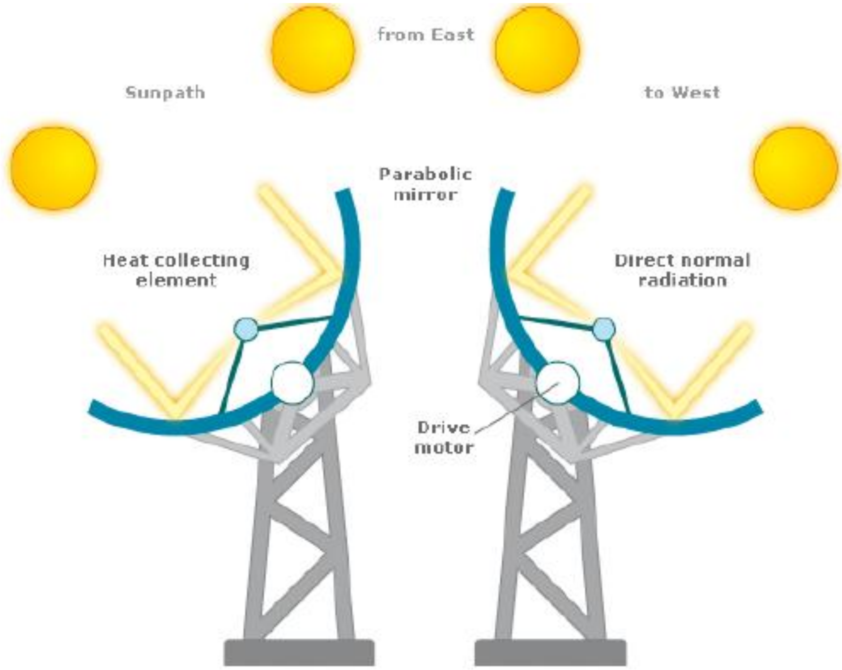


Figure (3.7): Parabolic trough collector tracking sun path.

PTC can be tracked in several different ways. The orientation or tracking which are generally used is as follows [36]:

- East-West tracking
- North-South tracking.

There are advantages and disadvantages for each of the tracking method.

3.2.4.1 East-West tracking

This is the most common tracking method in which the PTC is kept horizontal with its long axis in the east-west direction. The trough is continuously rotated in the north-south during the day. At solar noon, the solar rays fall normally on the collector plane and at all other times, the rays fall obliquely and creating end losses. These end losses which can be computed can be reduced by making the linear arrays long compared to the focal distance.

However in the E-W tracking, this cosine factor (or end loss) remains a source of loss at off-noon hours. It is known for this technique that sufficient amount of solar energy is collected within about 3 hour's period on either side of solar noon. Also, this tracking receives more radiation than the N-S tracking in winter. The other advantages of E-W tracking are its low cost, ease of alignment and tracking since it is mounted horizontally. The main disadvantage is the cosine loss at off noon hours.

3.2.4.2 North-South tracking

In the N-S tracking, the long axis of the PTC is fixed in the N-S direction with an arrangement of east-west diurnal motion. Sometimes, the PTC with N-S tracking is kept horizontally (better in summer) or with a tilt better in winter) from north direction. This tilt angle is very important and is generally equal to the latitude of the place. At this tilt angle, the solar intensity available on the trough on 21st December and 21st June will be equal to cos (23.45°) times the radiation at solar noon on west-east trough. Moreover, there is no cosine error or shading loss in this tracking technique. For better performance, the tilt angle can be varied about 12 times a year. If the trough tilted with a tilt equal to latitude, the trough in N-S tracking receives more radiation than E-W tracking especially near the equinoxes. In the N-S tracking, a tilt that required will make the system expensive due to the additional costs in substructure support and extra piping. It is known that in case of N-S tracking, the receipt of solar radiation in summer is more than in the E-W tracking. Moreover, the cosine factor is almost absent.

Figure (3.8) shows the schematic for the orientation of the above tracking options.

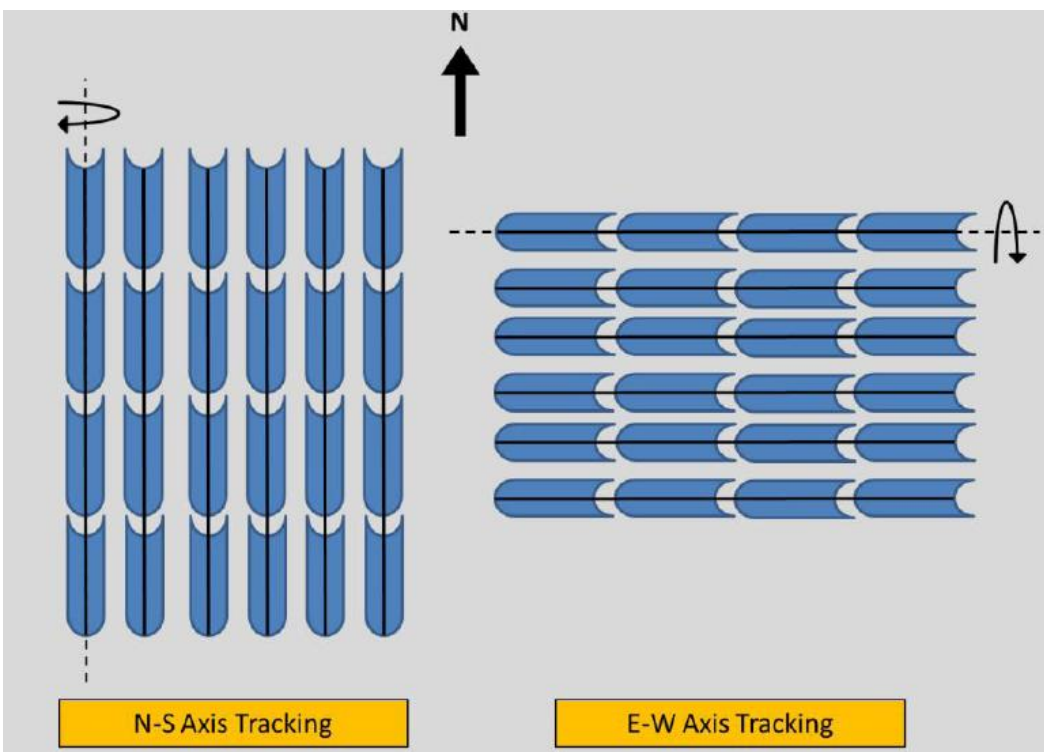


Figure (3.8): N-S and E-W axis tracking.

For a solar collector array rotated about a N-S axis with continuous adjustments, the angle of incidence is calculated as:

$$\cos\theta = (cos^2\theta_z + cos^2\delta\ sin^2\omega)^{1/2} \tag{3.19}$$

For a solar collector array rotated about an E-W axis with continuous adjustments, the angle of incidence is calculated as:

$$\cos\theta = (1 - cos^2\delta\ sin^2\omega)^{1/2} \tag{3.20}$$

The maximum amount of solar radiation which is utilized by a concentrating solar collector is calculated as:

$$Q_{max} = DNI \cos\theta \tag{3.21}$$

In this thesis, East–West tracking technique is used, which solar tracking by this mode maintains the plane of a solar beam, so that it is always normal to the collector aperture. Thus, the solar beam from different points of the parabolic trough reflecting surface is collected on the focal line receiver.

Finally, the tracking angle can be calculated as:

$$\theta = cos^{-1}\sqrt{1 - [\cos(\alpha_s - \beta) - \cos(\beta)\cos(\alpha_s)(1 - \cos(\gamma_s - \gamma))]^2} \tag{3.22}$$

3.2.5 Thermal storage

As previously mentioned, one of solar power technology's restrictions or inconveniences is the unavailability of sunlight during certain periods of time such as night, cloudy days or even whole seasons in the case of some countries. Modern life however, requires continuous energy availability; therefore today's energy systems should be prepared and designed to provide it. When using solar energy, one of the solutions to offset the effect of intermittency is to design hybrid plants that use sunlight when it is available and fuel during non-solar periods. Nevertheless there are other solutions that do not require fossil fuel consumption and that can therefore deliver lower priced and more ecological energy. These types of plants receive the name of *energy storage plants*.

CSP substation comprises a typical characteristic of daily and seasonal variation of the energy yield from solar field. Consequently, the energy output of the plant fluctuates, and the power block size is either too big or too small for most time of the year. In order to make CSP more dispatchable, the CSP substation can easily be coupled with thermal energy storage (TES) which can significantly increase the value of electricity delivered to the grid both in terms of capacity- related and energy-related services.

One of the most important characteristics of using a thermal storage system is the very high efficiency of the storage, with an annual efficiency of 99% possible for commercial plants. The only losses come from [37]:

- Slow heat loss through the tank walls, which is kept to a minimum via insolation.
- The heat exchange process between mediums, i.e., salt to steam for towers, or oil to salt, salt to oil, and then to steam, in the case of a trough system.

As combining TES system with CSP substation, the size of the power block can be reduced while the annual production is almost maintained, however the actual output depends on the ratio of storage to solar field to turbine size.

Following TES options are available for CSP plants [38]:

- Molten salt storage (one or two tank).
- Thermocline storage with molten salt and filler materials.
- Concrete storage systems.
- Storage by phase change materials.
- DISTOR concept (energy storage for direct steam solar power plants).
- Steam storage systems.
- Oil storage systems.

The most common use in solar power plant storage system is molten salt. The molten salt mix for storage at 60% of weight to 40% mix of sodium and potassium nitrate know as solar salt. At room temperature, solar salt is a white crystalline solid. Therefore, during plant commissioning, it is necessary to melt the entire salt inventory. The salt inventory then remains in the liquid state for the operating life of the plant. Solar salt is a eutectic mixture, meaning that this particular composition melts at a lower temperature than any other ratio of the two salts, and that at this ratio; both of the salts begin melting at the same temperature. Solar salt has a relatively high freezing point of 220º C, which is manageable for a heat transfer fluid in a solar power plant, but would be more challenging as the HTF in a trough solar field. It is important to avoid freezing of the molten salt within tubing for the following reasons:

1- This can cause a blockage which prevents flow of molten salt.
2- The frozen slug or section must be carefully thawed.

3- A small number of freeze/thaw cycles can result in tube rupture.

A proven form of storage system operates with two tanks as shown in figure (3.9). The storage medium for high temperature heat storage is molten salt which contain liquid potassium and sodium nitrate as cheap mineral salts that are normally used in synthetic fertilizer production.

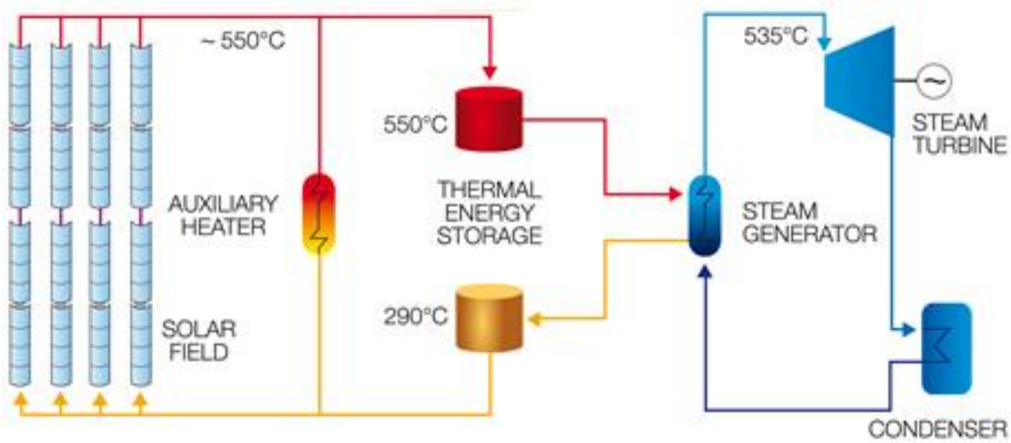


Figure (3.9): Two tank of molten salt for thermal energy storage [39].

When we want to compare between storage processes, there are two main processes to load thermal energy storage systems: *direct* and *indirect* systems. Direct systems use the same fluid for storage and for the solar field whereas indirect systems use a different fluid for each purpose. One of the problems with direct systems is that molten salt solidify at temperatures in between 120°C and 220°C, and there is the risk that they may solidify in the solar field during the night.

Indirect energy storage systems are generally loaded by running hot working fluid from the solar field through heat exchangers. The cold molten salt, which come from the cold storage tanks, are also run through these same heat exchangers and consequently suffer a temperature rise. The heated molten salt are then reserved in a storage tank and subsequently used. Later, when there is energy demand during non-solar periods, the system operates in reverse where the molten salt transfers their reserved heat to the working fluid through the same heat exchangers. This creates steam once again, which activates the plant during hours without sunlight.

Figure (3.10) show two tank direct molten salt energy storage which used in this thesis with molten salt as HTF as well as storage medium.

Because the energy generation system is completely independent of the energy collection system, a steady flow of power can be produced regardless of whether the sun is shining at full strength, or partial strength, or whether it is cloudy, or night time as long as there is sufficient energy stored in the hot salt tank. The mirror fields are oversized to allow the storage tanks to be filled during the day while electric power is generated simultaneously.

Figure (3.10): Two tank direct molten salt thermal energy storage.

Figure (3.11) shows two tank indirect storage system

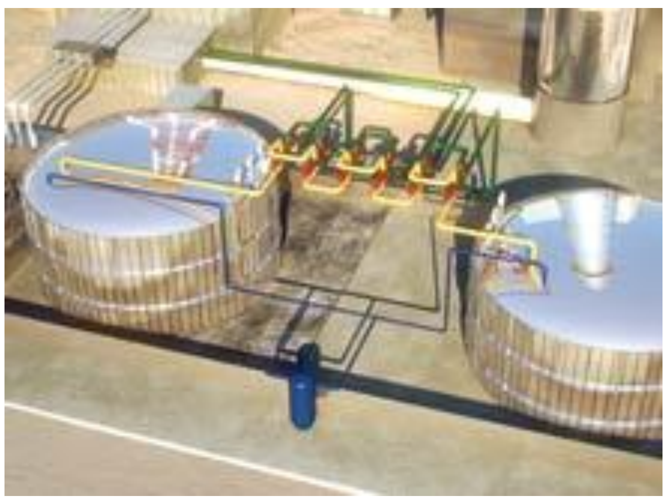


Figure (3.11): Two tank indirect molten salt thermal energy storage.

The exact balance of mirror field size, to turbine size, to storage size can be optimized depending on the desired performance of the CSP plant. For example, a plant with upwards of 15 hours of storage can act as a base load power plant, while a plant with 6–8 hours of storage but a larger turbine can meet the afternoon-evening peak power demand. Clearly, even a plant with 17 hours of storage cannot operate for more than a day during an extended cloudy period.

3.3 Power generation equipment

3.3.1 Introduction

As the sun's energy has been collected and concentrated to form a high temperature heat source, energy must now be converted into the desired final product. For electricity production, the solar collector and receiver system can be coupled with conventional power generation equipment to create a solar thermal power plant. The *heart* of the CSP plant is the power block, hence the principal objective of a solar thermal power plant is the generation of electricity, and a number of different thermodynamic cycles can be used to convert the thermal energy collected by the receiver into electrical power.

The choice of which power cycle to use in a given solar power plant is based to a large degree on the temperature at which the sun's energy is harnessed. For each power generation cycle, a range of temperatures can be identified within which the cycle usually operates, due either to the presence of a thermodynamic optimum or because material limitations prevent operation at higher temperatures. Higher temperature power generation cycles are generally more efficient, and the use of such cycles can potentially lead to an overall reduction in the cost of the electricity produced. The level of temperature achieved in a solar power plant is linked to the concentration ratio of the solar collector equipment. For each concentration ratio, an optimum temperature can be identified at which the thermodynamic potential of the system is maximized; higher temperatures can be reached at the same concentration ratio, but the efficiency of the system will be less.

Additionally, due to the uncontrollable nature of the solar supply, it is desirable that turbines be able to start as quickly as possible, in order for the plant to be able to harvest as much as possible of the sun's energy once it becomes available. Table (3.2) show operation conditions of the contemporary solar power plant.

The most widespread power generation cycle in solar thermal power plants is the Rankine steam cycle [40], and to date all utility scale solar thermal power plants have used steam cycle power generation equipment for electricity production. This steam cycle maintain an acceptable efficiency of the lower temperature, increase the average heat delivery temperature and avoid wetness problems in the last stages of the steam turbines.

The technology behind steam cycles is very mature and its use was seen as presenting a lower risk when development of the first solar power plants began. Steam cycles in solar thermal power plants typically operate with live steam temperatures between 250°C and 550°C, with linear

Fresnel and parabolic trough collector power plants at the lower end of the temperature range (250°C to 400°C).

Table (3.2): Operation conditions of contemporary solar power plants [40].

Power plant type	Steam parameter		Typical size [MWe]	Storage size [hours]
	Temperature [º C]	Pressure [bar]		
Parabolic trough	377	100	50-250	6-8
Molten salt tower	542	105	20-120	3-15
Direct steam tower	550	165	20-150	-
Linear fresnel	270	55	1-30	-

Contemporary steam turbines are limited to maximum operating temperatures of around 600°C by material constraints in the turbine blades.

3.3.2 Parabolic trough collector power plants

Over 90% of the installed capacity of solar thermal power plants is made up of parabolic trough systems, which are currently the most mature of the concentrating solar power technologies.

A typical parabolic trough power plant consists of three separate fluid loops as shown in figure (3.12). Three loops are thermal oil loop, steam loop, and condensation loop. A first loop consists of high temperature thermal oil which flows through the parabolic trough field and it is heated by the action of concentrated solar energy. Thermal oil begins to degrade above temperatures of around 400°C, restricting temperatures in the thermal oil loop to below 390°C and limiting the steam temperatures that can be achieved. Thermal oil from the solar field is sent to a steam generator to drive the power cycle, with any excess oil being diverted to the thermal energy storage system.

The power cycle employed in parabolic trough plants is a conventional reheat Rankine cycle, with water/steam as the working fluid. Due to the temperature limitations in the thermal oil, steam conditions at the inlet of the high pressure turbine are around 377°C at 100 bar, relatively low compared to modern fossil-fired steam power plants. The poor steam conditions generally require the use of evaporative cooling in order to ensure a sufficiently high efficiency of the power cycle. Typical efficiencies for the power block of a PTC power plant are in the region of 40%.

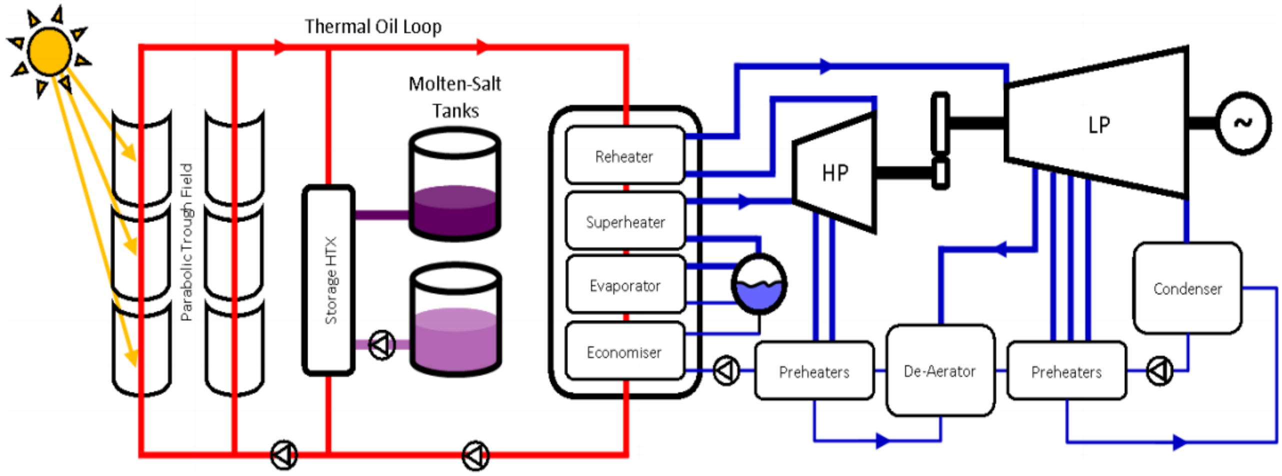


Figure (3.12): Parabolic trough solar power plant.

The combination of a low-upper temperature for the thermal oil and a high freezing temperature for the molten salt means that the storage units operate across a relatively small temperature range (220°C – 390°C, giving temperature range of around 170°C). This leads to low storage densities, and need large storage tanks. The key limitation of contemporary parabolic trough power plants is the low temperature imposed by the use of thermal oil as a primary heat transfer fluid.

There have been a number of propositions to use molten salt directly as a working fluid in the parabolic trough field as in this thesis, which would allow operation up to be around 580°C and greatly simply the operation of the thermal energy storage units. However, the risk of the salt freezing within the piping of the collector field is very high, and such an event would be very costly to repair.

3.3.3 Functioning of the plant

Figure (3.13) show the PTC power plant which contains two turbines: High pressure (HP) and Low pressure (LP), generator, superheater, two preheaters, reheater, an evaporator, economizer and condenser. In order to explain the plant's functioning in the clearest way, it is important to bear understand that this plant works with two different working fluids: HTF and steam/water.

On the one hand, HTF is responsible of absorbing the heat power that is produced by irradiation at the collector. Once it passes through it, it enters the plant at a high temperature, typically between 300°C and 400°C. When entering the system, it first passes through the reheater and superheater, where it exchanges heat with the steam produced by the evaporator, rising the steam's temperature before it enters the turbine. The HTF then passes through the evaporator where it again gives away part of its heat to water to transform it to steam. When passing through the economizer, the HTF exchanges once again heat, giving it this time to liquid water for the increasing of its temperature at the entrance of the evaporator. This helps in the improvement of the power given by the plant and the plant’s efficiency. At this point, the HTF exits the plant and goes back to the collector; where it receives power from the sun and gets heat and ready to restart the process. Water, on the other hand, transforms into steam with the heat power received by HTF. The resultant reheated steam passes through turbines, where its heat power is transformed into mechanical power and then to electrical power.

Another very important device in the plant is the condenser. The remaining steam from the turbines, as well as the remaining hot water, is cooled here. In some cases, condensers cool the incoming water by making it exchange heat with water from rivers or the sea; which has a lower temperature. In other cases, when water from these sources cannot be used, condensers are connected to cooling towers, which cool the water by two different methods: making it exchange heat with environment air or by the partial evaporation of the incoming water. After passing through the condenser, the resulting water goes into a pump, where it suffers a pressure increase. At this pressure, it enters the economizer, where it increases its temperature. After this, the heated water enters the evaporator where it changes into steam. It then runs through the superheater and enters the turbine in the form of heated steam. The process is repeated in a closed circuit.

3.3.4 The four processes of the Rankine cycle [41]

As mentioned previously, the thermodynamic process in this thesis is called Rankine cycle. It converts heat into work and is mostly used in power plants. This cycle generates approximately an 80% of the electric power used throughout the world.

The thermodynamic mechanism for Rankine cycle passes through four processes which are explained below according to temperature entropy (T-S) diagram of a simple Rankine cycle shown in figure (3.13).

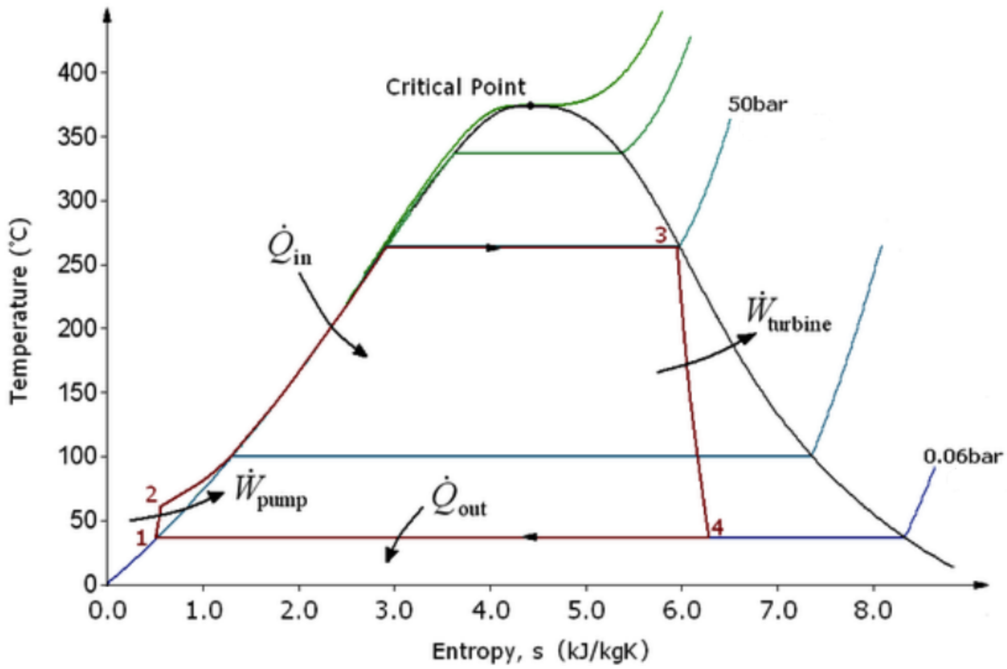


Figure (3.13): T-S diagram of a simple Rankine cycle.

The T-S diagram of a simple Rankine cycle consists of four processes (1-2, 2-3, 3-4 and 4-1).

Process 1-2: During this process, water is pumped from low pressure to high pressure.

Process 2-3: In this part of the cycle, the high pressure working fluid enters a boiler where it receives heat power and transforms into dry steam.

Process 3-4: The saturated dry steam expands by running through a turbine; therefore its temperature and pressure decrease notoriously. Some condensation may occur in this process.

Process 4-1: The resulting fluid that exits the turbine passes through the condenser where it is fully transformed into saturated water at a constant temperature.

There are some variations that can be made to the Rankine cycle in order to increase its efficiency, which are adding of regenerators, economizers or superheaters.

CHAPTER FOUR

PROJECT DESIGN

4.1 Project location (case study: The Turkish-Palestinian Friendship hospital)

In this thesis, a small solar power plant is designed as a case study for this project. The interested location is the Islamic university land located in Al-Zahra town. The Palestinian president awards this land for the Islamic university of Gaza with total area of approximately 150000 m^2. The engineering office in the university planned this land to represent the second part of the university. According to records of the engineering office in the university, figure (4.1) shows the site plan of the land.

The case study in this thesis is the Turkish-Palestinian friendship hospital. The hospital is established over an area of 33800 m^2 of the university land. It is primarily considered an educational institution of the university in addition to providing services to the Palestinian community, support and enhance the resilience of the Palestinian citizen. This hospital will provide special distinctive places for students in the faculty of Medicine at the highest international levels with Turkish design, and it would be a quantum leap in the health field in Gaza Strip. This hospital will be a monument symbolizing the Turkish-Palestinian friendship. According to technical information of hospital loads which taken from the engineering office, the electrical loads is given in table (4.1).

Table (4.1): Electrical loads for Turkish-Palestinian friendship hospital.

Load type	Total connected load (KW)	Demand load (KW)
Lighting	285	67
Sockets	760	40
Kitchen	85	68
Lifts	92	74
X-ray machine	140	140
A/C mechanical loads	4142	3320
UPS	450	450
Total	**5954**	**4159**

As mentioned previously, this thesis presents a design of thermal solar power plant for Turkish-Palestinian friendship hospital in the Islamic university land located in Al-Zahra town with net power of 5.40 MWe**.** As we will see later in SAM program, to design a power plant with total demand output power, a free aperture reflective area equal to 39240 m^2 is wanted (30.35 acres as total area). Note that the selected buildings are the only existing in whole land.

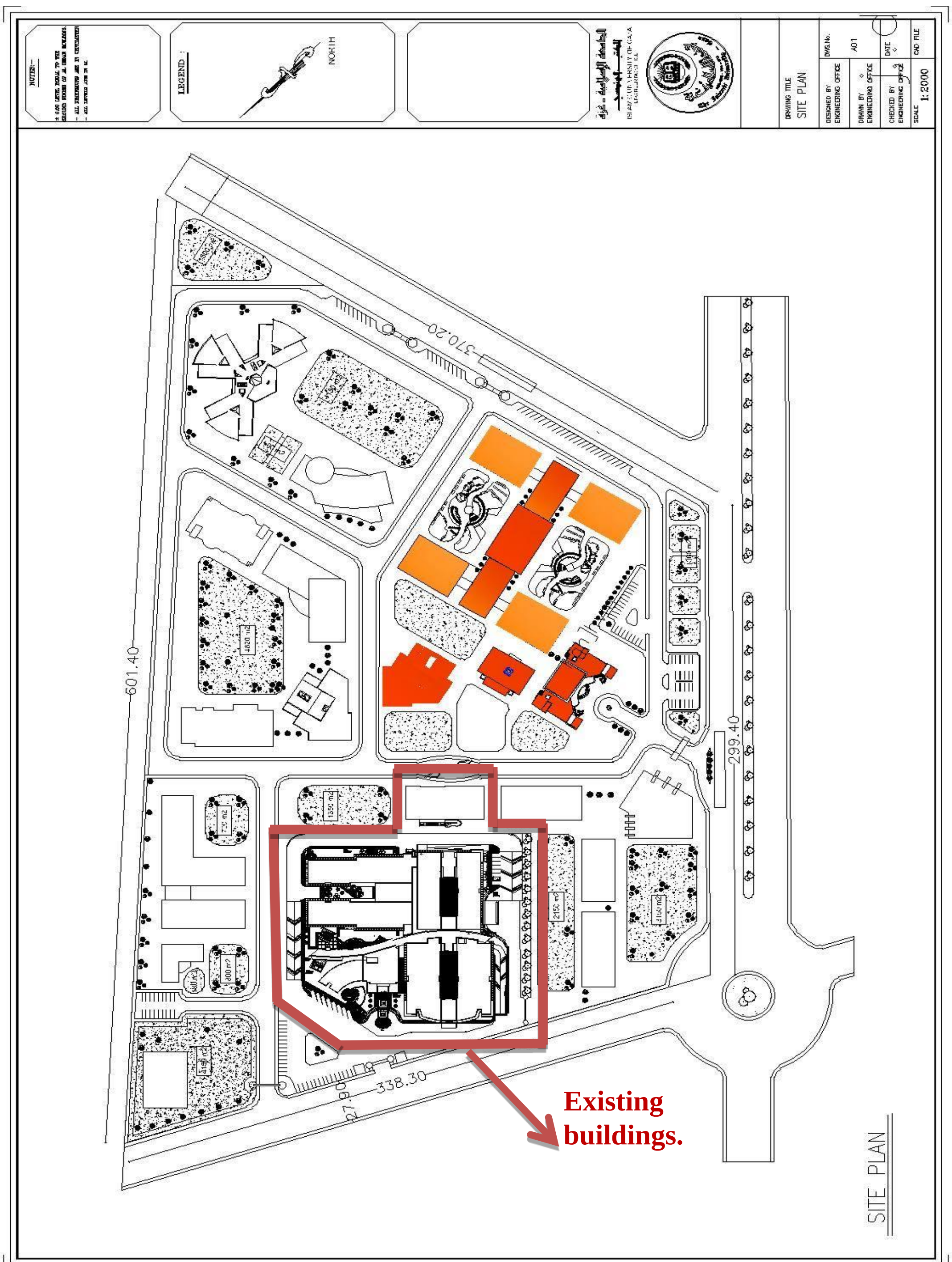


Figure (4.1): Site plan of the university land

The electrical load shown in table (4.1) are distributed over the area of the hospital. The power system shown in chapter (3) can be built in free land and connect it with step up/down transforms, and finally feed the electric room of the hospital. The overall system will achieve very good efficiency in the presence of thermal storage system as we will see in the next chapter.

Note that, the electrical grid can be connected to the hospital to act as alternative source of electricity when any urgent problems occurred in thermal solar power station.

4.2 Introduction to SAM [42]

We know that predicting the output of a CSP system is a complex process. Thermal systems include multiple subsystems whose behavior at any point in time depends not only on the instantaneous conditions that the whole system experiences, but also the recent history of its operation. There are a range of approaches to modeling CSP systems, and it is an on-going area of research. One of the most respected is the freely available SAM developed as said previously by NREL, Sandia National Laboratories, the University of Wisconsin, and other organizations in the USA. Figure (4.3) shows the interface of the program.

Figure (4.3): Starting of System Advisor Model.

SAM originally developed in 2005 and called the *Solar Advisor Model*. It was used at first internally by the U.S. Department of solar energy technologies program for systems-based analysis of solar technology improvement opportunities within the program. The first public version was released in August 2007 as version 1, making it possible for solar energy professionals to analyze photovoltaic systems and concentrating solar power parabolic trough systems in the same modeling platform using consistent financial assumptions. Since 2007, two new versions have been released each year, adding new technologies and financing options. In 2010, the name changed to *System Advisor Model* to reflect the addition of non-solar technologies.

The NREL and Sandia continue to use the model for program planning and grant programs. Manufacturers are using the model to evaluate the impact of efficiency improvements or cost reductions in their products on the cost of energy from installed systems. Project developers use SAM to evaluate different system configurations to maximize earnings from electricity sales. Policy makers and designers use the program to design and experiment projects with different incentive structures.

4.3 Financial Models in SAM

SAM's financial model calculates financial metrics for various kinds of power projects based on a project's cash flows over an analysis period that the user specifies. The financial model uses the system's electrical output calculated by the performance model to calculate the series of annual cash flows. SAM includes financial models for the following kinds of projects:

- Residential (retail electricity rates)
- Commercial (retail rates or power purchase agreement)
- Utility-scale (power purchase agreement):
- Single owner
- Leveraged partnership flip
- All equity partnership flip
- Sale leaseback

4.3.1 Residential and Commercial Projects

Residential and commercial projects are financed through either a loan or cash payment, and recover investment costs through savings from reduced electricity purchases from the electricity service provider. For electricity pricing, SAM can model simple flat buy and sell rates, monthly net metering, or complex rate structures with tiered time-of-use pricing.

4.3.2 Power Purchase Agreement (PPA) Projects

Utility and commercial PPA projects are assumed to sell electricity through a power purchase agreement at a fixed price with optional annual escalation and time-of-delivery (TOD) factors. For these projects, SAM calculates:

- Levelized cost of energy (LCOE).
- PPA price (electricity sales price).
- Internal rate of return (IRR).
- Net present value (NPV).
- Debt fraction or debt service coverage ratio

SAM can either calculate the IRR based on a specified power price, or calculate the power price based on the specified rate of return.

4.4 Design steps in the program

4.4.1 Technology and financing option

The first step in creating a SAM file is to choose a technology and financing option for your project. SAM automatically populates input variables with a set of default values for the type of project. It is your responsibility as an engineer to review and modify all of the input data as appropriate for each analysis.

According to this project, concentrating solar power technology is chosen, and parabolic trough (physical model) is determined as sub-choice from CSP technology. Because of the project is owned by the Islamic University of Gaza, advance utility independent power producer (IPP), options (single owner) is used.

4.4.2 Location and resource

To describe the renewable energy resource and weather conditions at a project location, SAM requires a weather data file. Depending on the kind of system you are modeling, you either choose a weather data file from a list, download one from the internet, or create the file using your own data. In this point of view, information about a project's location is provided. Whether data file for Bet-Dagan, which downloaded from web link from the program and modified using data obtained in chapter 2, is used as an alternative file to represent Gaza Strip data. The data used are:

Latitude=32°, longitude=34.82°, direct normal=1920.5 KWh/m^2, global horizontal=1874.4 KWh/m^2, dry-bulb temperature=19°C and wind speed=3 m/s

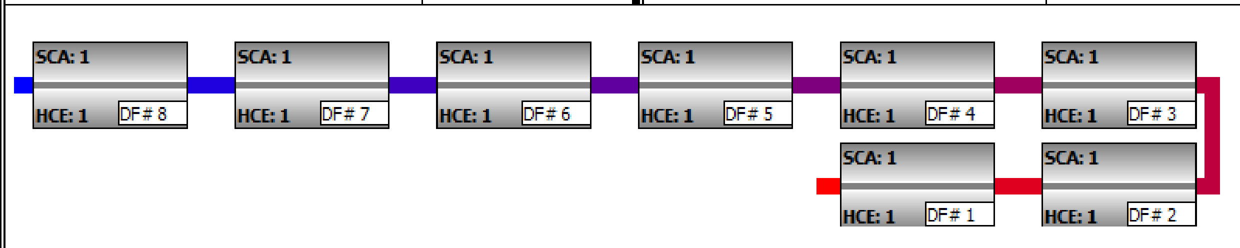
4.4.3 Solar field

In this section of project, all solar collectors details are presented. The design for this project involves parameters as below. Note that in solar filed parameter, option 1 is chosen, which means that solar multiple is entered and the program calculate the total area wanted for power plant. Table (4.2) shows values that used in the design of this project.

Table (4.2): Solar field parameters.

Parameter	Values	Parameter	Values
Solar field parameters			
Solar multiple	2	Header pipe roughness	4.57×10^{-5}
Row spacing	15 m	HTF pump efficiency	0.85
Stow angle	170°	Freeze protection temperature	150 °C
Deploy angle	10°	Irradiation at design	950 W/m^2
Number of filed subsections	2	Allow partial defocusing	Simultaneous
Heat transfer fluid			
Field HTF fluid	Hitec Solar Salt	Maximum single loop flow rate	12 Kg/s
Design loop inlet temperature	293 °C	Header design min flow velocity	2 m/s
Design loop outlet temperature	391 °C	Header design max flow velocity	3 m/s
Minimum single loop flow rate	1 Kg/s		
Collector orientation			
Collector tilt	32°	Collector azimuth	180°
Mirror washing			
Water usage per wash	0.7 L/m^2,aperture	Washes per year	63
Plant heat capacity			
Hot piping thermal inertia	0.2 KWht/K-MWt	Field loop piping thermal inertia	4.5 Wht/K-m
Cold piping thermal inertia	0.2 KWht/K-MWt		
Land area			
Non-solar field land area multiplier	1.2		

Single loop configuration			
SCA/HCE assemblies per loop	8		



The notation appear in the single loop configuration (SCA:1) indicates that the assembly consist of a type 1 collector, and (DF#1) indicates the collector's defocus order is 1.

Furthermore, the color of lines joining assemblies is changed from cold side (blue) to hot side (red). Also, color of the line in the center of assembly represents the type of chosen receiver.

4.4.4 Collectors (SCAs)

In this section, type 1 of collectors is chosen. Table (4.3) shows parameters for the collector used in this project.

Table (4.3): Collectors parameters.

Parameter	Values	Parameter	Values
Configuration name: SAM/CSP Physical Trough SCAs/Luz LS-3			
Collector geometry			
Reflective aperture area	545 m^2	# of modules per assembly	12
Aperture width, total structure	5.75 m	Avg. surface-to-focus path length	2.11 m
Length of collector assembly	100 m	Piping distance between assemblies	1 m
Optical parameters			
Incidence angle modifier coef. F0	1	Incidence angle modifier coef. F2	-0.1763
Incidence angle modifier coef. F1	0.0506	Mirror reflectance	0.935
Geometry effects	0.98	Dirt of mirror	0.95
Tracking error	0.99	General optical error	0.99

4.4.5 Receivers (HCEs)

In receiver configuration, type 1 of heat collection elements is chosen. Table (4.4) shows parameters for the receiver that used in this project.

There are four variations at maximum for each type of receiver. An important parameter in this position is variant weighting fraction. The summation of variant weighting fraction for four variations must be equal 1.

Table (4.4): Receivers parameters.

Parameter	Values	Parameter	Values
Configuration name: Schott PTR70 2008			
Receiver geometry			
Absorber tube inner diameter	0.066 m	Absorber flow plug diameter	0 m
Absorber tube outer diameter	0.07 m	Internal surface roughness	4.5×10^{-5}
Glass envelop inner diameter	0.115 m	Absorber flow pattern	Tube flow
Glass envelop outer diameter	0.12 m	Absorber material type	304L

Parameter and variations	Varaition 1	Varaition 2	Varaition 3	Variation 4
Variant weighting fraction	0.985	0.01	0.005	0
Absorber absorptance	0.96	0.96	.8	0
Absorber emittance	Table	0.65	0.65	0
Envelope absorptance	0.02	0.02	0	0
Envelope emittance	0.86	0.86	1	0
Envelop transmittance	0.963	0.963	1	0
Annulus gas types	Hydrogen	Air	Air	Hydrogen
Annulus pressure (torr)	0.0001	750	750	0
Estimated average heat loss	150	1100	1500	0
Bellows shadowing	0.96	0.96	0.96	0.963
Dirt on receiver	0.98	0.98	1	0.98

4.4.6 Power cycle

In power cycle configuration, electrical, mechanical and thermal characteristics appear in design. This site in design contains the most important parameters like gross output power, heat to electrical conversion efficiency and condenser type.

Table (4.5) shows parameters for the power cycle components that used in this project.

Table (4.5): Power cycle parameters.

Parameter	Values	Parameter	Values
Plant capacity			
Design gross output	6 MWe	Estimated gross to net conversion factor	0.9
Power block design point			
Rated cycle conv. efficiency	0.405	Aux. heater outlet set temp.	391 °C
Boiler cycle blow down fraction	0.02	Fossil dispatch mode	Min. backup level
Fossil backup boiler LHV efficiency	0.9		
Plant control			
Low resource standby period	2 hr	Min. required startup temp.	300 °C
Fraction of thermal power needed for standby	0.2	Fraction of thermal power needed for startup	0.2
Power block standby time	0.5 hr	Minimum turbine operation	0.25
Max. turbine over design operation	1.05	Turbine Inlet Pressure Control	Fixed pressure
Cooling system			
Condenser type	Evaporative	Approach temperature	5 °C
Ambient temp. at design	20 °C	Min. condenser pressure	1.25 in Hg
Ref. Condenser Water dT	10 °C	Cooling system part load levels	2

4.4.7 Thermal storage

In thermal storage system, variables describe the thermal energy storage system are appeared. The thermal storage dispatch control variables determine when the system dispatches energy from the storage system and from a fossil-fired backup system if the system includes one.

Hitec molten salt is used as a storage medium in addition to use it as HTF in the system (direct method). Table (4.6) shows parameters for thermal storage system that used in this project. In the last table, *generic summer peak* is used as dispatch schedule to obtain the maximum power from the plant in summer peak. Also weekday and weekend schedule show the period number used in the specified time in the year.

Table (4.6): Thermal storage system parameters.

Parameter	**Values**	**Parameter**	**Values**
Storage system			
Full load hours of TES	8 hr	Hot tank heater set point	365 °C
Parallel tank pairs	1	Tank heater capacity	15 MWht
Tank height	20 m	Tank heater efficiency	0.98
Tank fluid min height	1 m	Initial TES fluid temp.	300 °C
Tank loss coeff.	0.4 W/m^2-K	Storage HTF fluid	Hitec Solar Salt
Cold tank heater set point	250 °C		
Thermal storage dispatch control			
Current dispatch schedule: SAM/CSP Physical Trough TES Dispatch/Generic Summer Peak			

	Storage Dispatch w/ solar*	Storage Dispatch w/o solar*	Turb. out. fraction*	Fossil fill fraction*	TOD Factor
Period 1:	0	0	1.05	0	2.064
Period 2:	0	0	1	0	1.2
Period 3:	0	0	1	0	1
Period 4:	0	0	1	0	1.1
Period 5:	0	0	1	0	0.8
Period 6:	0	0	1	0	0.7
Period 7:	0	0	1	0	1
Period 8:	0	0	1	0	1
Period 9:	0	0	1	0	1

Weekday Schedule

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Feb	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Mar	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Apr	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
May	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Jun	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	2	2	2	3	3	3
Jul	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	2	2	2	3	3	3
Aug	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	2	2	2	3	3	3
Sep	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	2	2	2	3	3	3
Oct	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Nov	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
Dec	6	6	6	6	6	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5

Weekend Schedule

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Feb	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Mar	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Apr	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
May	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Jun	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jul	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Aug	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Oct	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Nov	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Dec	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

4.4.8 Parasitics

The variables on the parasitics page define electrical loads in the system. For each hour of the simulation, SAM calculates the parasitic load and subtracts it from the power cycle's gross electrical output to calculate the net electrical output. Table (4.7) shows parameters for parasitics that used in this project.

Table (4.7): Parasitics parameters.

<table>
<tr><th>Parameter</th><th>Values</th><th colspan="2">Parameter</th><th colspan="2">Values</th></tr>
<tr><th colspan="6">Parasitics</th></tr>
<tr><td>Piping thermal coefficient</td><td>0.45 W/m^2-K</td><td colspan="2">Required pumping power for HTF through storage</td><td colspan="2">0.15 KJ/Kg</td></tr>
<tr><td>Required pumping power for HTF through power block</td><td>0.55 KJ/Kg</td><td colspan="2" rowspan="2">Fraction of rated gross power consumed at all time</td><td colspan="2" rowspan="2">0.0055</td></tr>
<tr><td>Tracking power</td><td>125 W/sca</td></tr>
<tr><th></th><th></th><th>Factor</th><th>Coeff. 0</th><th>Coeff. 1</th><th>Coeff. 2</th></tr>
<tr><td>Balance of plant parasitic</td><td>0 MWe/MW cap</td><td>1</td><td>0.483</td><td>0.517</td><td>0</td></tr>
<tr><td>Absorber absorptance</td><td>0.02273 MWe/MW cap</td><td>1</td><td>0.483</td><td>0.517</td><td>0</td></tr>
</table>

4.4.9 Performance adjustment

The performance adjustment variables allow designer to model reductions in the system's output due to maintenance down times (availability), system shutdowns required by the grid operator (curtailment), annual reduction in system output due to aging of equipment (degradation), or any other factor that may cause the energy delivered to the grid to be less than the energy value that SAM's performance model calculates. Table (4.8) shows parameters for performance adjustment.

Table (4.8): Performance adjustment parameters.

<table>
<tr><th>Parameter</th><th>Values</th><th>Parameter</th><th>Values</th></tr>
<tr><th colspan="4">System Output Adjustments</th></tr>
<tr><td>Percent of annual output</td><td>0.96%</td><td rowspan="2">Hourly factors</td><td rowspan="2">All values =1 (Full load)</td></tr>
<tr><td>Year-to-year decline in output</td><td>0%</td></tr>
</table>

4.4.10 Trough system costs

In this section of thesis, parameters of project construction, fixed costs and operation and maintenance costs are listed. Table (4.9) shows these parameters.

Table (4.9): Trough system costs

Parameter	Values	Parameter	Values
Direct Capital Costs			
Site improvement	5 $/m^2$	Power Plant	700 $/KWe
Solar field	30 $/m^2$	Balance of Plant	80 $/KWe
HTF system	60 $/m^2$	Contingency	5%
Storage	60 $/KWht		
Operation and Maintenance Costs			
Fixed cost by capacity	50 $/KW-yr	Variable cost by generation	2 $/MWh

4.4.11 Financing

This section describes the inputs on the financing page for the utility single owner financing option. Table (4.10) shows the most important parameters for financing section in project.

Table (4.10): Financing parameters.

Parameter	Values	Parameter	Values
Solution mode: Specify PPA Price			
IRR Target	12%	Target Year	25
PPA Price	0.1 $/KWh	PPA Price Escalation	0.51 %/year
Analysis parameters			
Analysis period	25 years	Real discount rate	5 %/year
Inflation rate	0.5 %/year		
Tax and Insurance Rates			
Federal income tax rate	30 %/year	Assessed percent	100 % of installed cost
Insurance rate (Annual)	0.5 % of installed cost		
Construction Financing			
Loan 1			
Percent of installed costs	100	Months prior to operation	24

Up-front fee (% of principal)	1	Annual interest rate (%)	5
Project Term Debt			
Debt Service converge ratio (DSCR)	1.3	Debt closing costs	450000 $
Tenor	15 years	Up-front fee	2.75 $ of total debt
Annual All-in interest rate	6%		
Reserve Accounts			
Interest on reserves	1.75 %/year	Debt service reserve account	6 months of principal and interest (P&I) payments
Working capital reserve	6 months of operating costs		
Major equipment replacement reserve accounts			
Reserve account 1			
Replacement cost	0.25 $/KW	Replacement frequency	12 years

4.5 Tracking control

The tracking control used in this thesis depends on self-tracking module (reference plant) that is tightly joined with collector. Solar collectors will rotate slowly east to west during each day to track the sun's movement and to keep the sun's rays focused on the absorber tube. This reference plant uses hydraulic actuators which are driven by a 1 hp (0.746 kW) electric pump motor.

The driver intermittently tracks the sun (low speed) and continuously stow the SCAs (high speed) during the appropriate operation mode.

Each SCA will track the sun via a logic controller located in the collector drive housing. The logic is preprogrammed using a GPS to orient the SCA at the calculated sun position. Additionally included in this reference plant design is an empirical sun tracker that directly watches the sun's path by measuring a voltage differential created by a shadow casted on a flat plate PV cell which sits centrally behind the HCE just in front of the mirror as shown in figure (4.3). This empirically based tracker will typically orient the SCA during operation while the logic tracker will be used for deploy and stow positioning, or when clouds obscure the sensor.

Note that, deploy and stow angles appear in solar field section mentioned previously.

Figure (4.3): Empirical sun tracker.

4.6 System uncertainty

Uncertainties are unavoidable signals appear in a real control system. The uncertainty can be classified into two categories: *disturbance signals* and *dynamic perturbations*. The former includes input and output disturbance, sensor noise and actuator noise, etc. The latter represents the discrepancy between the mathematical model and the actual dynamics of the system in operation [43].

Typical sources of the discrepancy include high frequency dynamics, neglected nonlinearities in the modeling, effects of deliberate reduced-order models, and system parameter variations due to environmental changes or other external effects.

Due to the changes in system parameters, an uncertain threat is presented to the system, therefore such a system need special type of control system called *Robust* to guarantee the stability to the perturbed parameters [44].

As seen in chapter 2, weather conditions can be affected by uncertain parameter. There are many parameters that entered uncertainty to the system. These parameters will make variations in system performance. Due to rare resources of parallel computers, only some uncertain parameters are taken in this system. These parameters are listed in the table (4.11) as an interval with lower and upper limits.

Table (4.11): Parameters with uncertainty.

Parameter	Range of uncertainty
Dirt of mirror	[0.8 , 1]
Tracking error	[0.9 , 1]
Tank loss coefficient	[0.3 , 0.6]
Piping thermal loss coefficient	[0.3 , 0.6]
Row spacing	[10 , 20]
Washes per year	[53 , 63]
Rated cycle conversion efficiency	[0.39 , 0.43]

Note that in addition to simulating a system's performance over a single year and calculating a project cash flow over a multi-year, parametric analysis is used to see the effect of uncertain parameters on system performance. Parametric analysis assigns multiple values to input variables to create graphs and tables showing the value of output metrics for each value of the input variable. It is useful method for optimization and exploring relationships between input variables and results.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

In the previous chapter, the project design is done with specified parameters values listed in various tables. Once the input variables values are satisfied, we run simulations, and then examine results. A typical analysis involves running simulations, examining results, revising inputs, and repeating that process until having confidence in results. All analysis is done in the presence of uncertainty in various locations in the system.

In this chapter, different results are presented according to the input parameters for the system. The results will show the using of direct method, which used Hitec molten salt for transfer heat from solar field to the power cycle in addition to use it in thermal storage system. There will not be danger from freezing the molten salt in pipes because of Gaza Strip weather and temperature cannot be in the risk range.

5.2 Direct method results

As direct method is used in the simulation of project, the results obtained from SAM program are as in the table (5.1).

Table (5.1): Output values.

Parameter	Values	Parameter	Values
Solar field			
Single loop aperture	4360 m^2	Actual number of loops	9
Loop optical efficiency	0.741605	Total aperture reflective area	39240 m^2
Actual solar multiple	2	Field thermal output	26.3736 MWt
Total required aperture	19338.2 m^2	Total loop conversion efficiency	0.717792
Required number of loops	4.43539		
Collectors (SCAs)			
Length of single module	8.33333 m	Incidence of angle modifier	0.980043

End loss at summer solstice	0.999153	Optical efficiency at design	0.853162
Parameter	**Values**	**Parameter**	**Values**
Receivers (HCEs)			
Heat loss at design	166.25 W/m	Optical derate	0.869242
Power cycle			
Estimated net output at design	5.4 MWe	Design inlet temperature	391 °C
Design outlet temperature	293 °C		
Thermal storage			
Storage volume	1378.06 m^3	Storage HTF min. temp.	238 °C
TES thermal capacity	105.495 MWt	Storage HTF max. temp.	593 °C
Tank diameter	9.36643 m	Fluid temperature	342 °C
Min. fluid volume	68.903 m^3	TES fluid density	1872.49 Kg/m^3
Estimated heat loss	0.0846748 MWt	TES specific heat	1.50182 KJ/Kg-K
Trough system costs			
Site improvements	196200 $	Contingency	736873.52 $
Solar field	1177200 $	Total direct cost	15474343.8 $
HTF system	2354400 $	EPC and owner cost	1702177.82 $
Storage	6329670.33 $	Total land cost	303533.34 $
Fossil backup	0	Total indirect cost	2005711.17
Power plant	4200000$	Total installed cost	17480055. $
Balance of plant	480000 $	Est. total installed cost/net capacity	3237.05 $/KW

After numerical results are tabulated in the previous table, the graphs below demonstrate the type of output available and the possibilities for doing parametric analyses within SAM for parabolic trough collectors CSP models. The following figures contains results screen for a project with a standard 5.4 MW parabolic trough plant with 8 hours of thermal storage.

Figure (5.1) shows the net electrical output power available for each month of a year. As we see in Meteonorm software that the temperature be maximum in summer months, so maximum available power will be in this period of the year. The maximum value be in August, and equal 1453 MWh.

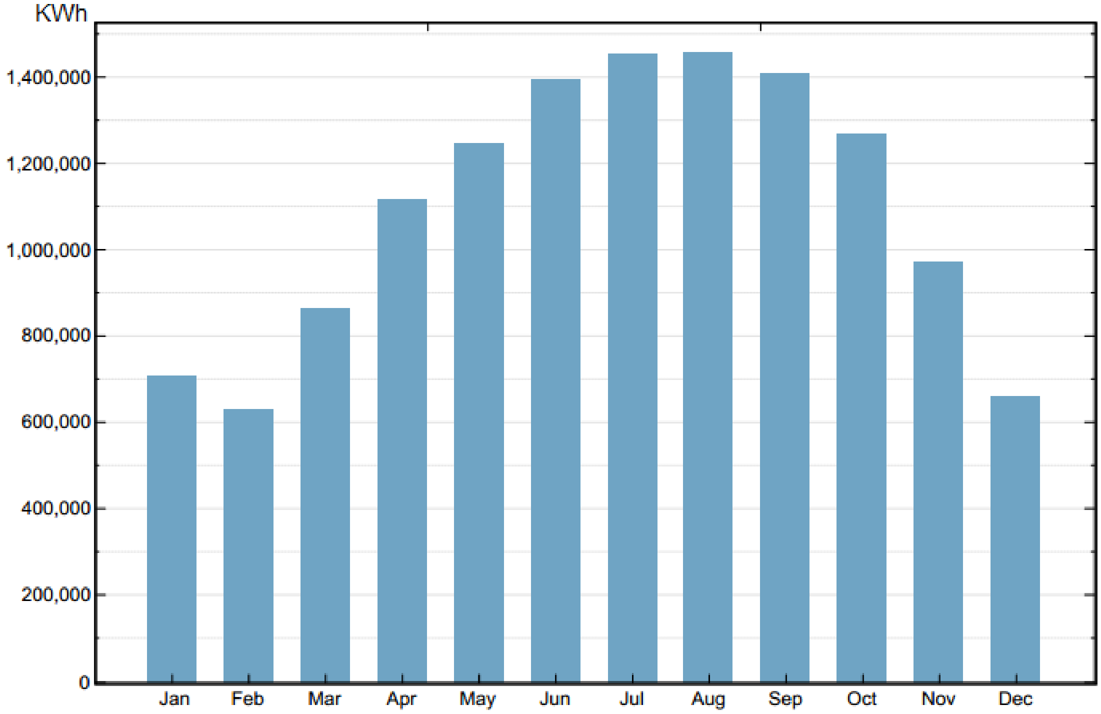


Figure (5.1): Monthly electrical output power.

Figure (5.2) shows the annual electrical output power over a period of analysis (25 years). SAM program calculate these values as an average value from the previous figure, and it also assume that the annual power will be fixed for all years.

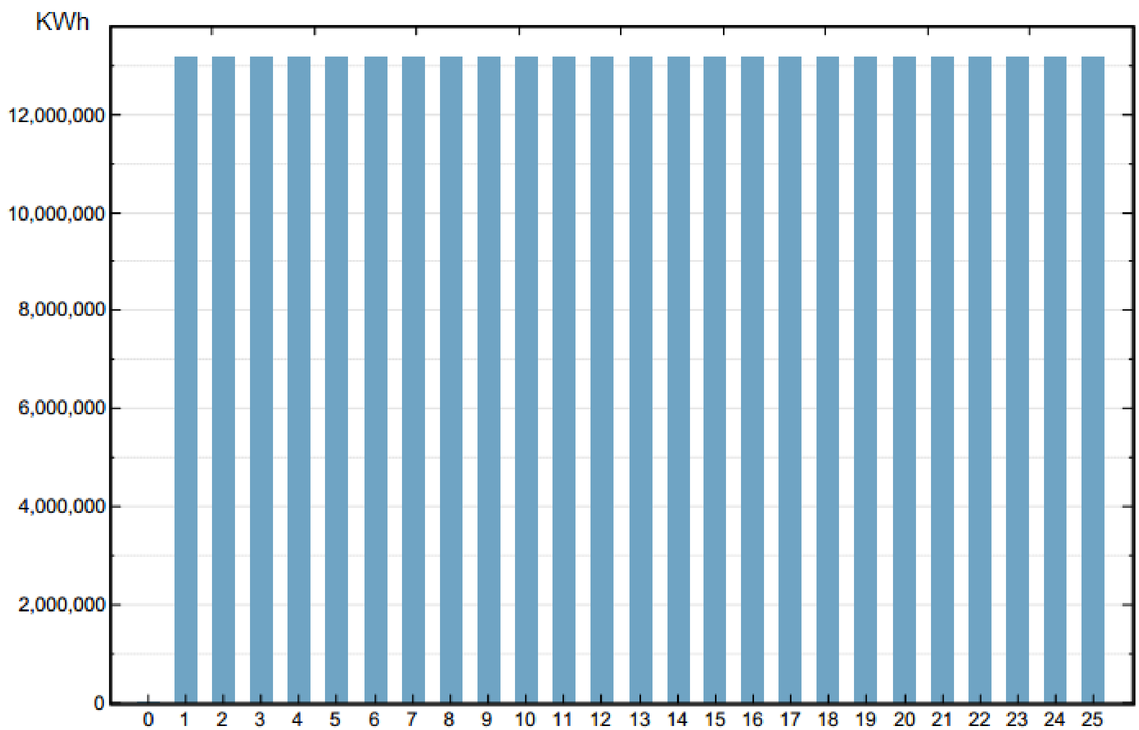


Figure (5.2): Annual electrical output power.

Figure (5.3) shows the annual energy flow in different part of the system starting with annual total incident solar radiation and ending with annual net electric output power.

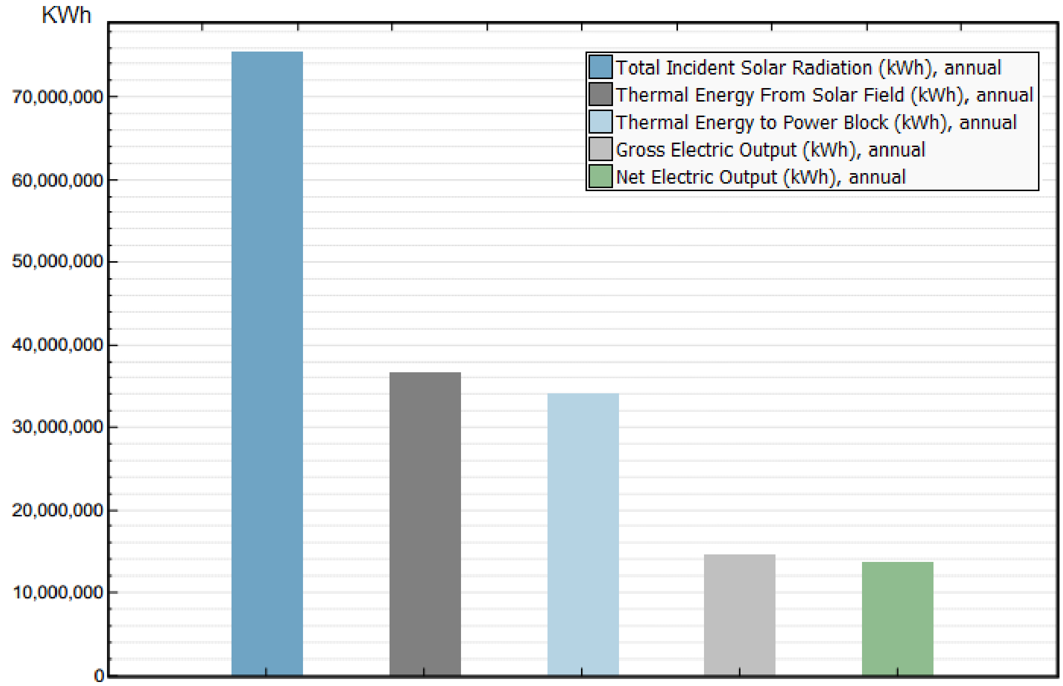


Figure (5.3): Annual energy flow.

The total cost per watt is shown in figure (5.4). This cost involves the cost consumed by each part of the system to produce the electric power.

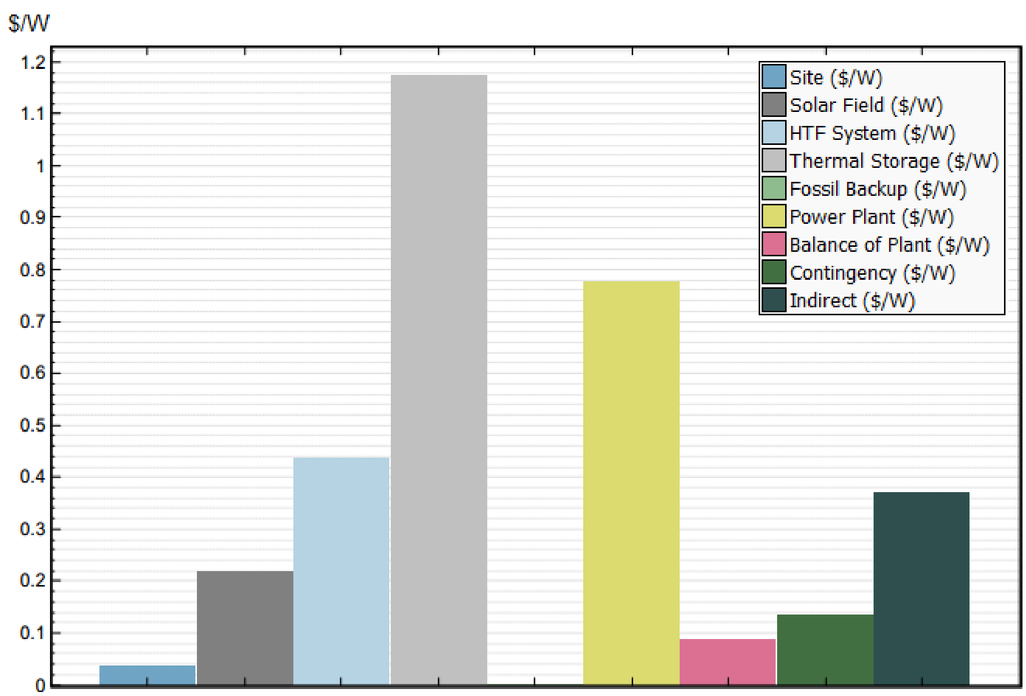


Figure (5.4): Cost per Watt.

For all financing options, SAM calculates both a real and nominal LCOE value. The real LCOE is a constant dollar, inflation-adjusted value. The nominal LCOE is a current dollar value. This thesis takes real LCOE into account to be the sensitive parameter we take care with it because it is appropriate for long-term analyses. The achieved real LCOE equal to 12.33 cent/KWh and nominal LCOE equal to 12.99 cent/KWh. Figures (5.5) and (5.6) show the stacked real and nominal LCOE respectively, and the color legend for the LCOE are as follows:

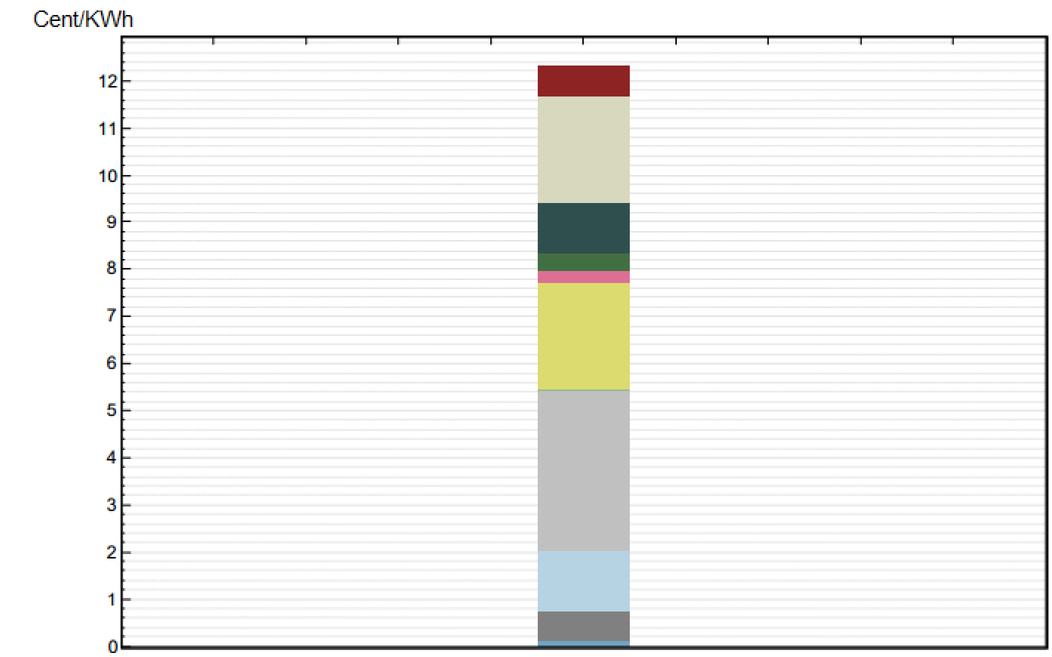


Figure (5.5): Stacked real LCOE.

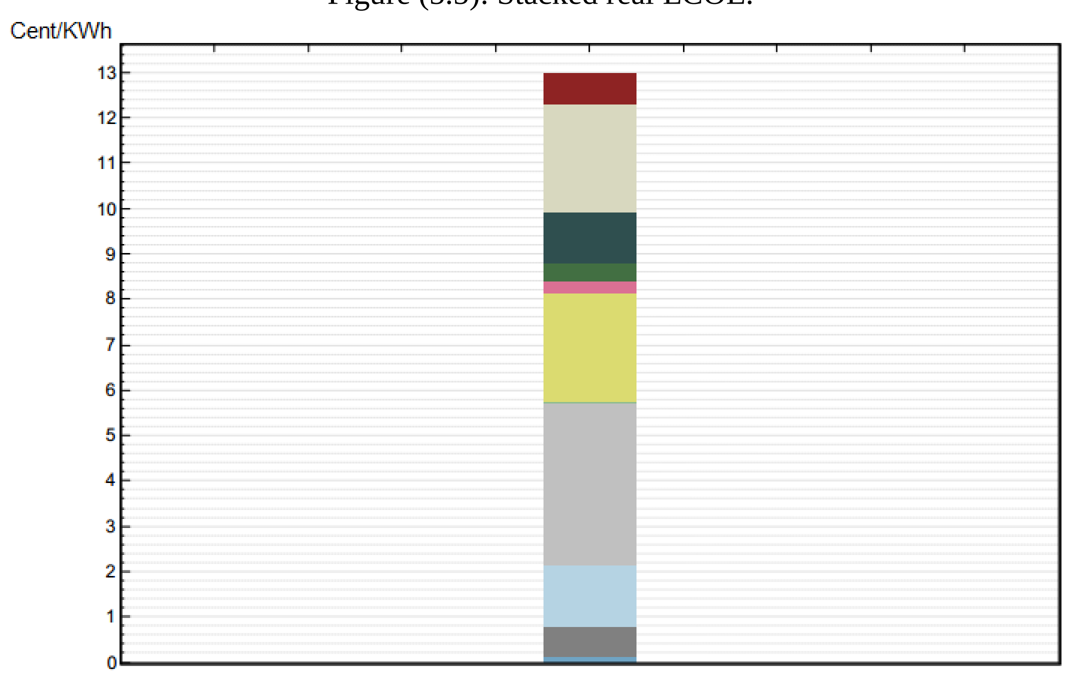


Figure (5.6): Stacked nominal LCOE.

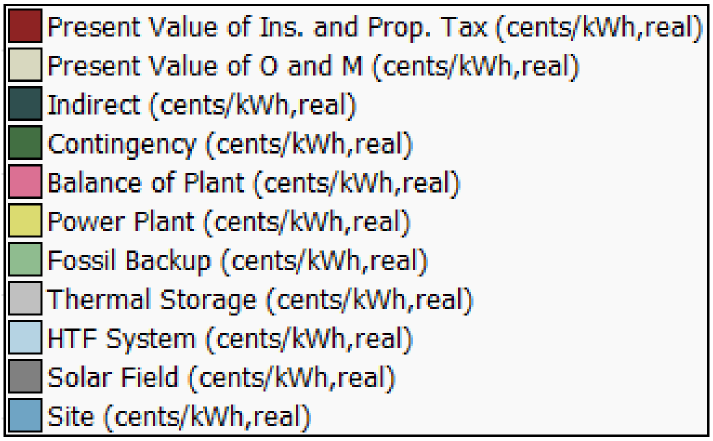


Figure (5.7): Legend for real and nominal LCOE.

The financial calculation of project takes the imposed tax into account, so that figure (5.8) shows the project returns after tax cash flow for the project analysis period (25 years).

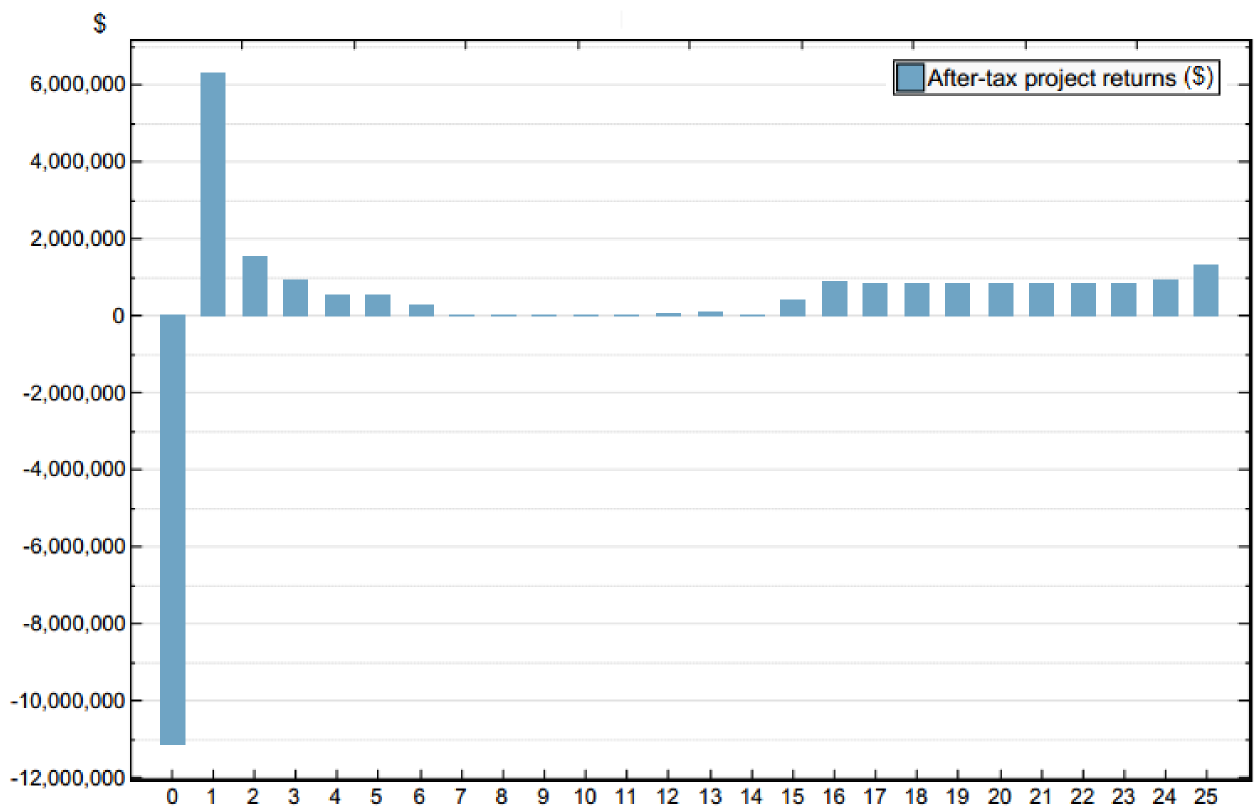


Figure (5.8): Project after tax cash flow.

The following figure (5.9) shows the project cumulative IRR which is the nominal discount rate that corresponds to a net present value of zero for projects with commercial PPA or utility financing.

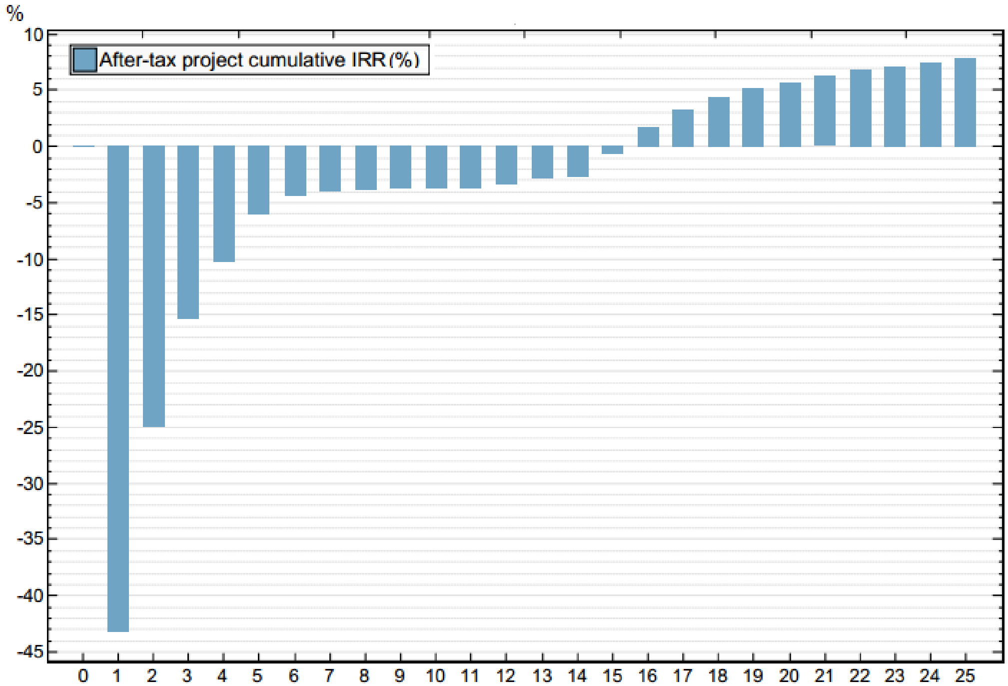


Figure (5.9): Project cumulative IRR.

A very important parameter in measuring economic feasibility of the project is the NPV. It includes both revenue and cost. In general, a positive NPV indicates an economically feasible project, while a negative NPV indicates an economically infeasible project. Figure (5.10) shows the project cumulative NPV.

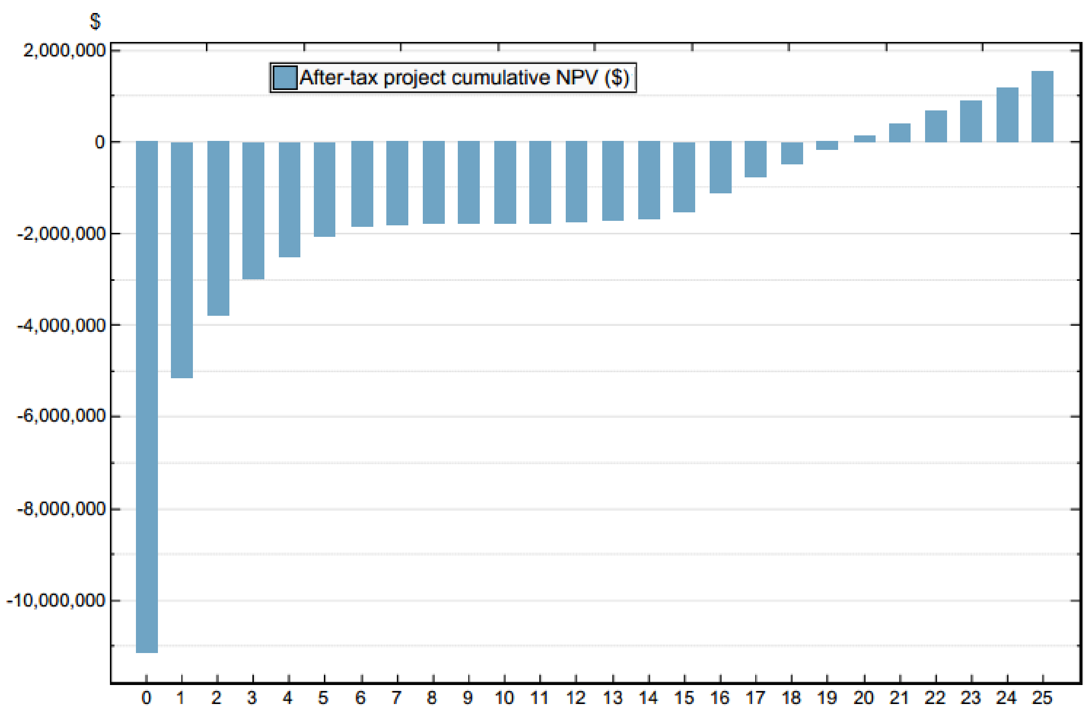


Figure (5.10): Project cumulative NPV.

As seen clearly in figure (5.10), the sustainability for the project is very promising.

In addition to all results shown above, SAM program also show time series tab. The time series tab shows a line graph of the selected variables over time.

Figure (5.11) shows the time series for DNI and net electric power output over a year, where the red color represents DNI and the green color represents the output power.

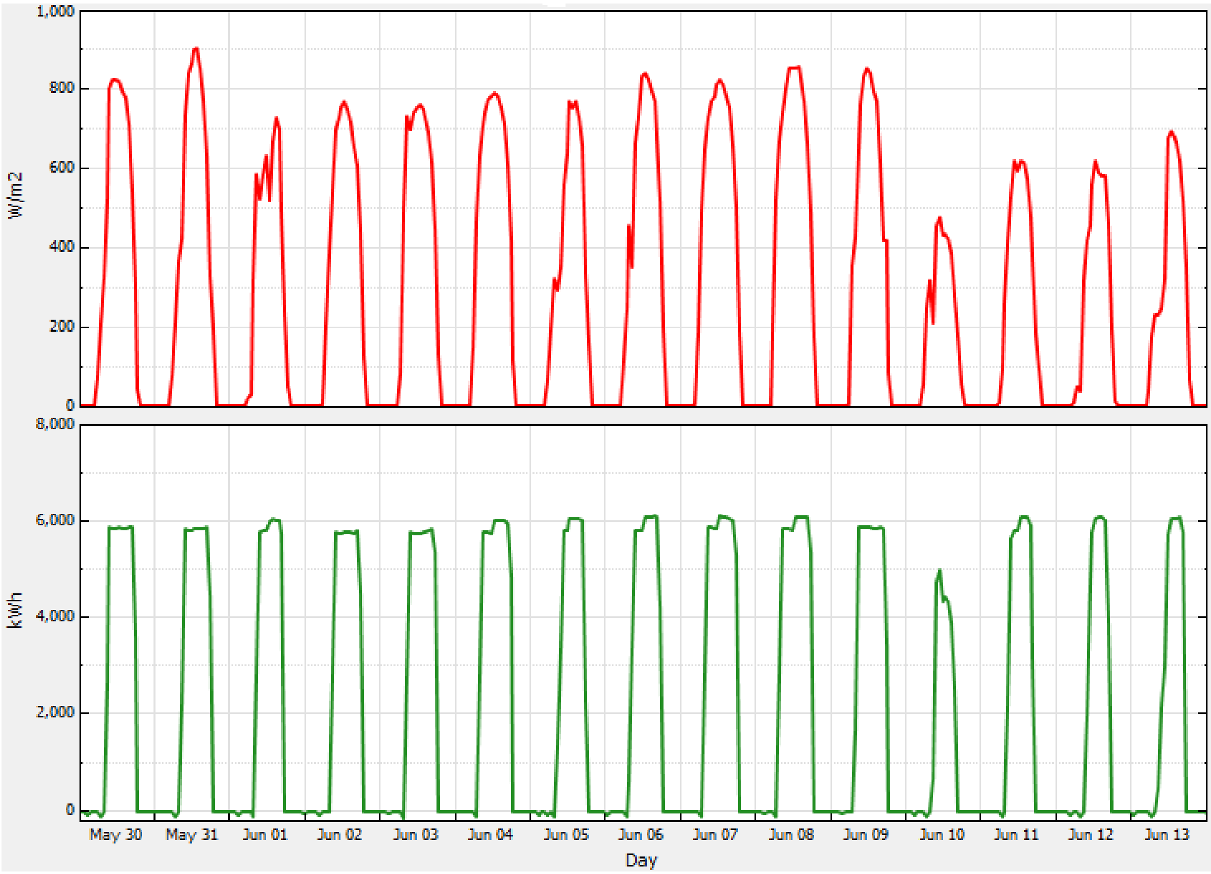


Figure (5.11): Time series for DNI and net output electric power.

Another important figure in this field is the annual profile. An annual profile is calculated by averaging all of the monthly profiles.

Figure (5.12) shows the annual profile for DNI and net electric output with the same above color indication. Note that, one can show profile for any wanted month by checking it to appear in the view screen.

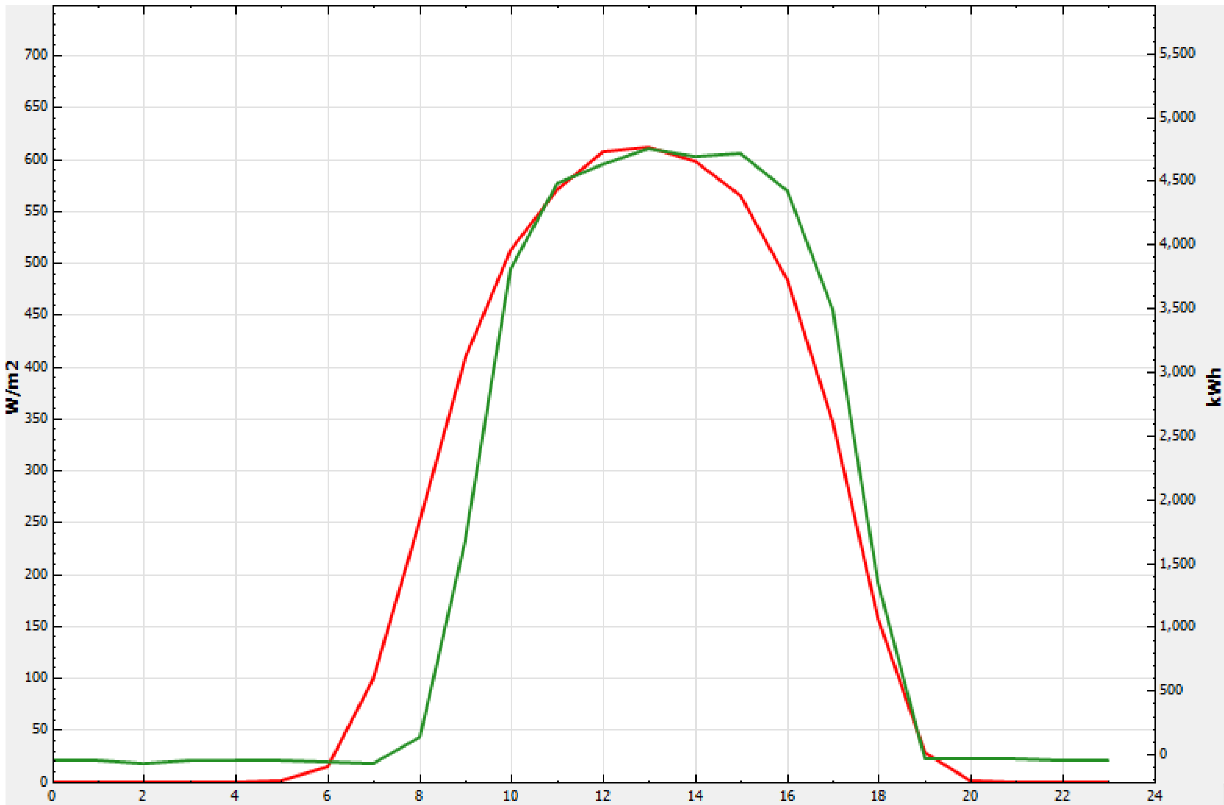


Figure (5.12): Annual profile for DNI and net output electric power.

The metric table for the direct method of this project is given in the table (5.2). This gives the total view for the user about the project, and summarizes the most important properties.

Table (5.2): Metric table for the project.

Metric	Value
Annual Energy	13,159,002 kWh
PPA price	10.00 ¢/kWh
LCOE Nominal	12.99 ¢/kWh
LCOE Real	12.33 ¢/kWh
IRR target year	25
IRR target	12.00 %
IRR actual year	-1
IRR in target year	0.00 %
After-tax IRR	7.88 %
After-tax NPV	$ 1,536,740.38
PPA price escalation	0.51 %
Debt fraction	43.84 %
Direct Cost	$ 15,474,343.85
Indirect Cost	$ 2,005,711.17
Financing Cost	$ 2,363,326.99
Total project cost	$ 19,843,382.00
Total debt	$ 8,700,113.00
Total equity	$ 11,143,269.00
Capacity factor	27.8 %
Gross to Net Conv. Factor	0.93
Annual Water Usage	38,999 m3
Total Land Area	30.35 acres

5.3 Uncertainty effect results

Now the results below will show the effects of uncertain parameter variations on the system performance. Figure (5.13) shows the annual electric output vs. dirt of mirror. The result shows in general that as the dirt of mirror increase, the output electric power will decrease. This is logically true in real life due to decrease in solar energy that reaches to receivers.

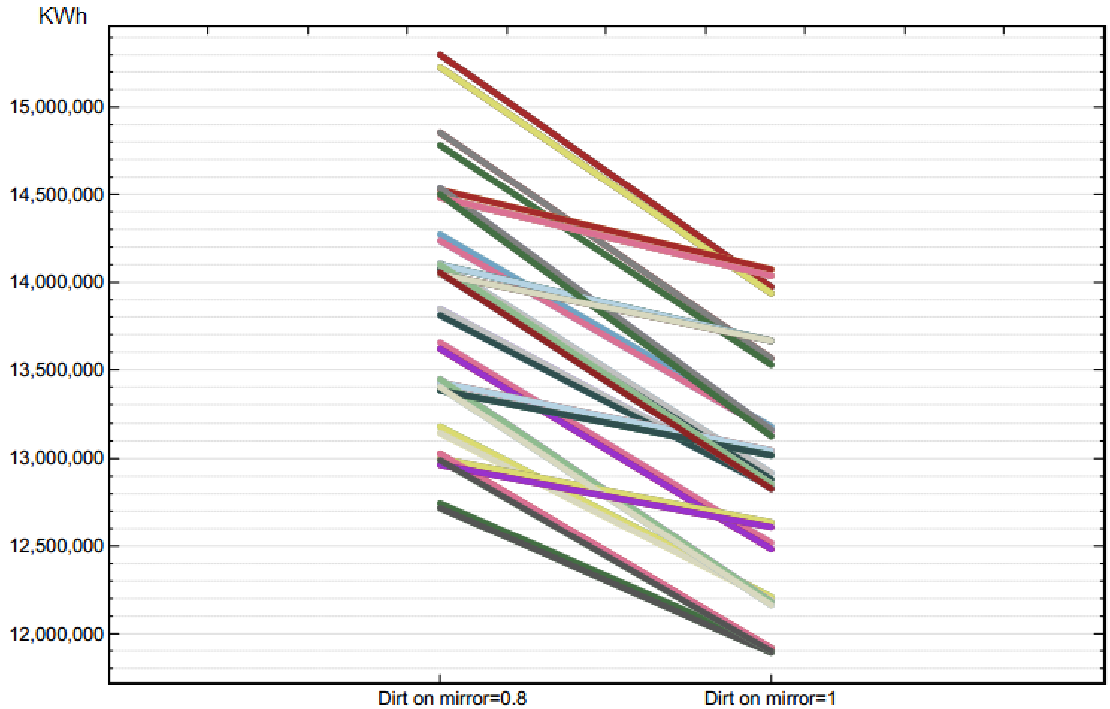


Figure (5.13): Annual output vs. dirt of mirror.

Where the color legend for this graph is shown in figure (A.1) in appendix A. This figure is a part of real legend, where the full legend contains 84 colors, but there are slightly different between values of close colors. Table (B.1) show the completed values, which is given in appendix (B).

Note that these colored lines results from variation in uncertain parameters.

Containing results, figure (5.14) shows the annual energy vs. row spacing between reflectors. The figure explains that as the row spacing increase, the annual energy increase. This is because of the shadowing between neighboring SCA will decrease, and each collector will have the maximum amount of solar radiations.

The legend colors for this figure is shown in figure (A.2) in appendix A, and full data is given in tale (B.2) in appendix B.

When connecting the cost with the efficiency, there will be trade-off between these two criteria. Figure (5.15) shows the relation between annual energy, rated cycle conversion efficiency and real LCOE. There will not be deterministic relations because a lot of parameters effect on each other.

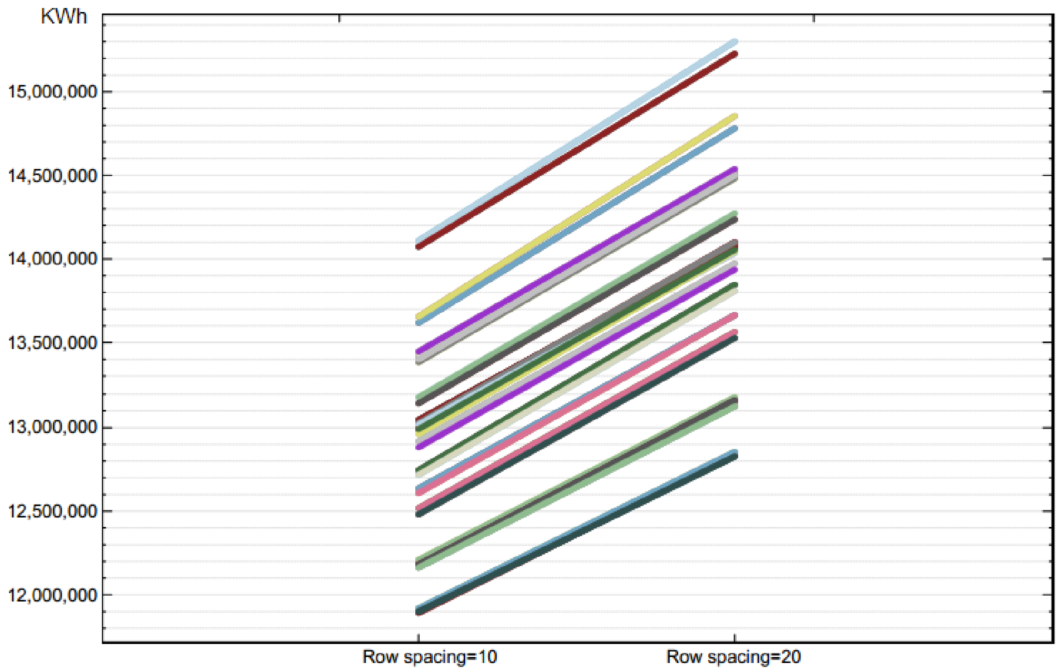


Figure (5.14): Annual energy vs. row spacing.

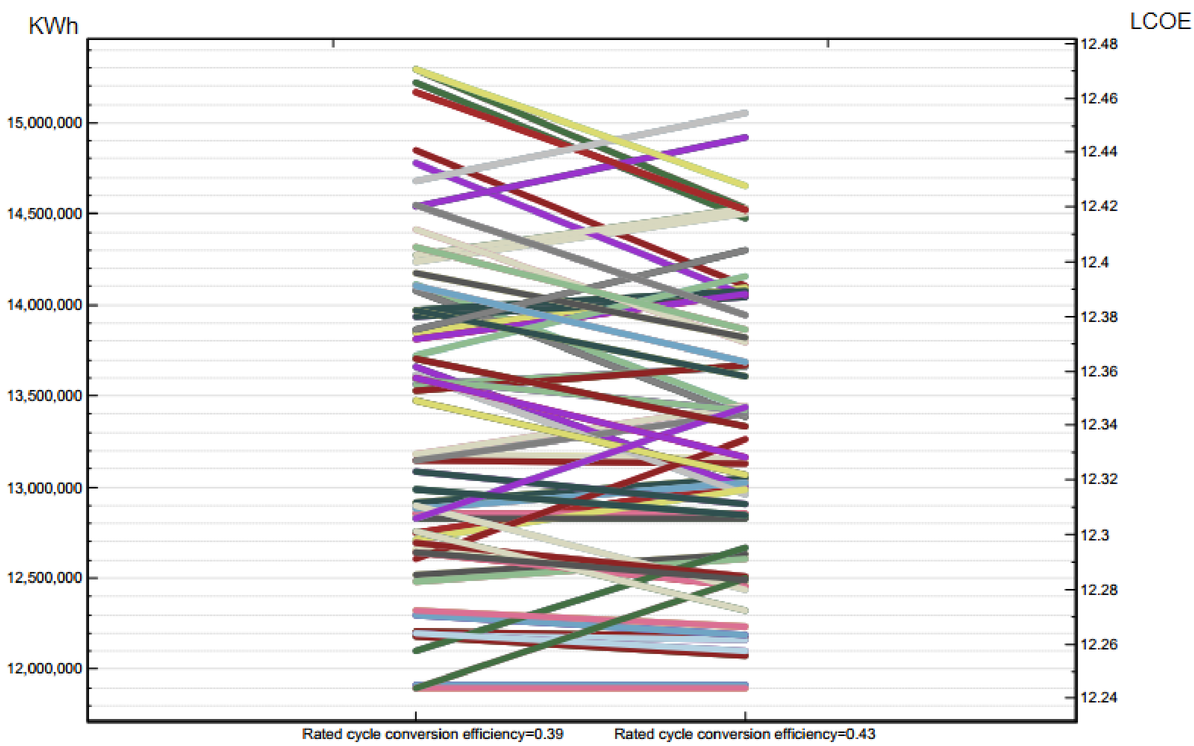


Figure (5.15): Annual energy and LCOE real vs. conversion efficiency.

The color legend for the above figure is shown in figure (A.3) in appendix A, and full data is shown in table (B.3) in appendix (B).

The monthly net electric output in the presence in uncertainty in parameters will be as shown in figure (5.16).

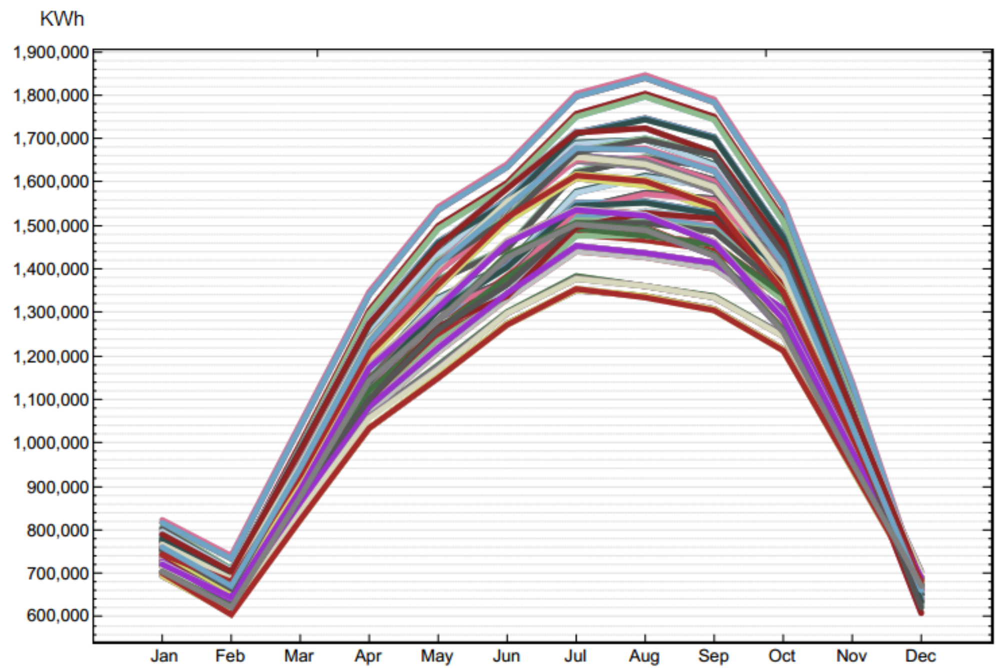


Figure (5.16): Monthly net electric output with uncertainty.

The color legend for the above figure is shown in figure (A.4) in appendix A, and full data is shown in table (B.4) in appendix (B).

As mentioned previously that the important parameter taken in calculating the cost of electricity from this project is LCOE real which is here equal to 12.33 cent/KWh. If this value is compared with the price of KWh in Gaza Strip (12.75 cent/KWh at the time of study), It is seen that this project achieve less price, in addition to clean energy that of offer it. Also, the present value of the project equal to 1536740.38 $ which indicate that the project is economically feasible.

Finally, SAM does not forget to calculate losses in the system and get the system output to grid after subtracting all losses. Figure (5.17) shows the loss diagram for the system.

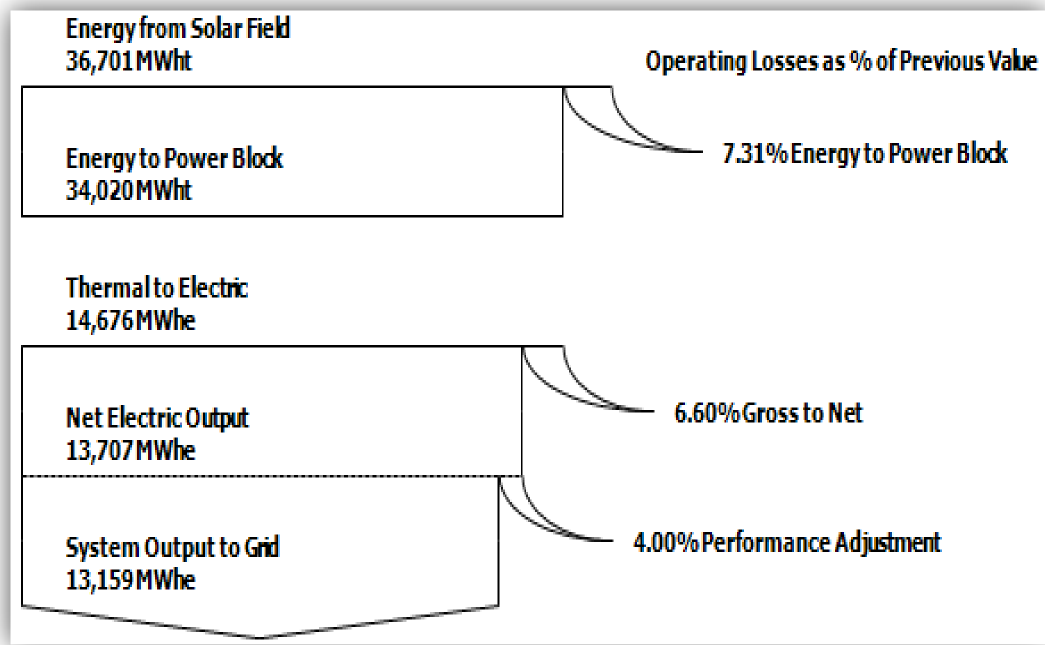


Figure (5.17): Loss diagram for the system.

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Solar energy plays an important role in generating electric power, it is clean and unlimited. We know that as the installed solar power plants capacity rises in the world, the technology costs will fall and it will be an increasingly common. Using robust techniques in different part of the system will play an important role in enabling these technologies and improving the efficiency.

In this thesis, the theoretical performance of PTC solar thermal power plant is investigated with self-tracking mechanism. Completed study is proposed to build solar thermal power plant for Turkish-Palestinian friendship hospital in the Islamic university land located in Al-Zahra town with net power of 5.40 MWe.

The complete solar power block was designed for simple Rankine power generation cycle for the proposed power plant with net power cover the demand load.

The design made using SAM software, which present economic feasibility study for the project in addition to the technical design. SAM allows users to examine solar and other renewable technologies on economic, technological and operational bases.

Also, a framework for characterizing system uncertainty is developed in various positions of the system. The uncertainty conditions involve change in weather conditions, solar irradiance or change in system parameters values.

The validation of the results obtained shows that the proposed methodology is suitable for any location, and that an optimum configuration can be achieved by sensitivity analysis.

Financial analysis shows plant investment costs, which is appeared in IRR and NPV.

On the other hand, LCOE is achieved average electricity prices less than the actual price in Gaza Strip with another good things like clean energy and unpolluted resource of energy that decrease the carbon emission to the air.

Some difficulties are found in this thesis. First, there is no meteorological database for Gaza Strip to depend on it in solar field analysis, so that similar location data (Bet Dagan) is used with little variation to get exact expression for Gaza Strip location.

Also, this thesis is considered a first project of its kind in concentrating thermal solar power plants in Palestine is spite of little available resources. Previous studies done in different locations in the world are taken as lights in the track of achievement the goal of the study.

Finally, unavailability of TRANSYS software make it impossible to design own controller for the proposed system. So, the study depend on self-tracking mechanism that solar collector provided with it to reach to the tracking goal. Actually SAM program says that all concentrating solar system is provided with tracking system to maximize the collected solar energy.

6.2 Future work

The following important points will be proposed as a future work and development for this thesis:

- Large power plant can be designed with total output power cover the leakage of electricity in any location. This will reduce the total cost for the project, reduce the price of KWh of electricity and contribute in solving electricity problem.
- Make the system more robust by taking more parameters into account as uncertain parameters in the system such as piping distance between assemblies, stow angle, deploy angle, storage HTF fluid and a lot of other parameters.
- Because of very long simulation time when using more uncertain parameter, it is recommended to use parallel computers to do this task. This technique require dividing the overall system into independent subsystem, so that each processor can simulate one subsystem in parallel, and in final stage, the machine combine all subsystems to output the total results.
- Design the proposed system using TRANSYS software, which has good capabilities and interaction with other software such as MATLAB. This will enable user to design any wanted control technique and apply it to achieve wanted criteria.

Actually, it has become necessary to make the best efforts to increase renewable energy projects especially in this decade, where other countries such as USA, Spain and Israel work rapidly in this field of energy.

Finally, it is really hoped that this thesis can be applied practically and help people in our country to reduce the electricity problem facing it in our daily life. Also, wishing that the contributed research can be used as guidance and pilot project for future solar projects in many countries in our region, especially for my homeland Palestine.

REFERENCES

[1] International energy agency IEA, *World energy outlook 2012*. Available online at: http://www.iea.org/publications/freepublications/publication/name,33339,en.html.
(access date:28.05.2014)

[2] Vasilis Fthenakis. *Third Generation Photovoltaic*. InTech, March, 2012.

[3] J. Duffie and W. Beckman. *Solar Engineering of Thermal Processes*, Second Edition. New York, NY: John Wiley and Sons, 1991.

[4] Solar med atlas, available online at:
http://www.solar-med-atlas.org/solarmedatlas/map.htm#c=31.46147,34.651798&t=dni&z=8.
(access date:28.05.2014)

[5] R. Desai. *Thermo-economic analysis of a solar thermal power plant with a central tower receiver for direct steam generation*, Master thesis, KTH Royal Institute of Technology, European joint masters in management and engineering of environment and energy, September 2013.

[6] O. Abdulla, R. AI-Badwawi, H. AI-Hadi, H. AI-Riyami, and A. AI-Nadabi. *Impact of a 200 MW concentrated receiver solar power plant on steady-state and transient performances of Oman transmission system*, IEEE international power engineering and optimization conference (PEOC), Melaka, Malaysia, 6-7 June, 2012.

[7] Y. Usta. *Simulation of a large scale solar thermal power plant in Turkey using concentrating parabolic trough collectors*, Master thesis, The graduate school of natural and applied science, Middle East technical university, December 2010.

[8] M. Dicorato, G. Forte, M. Pisani and E. De Tuglie. *One-axis tracking optimization of concentrating solar power plant for electricity production*, 45th Universities Power Engineering Conference (UPEC), 31st Aug - 3rd Sept, 2010.

[9] M. Jahromi, B. Dehghan, A. Jahromi and S. Zarie. *Design and modeling control system for a solar power plant*, Second international conference on computer and electrical engineering, Islamic Azad University, Iran, 2009

[10] A. Scott, R. Pitz-Paal., P. Schwarzboezl, N. Blair, and R. Cable. *TRNSYS modeling of the SEGS VI parabolic trough solar electric generating system*, Proceedings of Solar Forum, Washington, D.C, April 2001.

[11] A. Rabia, *Potential of Application of PV System for BWRO Desalination in Gaza*, GCREEDER, Amman, Jordan, 2009.

[12] D. Goswami, F. Kreith, J. Kreider, and F. Kreith. *Principles of Solar Engineering*, second edition, Taylor & Francis, Philadelphia, PA, 2000.

[13] H. Woolf. *On the Computation of Solar Evaluation Angles and the Determination of Sunrise and Sunset Times*. National Aeronautics and Space Administration Report NASA TM-X-164, USA, 1968.

[14] L. Valenzuela. *STE plants with parabolic trough collectors*, 3rd SFERA Summer School, Solar Thermal Electricity Generation, Almería, 27-28 June, 2012

[15] W. Stine and M. Geyer, *Power From The Sun*, 2001.
Available online at: http://www.powerfromthesun.net/Book/chapter04/chapter04.html

[16] J. Duffie and W. Beckman. *Solar engineering of thermal processes*.3rd, Hoboken, New Jersey: John Wiley & Sons, 2006.

[17] T. Kornshage, S. Quaschning and V. Dersch. *Sokrates Projekt Solarthermische Kraftwerks technologiefür den Schutz des Erdklimas*. Freiburg, Stuttgart: Fraunhofer Institute for solar Energy systems, Technology database AP2 /AP2.1, German Aerospace center (DLR), pp. 10, 2004.

[18] S. AlBarqouni. *Re-evaluation and re-design stand-alone PV solar lighting projects in Gaza Strip, Palestine*, master thesis, The Islamic university of Gaza, 2010.

[19] V. Quaschning. *Renewable Energy World*. Vol. 6, pp. 109-113, 2003.

[20] SAM admin. *Welcome to SAM*, 2010-04-05. Available online at: https://sam.nrel.gov/

[21] E. Camacho, F. Rubio, M. Berenguel and L. Valenzuela. *A survey on control schemes for distributed solar collector fields. Part I: Modeling and basic control approaches*, Solar Energy, pp. 1240–1251, 2007.

[22] A1. Czanderna, K. Masterson, and M. Terence. Glass *Mirrors for Solar Thermal Systems*. Solar Energy Research Institute, Cole Boulevard, Colorado 80401.

[23] C. Turchi. *Parabolic Trough Reference Plant for Cost Modeling with the Solar Advisor Model (SAM)*, Technical Report NREL/TP-550-47605, July 2010.

[24] J. Gordon. *Solar Energy: The State of the Art*, ISES position papers, 2001.

[25] D. Goswami and F. Kreith. *Energy conversion*, CRC, 2008.

[26] H. Riveros and A. Oliva. *Graphical Analysis of Sun Concentrating Collectors*, Solar Energy, No.4, pp. 313-322, 1986.

[27] W. Jeter and M. Sheldon. *Optical and Thermal Effects in Linear Concentrating Collectors*, Diss. George Institute of Technology, 1979.

[28] H. Garg and J. Prakash. *Solar Energy Fundamentals and Applications*, Tata McGraw-Hill Publishing Company Limited, Copyright © 2008.

[29] M. Iqbal. *An Introduction to Solar Radiation*, Academic, Toronto, 1983.

[30] O. Garcia and N. Velazquez. *Numerical Simulation of Parabolic Trough Solar Collector: Improvement using Counter Flow Concentric Circular Heat Exchangers*, Journal of Heat and Mass Transfer 52, pp 597–609, 2009.

[31] M. Roesle, V. Coskun and A. Steinfeld. *Numerical Analysis of Heat Loss From a Parabolic Trough Absorber Tube With Active Vacuum System*, Journal of Solar Energy Engineering, July 28, 2011.

[32] R. Forristall. Heat *Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver*. National Renewable Energy Laboratory (NREL), Colorado, 2003.

[33] S. Kalogirou. *Solar Thermal Collectors and Applications*. Progress in Energy and Combustion Science No. 30, pp. 231-295, 2004.

[34] S. Thepa, K. Kirtikara, J. Hirunlabh and J. Khedari. *Improving Indoor Conditions of a Thai-Style Mushroom House by Means of an Evaporative Cooler and Continuous*, Renewable Energy 17, pp 359-3693, 1999.

[35] A. Kahrobaian and H. Malek mohammadi. *Energy Optimization Applied to Linear Parabolic Solar Collectors,* Journal of Faculty of Engineering, No. 1, pp. 131-144, 2008.

[36] K. Boulting. *Development of a Solar Flux Tracker for Parabolic Trough Collectors*, Sandia National Laboratories, Department of Energy, United States, 1982.

[37] R. Dunn, P. Hearps, and M. Wright. *Molten-Salt Power Towers: Newly Commercial Concentrating Solar Storage*, Proceedings of the IEEE Vol. 100, No. 2, February 2012.

[38] G. Glatzmaier. *New Concepts and Materials for Thermal Energy Storage and Heat Transfer Fluids*, Technical Report NREL/TP- 5500-52134, May 20, 2011.

[39] P. Mukund. *Wind and solar power systems*, CRC Press, Washington, D.C. ISBN 0-8493-1605-7, 1999.

[40] H. Müller-Steinhagen and F. Trieb. *Concentrating Solar Power: a Review of the Technology*, Ingenia, Volume 18, pp. 43 – 50, 2004.

[41] Wiser and H. Wendell. *Energy resources: occurrence, production, conversion and use*. Birkhäuser. p. 190, 2000.

[42] N. Blair, A. Dobos, J. Freeman, T. Neises, and M. Wagner. *System Advisor Model, SAM 2014.1.14: General Description*, Technical Report, National Renewable Energy Laboratory, February 2014.

[43] D. Gu, P. Perkov and M. Konstantinov. *Robust control design with MATLAB*, Springer Verlag London Limited, 2005.

[44] M. Hussein. *Assessing 3-D Uncertain System Stability by Using MATLAB Convex Hull Functions*, International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 2, No. 6, 2011.

VITA

Nader Taleb was born in Saudi Arabia in December 1984. He completed his study in Palestinian schools and achieve the third person over Gaza Strip in Tawjihi exams.

He enrolled with the faculty of engineering in the Islamic University of Gaza from 2003 to 2007 and received a Bachelor of Science in electrical engineering in 2007 with excellent percentage.

He got a job in Palestinian Energy and natural resources associate (PENRA) as electrical engineer. He began work toward a Master of Science in control system engineering at the Islamic University of Gaza in the Fall of 2012. He finished his study in master degree with first honor. He interested in power generation and renewable energy especially in solar energy and obtaining electricity from the sun.

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APPENDIX A

(A.1): Legend colors for figure (5.13)

(A.2): Legend colors for figure (5.14)

(A.3): Legend colors for figure (5.15)

(A.4): Legend colors for figure (5.16)

APPENDIX B

(B.1): Completed values for Annual output vs. dirt of mirror

Parameterized Input(s)	Annual Energy (KWh)	
	Dirt on mirror=1	Dirt on mirror=0.8
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3}	1.22E+07	1.32E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3}	1.25E+07	1.37E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3}	1.19E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.22E+07	1.31E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.25E+07	1.36E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.19E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.40E+07	1.53E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.32E+07	1.43E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.36E+07	1.48E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.29E+07	1.39E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.39E+07	1.52E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.39E+07	1.52E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6}	1.31E+07	1.42E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.35E+07	1.48E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6}	1.28E+07	1.38E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3}	1.22E+07	1.32E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3}	1.22E+07	1.32E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.25E+07	1.37E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3}	1.19E+07	1.27E+07

{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6}	1.22E+07	1.31E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.25E+07	1.36E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.25E+07	1.36E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.19E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.40E+07	1.53E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.32E+07	1.43E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.36E+07	1.48E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.29E+07	1.39E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3}	1.29E+07	1.39E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.39E+07	1.52E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.39E+07	1.52E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6}	1.31E+07	1.42E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.35E+07	1.48E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6}	1.28E+07	1.38E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3}	1.22E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.26E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3}	1.19E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6}	1.22E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.22E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.26E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.19E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.41E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.32E+07	1.45E+07

{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.37E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.37E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.40E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.40E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6}	1.31E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.37E+07	1.41E+07
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{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3}	1.22E+07	1.34E+07
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{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.26E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3}	1.19E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.30E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6}	1.22E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6}	1.26E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.26E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6}	1.19E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3}	1.41E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3}	1.32E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.32E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3}	1.37E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3}	1.29E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.40E+07	1.45E+07

{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.40E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6}	1.31E+07	1.45E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6}	1.37E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6}	1.37E+07	1.41E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6}	1.28E+07	1.41E+07

(B.2): Completed values for Annual energy vs. row spacing

Parameterized Input(s)	Annual Energy (KWh)	
	Row spacing=20	Row spacing=10
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.53E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.40E+07	1.29E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.43E+07	1.32E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.48E+07	1.37E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.36E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.39E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.29E+07	1.19E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.52E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.39E+07	1.29E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.42E+07	1.31E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.48E+07	1.36E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.35E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.38E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.53E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.40E+07	1.29E+07

{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.43E+07	1.32E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.48E+07	1.37E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.36E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.39E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.29E+07	1.19E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.52E+07	1.41E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.39E+07	1.29E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.42E+07	1.31E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.48E+07	1.36E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.35E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.38E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.48E+07	1.37E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.36E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.39E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.35E+07	1.25E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.38E+07	1.27E+07
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.37E+07	1.26E+07

{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.29E+07	1.19E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.40E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.29E+07	1.19E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.45E+07	1.34E+07

{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.40E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.32E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.40E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.45E+07	1.34E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.31E+07	1.22E+07
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.26E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.30E+07
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.19E+07

(B.3): Completed values for Annual energy and LCOE real vs. conversion efficiency

Parameterized Input(s)	Annual Energy (KWh)	
	Cycle conv. efficiency =0.43	Cycle conv. efficiency =0.39
{Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.34E+07	1.41E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.30E+07	1.29E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.34E+07	1.32E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.22E+07	1.22E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.30E+07	1.37E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.26E+07	1.25E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.30E+07	1.27E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	1.19E+07	1.19E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.34E+07	1.41E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.30E+07	1.29E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.34E+07	1.31E+07
{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.22E+07	1.22E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.30E+07	1.36E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.26E+07	1.25E+07
{Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.30E+07	1.27E+07
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{Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.35E+07
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{Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.22E+07	1.22E+07
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{Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	1.45E+07	1.43E+07
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.37E+07	1.35E+07
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	1.41E+07	1.38E+07
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	1.28E+07	1.28E+07

Parameterized Input(s)	**LCOE Real**	
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{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.3704	12.412
{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.2556	12.2627
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{Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.3722	12.3962

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{Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3806	12.4206
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{Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.4039	12.3749
{Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3631	12.391
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{Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.3217	12.3493
{Washes per year=63 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.2812	12.2933
{Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.2953	12.2576
{Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3112	12.3233
{Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.2796	12.3104
{Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2845	12.297

{Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3466	12.306
{Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3399	12.3644
{Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3287	12.3572
{Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2837	12.2935
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.3579	12.3821
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.3704	12.412
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.2556	12.2627
{Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.4455	12.42
{Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.3722	12.3962
{Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.4188	12.4619
{Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.2633	12.2703
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.4039	12.3749
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3631	12.391
{Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3806	12.4206
{Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.3458	12.3569
{Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.3217	12.3493
{Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.2812	12.2933
{Washes per year=53 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.2953	12.2576
{Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3112	12.3233
{Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.2796	12.3104
{Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2845	12.297
{Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3466	12.306
{Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3399	12.3644
{Washes per year=53 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3287	12.3572
{Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3631	12.391
{Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3806	12.4206
{Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2574	12.2641

{Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.4545	12.4298
{Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3751	12.4053
{Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.4281	12.4706
{Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2665	12.2724
{Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.2843	12.2436
{Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	12.307	12.3165
{Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	12.2723	12.3013
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.3399	12.3644
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	12.3287	12.3572
{Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	12.2837	12.2935

(B.4): Completed values for monthly net electric output with uncertainty.

Parameterized Input(s)	Net Electric Output (kWh) monthly											
	12	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	654401	1.11E+06	1.48E+06	1.64E+06	1.66E+06	1.62E+06	1.45E+06	1.38E+06	1.20E+06	985908	711420	805533
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	680125	1.01E+06	1.33E+06	1.45E+06	1.47E+06	1.48E+06	1.37E+06	1.25E+06	1.11E+06	888672	659345	743910
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	658068	1.03E+06	1.37E+06	1.50E+06	1.52E+06	1.52E+06	1.38E+06	1.28E+06	1.12E+06	911905	666349	763485
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	683610	967388	1.25E+06	1.34E+06	1.36E+06	1.38E+06	1.30E+06	1.18E+06	1.06E+06	849443	630923	718627
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	632815	1.07E+06	1.44E+06	1.59E+06	1.61E+06	1.58E+06	1.41E+06	1.33E+06	1.17E+06	941967	674457	778002

{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	658557	982320	1.30E+06	1.40E+06	1.43E+06	1.44E+06	1.34E+06	1.21E+06	1.07E+06	850868	627696	719755
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	637437	995429	1.33E+06	1.46E+06	1.48E+06	1.48E+06	1.34E+06	1.24E+06	1.09E+06	869055	634686	730441
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	669326	942143	1.22E+06	1.31E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	825125	610180	694287
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	651016	1.11E+06	1.48E+06	1.63E+06	1.66E+06	1.62E+06	1.45E+06	1.37E+06	1.20E+06	982033	707867	803002
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	677213	1.01E+06	1.33E+06	1.44E+06	1.47E+06	1.48E+06	1.37E+06	1.25E+06	1.11E+06	884934	656312	740859
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	655068	1.03E+06	1.37E+06	1.50E+06	1.52E+06	1.52E+06	1.38E+06	1.28E+06	1.12E+06	908536	663566	760280
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	681714	965292	1.25E+06	1.34E+06	1.36E+06	1.38E+06	1.30E+06	1.18E+06	1.06E+06	847722	628625	714483
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	629489	1.06E+06	1.44E+06	1.59E+06	1.61E+06	1.58E+06	1.41E+06	1.33E+06	1.16E+06	938263	671362	774287
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	656999	978528	1.29E+06	1.40E+06	1.43E+06	1.44E+06	1.33E+06	1.21E+06	1.07E+06	847231	624925	716843
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	634515	992373	1.33E+06	1.46E+06	1.48E+06	1.48E+06	1.34E+06	1.23E+06	1.08E+06	865949	632231	727594
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	665675	939345	1.22E+06	1.31E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	823350	607434	692552

{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	670223	1.14E+06	1.55E+06	1.79E+06	1.84E+06	1.80E+06	1.64E+06	1.54E+06	1.35E+06	1.04E+06	739990	823604
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	690678	1.04E+06	1.38E+06	1.58E+06	1.64E+06	1.65E+06	1.55E+06	1.40E+06	1.23E+06	943413	682123	758552
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	670800	1.06E+06	1.43E+06	1.64E+06	1.70E+06	1.69E+06	1.56E+06	1.44E+06	1.26E+06	962731	689322	773740
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	689490	985664	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.47E+06	1.32E+06	1.18E+06	897964	645654	722667
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	650502	1.10E+06	1.51E+06	1.75E+06	1.80E+06	1.76E+06	1.60E+06	1.50E+06	1.31E+06	996253	701529	790931
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	673144	1.01E+06	1.34E+06	1.54E+06	1.59E+06	1.61E+06	1.51E+06	1.36E+06	1.20E+06	905700	651637	735440
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	650060	1.02E+06	1.39E+06	1.60E+06	1.65E+06	1.65E+06	1.52E+06	1.40E+06	1.22E+06	922065	656012	744553
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	672427	958961	1.26E+06	1.43E+06	1.50E+06	1.51E+06	1.43E+06	1.28E+06	1.15E+06	869845	626371	703600
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	664933	1.13E+06	1.54E+06	1.78E+06	1.84E+06	1.80E+06	1.64E+06	1.53E+06	1.34E+06	1.04E+06	734985	817190
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	685332	1.04E+06	1.38E+06	1.58E+06	1.64E+06	1.65E+06	1.55E+06	1.40E+06	1.23E+06	940256	678474	754673
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	666451	1.05E+06	1.43E+06	1.64E+06	1.70E+06	1.69E+06	1.56E+06	1.43E+06	1.26E+06	956915	685198	769122

{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	688285	982016	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.46E+06	1.31E+06	1.18E+06	895243	644721	719698
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	645210	1.09E+06	1.51E+06	1.74E+06	1.80E+06	1.75E+06	1.59E+06	1.49E+06	1.30E+06	989987	696615	785133
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	670808	1.00E+06	1.34E+06	1.54E+06	1.59E+06	1.61E+06	1.51E+06	1.36E+06	1.19E+06	902288	648509	730160
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	645936	1.02E+06	1.39E+06	1.60E+06	1.65E+06	1.65E+06	1.52E+06	1.39E+06	1.22E+06	917199	651857	740566
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	671038	958247	1.26E+06	1.43E+06	1.49E+06	1.51E+06	1.43E+06	1.28E+06	1.14E+06	867552	626508	701540
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	654401	1.11E+06	1.48E+06	1.64E+06	1.66E+06	1.62E+06	1.45E+06	1.38E+06	1.20E+06	985908	711420	805533
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	680125	1.01E+06	1.33E+06	1.45E+06	1.47E+06	1.48E+06	1.37E+06	1.25E+06	1.11E+06	888672	659345	743910
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	658068	1.03E+06	1.37E+06	1.50E+06	1.52E+06	1.52E+06	1.38E+06	1.28E+06	1.12E+06	911905	666349	763485
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	683610	967388	1.25E+06	1.34E+06	1.36E+06	1.38E+06	1.30E+06	1.18E+06	1.06E+06	849443	630923	718627
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	632815	1.07E+06	1.44E+06	1.59E+06	1.61E+06	1.58E+06	1.41E+06	1.33E+06	1.17E+06	941967	674457	778002
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	658557	982320	1.30E+06	1.40E+06	1.43E+06	1.44E+06	1.34E+06	1.21E+06	1.07E+06	850868	627696	719755

{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	637437	995429	1.33E+06	1.46E+06	1.48E+06	1.48E+06	1.34E+06	1.24E+06	1.09E+06	869055	634686	730441
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	669326	942143	1.22E+06	1.31E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	825125	610180	694287
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	651016	1.11E+06	1.48E+06	1.63E+06	1.66E+06	1.62E+06	1.45E+06	1.37E+06	1.20E+06	982033	707867	803002
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	677213	1.01E+06	1.33E+06	1.44E+06	1.47E+06	1.48E+06	1.37E+06	1.25E+06	1.11E+06	884934	656312	740859
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	655068	1.03E+06	1.37E+06	1.50E+06	1.52E+06	1.52E+06	1.38E+06	1.28E+06	1.12E+06	908536	663566	760280
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	681714	965292	1.25E+06	1.34E+06	1.36E+06	1.38E+06	1.30E+06	1.18E+06	1.06E+06	847722	628625	714483
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	629489	1.06E+06	1.44E+06	1.59E+06	1.61E+06	1.58E+06	1.41E+06	1.33E+06	1.16E+06	938263	671362	774287
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	656999	978528	1.29E+06	1.40E+06	1.43E+06	1.44E+06	1.33E+06	1.21E+06	1.07E+06	847231	624925	716843
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	634515	992373	1.33E+06	1.46E+06	1.48E+06	1.48E+06	1.34E+06	1.23E+06	1.08E+06	865949	632231	727594
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	665675	939345	1.22E+06	1.31E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	823350	607434	692552
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	670223	1.14E+06	1.55E+06	1.79E+06	1.84E+06	1.80E+06	1.64E+06	1.54E+06	1.35E+06	1.04E+06	739990	823604

{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	690678	1.04E+06	1.38E+06	1.58E+06	1.64E+06	1.65E+06	1.55E+06	1.40E+06	1.23E+06	943413	682123	758552
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	670800	1.06E+06	1.43E+06	1.64E+06	1.70E+06	1.69E+06	1.56E+06	1.44E+06	1.26E+06	962731	689322	773740
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	689490	985664	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.47E+06	1.32E+06	1.18E+06	897964	645654	722667
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	650502	1.10E+06	1.51E+06	1.75E+06	1.80E+06	1.76E+06	1.60E+06	1.50E+06	1.31E+06	996253	701529	790931
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	673144	1.01E+06	1.34E+06	1.54E+06	1.59E+06	1.61E+06	1.51E+06	1.36E+06	1.20E+06	905700	651637	735440
{Rated cycle conversion efficiency=0.39 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	650060	1.02E+06	1.39E+06	1.60E+06	1.65E+06	1.65E+06	1.52E+06	1.40E+06	1.22E+06	922065	656012	744553
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	672427	958961	1.26E+06	1.43E+06	1.50E+06	1.51E+06	1.43E+06	1.28E+06	1.15E+06	869845	626371	703600
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	664933	1.13E+06	1.54E+06	1.78E+06	1.84E+06	1.80E+06	1.64E+06	1.53E+06	1.34E+06	1.04E+06	734985	817190
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	685332	1.04E+06	1.38E+06	1.58E+06	1.64E+06	1.65E+06	1.55E+06	1.40E+06	1.23E+06	940256	678474	754673
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	666451	1.05E+06	1.43E+06	1.64E+06	1.70E+06	1.69E+06	1.56E+06	1.43E+06	1.26E+06	956915	685198	769122
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	688285	982016	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.46E+06	1.31E+06	1.18E+06	895243	644721	719698

{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	645210	1.09E+06	1.51E+06	1.74E+06	1.80E+06	1.75E+06	1.59E+06	1.49E+06	1.30E+06	989987	696615	785133
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	670808	1.00E+06	1.34E+06	1.54E+06	1.59E+06	1.61E+06	1.51E+06	1.36E+06	1.19E+06	902288	648509	730160
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	645936	1.02E+06	1.39E+06	1.60E+06	1.65E+06	1.65E+06	1.52E+06	1.39E+06	1.22E+06	917199	651857	740566
{Rated cycle conversion efficiency=0.39 Washes per year=63 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	671038	958247	1.26E+06	1.43E+06	1.49E+06	1.51E+06	1.43E+06	1.28E+06	1.14E+06	867552	626508	701540
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	633270	1.05E+06	1.41E+06	1.56E+06	1.57E+06	1.54E+06	1.37E+06	1.31E+06	1.15E+06	934564	679098	774790
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	690378	1.03E+06	1.34E+06	1.46E+06	1.48E+06	1.49E+06	1.38E+06	1.26E+06	1.12E+06	902563	669306	758306
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	675164	1.05E+06	1.40E+06	1.53E+06	1.56E+06	1.55E+06	1.41E+06	1.31E+06	1.14E+06	930422	680406	781135
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	683068	964505	1.25E+06	1.33E+06	1.36E+06	1.38E+06	1.30E+06	1.17E+06	1.06E+06	846404	631925	717431
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	610897	1.02E+06	1.37E+06	1.52E+06	1.53E+06	1.50E+06	1.34E+06	1.27E+06	1.10E+06	892285	638432	746489
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	665544	997118	1.31E+06	1.41E+06	1.44E+06	1.45E+06	1.35E+06	1.22E+06	1.09E+06	863234	636172	730823
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	655672	1.01E+06	1.36E+06	1.49E+06	1.51E+06	1.51E+06	1.37E+06	1.26E+06	1.10E+06	888307	651215	753065

{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	668724	944978	1.21E+06	1.30E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	825781	608115	698956
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	629794	1.05E+06	1.41E+06	1.56E+06	1.57E+06	1.54E+06	1.37E+06	1.31E+06	1.14E+06	932003	676115	770228
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	686863	1.03E+06	1.34E+06	1.46E+06	1.48E+06	1.49E+06	1.38E+06	1.26E+06	1.12E+06	899675	665374	754942
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	672073	1.04E+06	1.40E+06	1.52E+06	1.55E+06	1.55E+06	1.40E+06	1.31E+06	1.14E+06	927211	675503	778191
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	681142	962986	1.24E+06	1.33E+06	1.36E+06	1.38E+06	1.30E+06	1.17E+06	1.06E+06	844070	629561	715375
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	607705	1.01E+06	1.36E+06	1.52E+06	1.53E+06	1.50E+06	1.34E+06	1.27E+06	1.10E+06	889450	635625	743181
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	664117	991057	1.31E+06	1.41E+06	1.44E+06	1.45E+06	1.34E+06	1.22E+06	1.08E+06	860858	633728	725993
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	652699	1.01E+06	1.36E+06	1.49E+06	1.51E+06	1.51E+06	1.36E+06	1.26E+06	1.10E+06	883868	649111	749694
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	664812	941642	1.21E+06	1.30E+06	1.33E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	824145	605764	699302
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	639820	1.08E+06	1.48E+06	1.70E+06	1.75E+06	1.71E+06	1.56E+06	1.46E+06	1.28E+06	988618	705067	785850
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	703465	1.05E+06	1.39E+06	1.59E+06	1.65E+06	1.66E+06	1.56E+06	1.41E+06	1.24E+06	951728	689091	770935

{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	689205	1.08E+06	1.46E+06	1.67E+06	1.73E+06	1.72E+06	1.59E+06	1.46E+06	1.28E+06	984665	706842	795697
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=53 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	691937	982802	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.46E+06	1.32E+06	1.18E+06	892732	645680	724949
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	624528	1.04E+06	1.44E+06	1.67E+06	1.70E+06	1.67E+06	1.52E+06	1.42E+06	1.24E+06	943052	668821	758556
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	682445	1.02E+06	1.35E+06	1.55E+06	1.60E+06	1.62E+06	1.52E+06	1.37E+06	1.21E+06	915595	659311	748184
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	666920	1.04E+06	1.42E+06	1.63E+06	1.68E+06	1.68E+06	1.55E+06	1.41E+06	1.24E+06	944613	674576	763483
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	672742	958172	1.26E+06	1.43E+06	1.49E+06	1.51E+06	1.43E+06	1.28E+06	1.15E+06	874814	624372	705022
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	635131	1.07E+06	1.47E+06	1.70E+06	1.74E+06	1.71E+06	1.55E+06	1.46E+06	1.27E+06	983781	700925	781141
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	700474	1.05E+06	1.38E+06	1.59E+06	1.64E+06	1.66E+06	1.55E+06	1.41E+06	1.24E+06	949242	688088	767419
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	684594	1.07E+06	1.45E+06	1.67E+06	1.72E+06	1.71E+06	1.58E+06	1.45E+06	1.28E+06	981728	703061	790545
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	689749	980711	1.29E+06	1.46E+06	1.52E+06	1.53E+06	1.46E+06	1.31E+06	1.17E+06	890524	644389	722006
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	619919	1.04E+06	1.43E+06	1.66E+06	1.70E+06	1.67E+06	1.52E+06	1.41E+06	1.23E+06	939344	664912	753634

{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	680585	1.01E+06	1.35E+06	1.55E+06	1.60E+06	1.62E+06	1.52E+06	1.36E+06	1.20E+06	924905	680490	743899
{Rated cycle conversion efficiency=0.43 Washes per year=53 Tank loss coeff=0.6 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	662421	1.04E+06	1.41E+06	1.62E+06	1.68E+06	1.68E+06	1.54E+06	1.41E+06	1.23E+06	940291	671256	758716
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=53 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	671931	956020	1.26E+06	1.43E+06	1.49E+06	1.50E+06	1.43E+06	1.28E+06	1.14E+06	875795	621818	702355
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	633270	1.05E+06	1.41E+06	1.56E+06	1.57E+06	1.54E+06	1.37E+06	1.31E+06	1.15E+06	934564	679098	774790
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	690378	1.03E+06	1.34E+06	1.46E+06	1.48E+06	1.49E+06	1.38E+06	1.26E+06	1.12E+06	902563	669306	758306
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	675164	1.05E+06	1.40E+06	1.53E+06	1.56E+06	1.55E+06	1.41E+06	1.31E+06	1.14E+06	930422	680406	781135
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	683068	964505	1.25E+06	1.33E+06	1.36E+06	1.38E+06	1.30E+06	1.17E+06	1.06E+06	846404	631925	717431
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	610897	1.02E+06	1.37E+06	1.52E+06	1.53E+06	1.50E+06	1.34E+06	1.27E+06	1.10E+06	892285	638432	746489
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	665544	997118	1.31E+06	1.41E+06	1.44E+06	1.45E+06	1.35E+06	1.22E+06	1.09E+06	863234	636172	730823
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	655672	1.01E+06	1.36E+06	1.49E+06	1.51E+06	1.51E+06	1.37E+06	1.26E+06	1.10E+06	888307	651215	753065
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	668724	944978	1.21E+06	1.30E+06	1.34E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	825781	608115	698956

{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	629794	1.05E+06	1.41E+06	1.56E+06	1.57E+06	1.54E+06	1.37E+06	1.31E+06	1.14E+06	932003	676115	770228
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	686863	1.03E+06	1.34E+06	1.46E+06	1.48E+06	1.49E+06	1.38E+06	1.26E+06	1.12E+06	899675	665374	754942
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	672073	1.04E+06	1.40E+06	1.52E+06	1.55E+06	1.55E+06	1.40E+06	1.31E+06	1.14E+06	927211	675503	778191
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	681142	962986	1.24E+06	1.33E+06	1.36E+06	1.38E+06	1.30E+06	1.17E+06	1.06E+06	844070	629561	715375
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=10 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	607705	1.01E+06	1.36E+06	1.52E+06	1.53E+06	1.50E+06	1.34E+06	1.27E+06	1.10E+06	889450	635625	743181
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	664117	991057	1.31E+06	1.41E+06	1.44E+06	1.45E+06	1.34E+06	1.22E+06	1.08E+06	860858	633728	725993
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	652699	1.01E+06	1.36E+06	1.49E+06	1.51E+06	1.51E+06	1.36E+06	1.26E+06	1.10E+06	883868	649111	749694
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=10 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	664812	941642	1.21E+06	1.30E+06	1.33E+06	1.35E+06	1.27E+06	1.15E+06	1.03E+06	824145	605764	699302
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	639820	1.08E+06	1.48E+06	1.70E+06	1.75E+06	1.71E+06	1.56E+06	1.46E+06	1.28E+06	988618	705067	785850
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	703465	1.05E+06	1.39E+06	1.59E+06	1.65E+06	1.66E+06	1.56E+06	1.41E+06	1.24E+06	951728	689091	770935
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	689205	1.08E+06	1.46E+06	1.67E+06	1.73E+06	1.72E+06	1.59E+06	1.46E+06	1.28E+06	984665	706842	795697

{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.3 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	691937	982802	1.29E+06	1.46E+06	1.53E+06	1.54E+06	1.46E+06	1.32E+06	1.18E+06	892732	645680	724949
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	624528	1.04E+06	1.44E+06	1.67E+06	1.70E+06	1.67E+06	1.52E+06	1.42E+06	1.24E+06	943052	668821	758556
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	682445	1.02E+06	1.35E+06	1.55E+06	1.60E+06	1.62E+06	1.52E+06	1.37E+06	1.21E+06	915595	659311	748184
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.3 Dirt on mirror=0.8}	666920	1.04E+06	1.42E+06	1.63E+06	1.68E+06	1.68E+06	1.55E+06	1.41E+06	1.24E+06	944613	674576	763483
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.3 Dirt on mirror=1}	672742	958172	1.26E+06	1.43E+06	1.49E+06	1.51E+06	1.43E+06	1.28E+06	1.15E+06	874814	624372	705022
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	635131	1.07E+06	1.47E+06	1.70E+06	1.74E+06	1.71E+06	1.55E+06	1.46E+06	1.27E+06	983781	700925	781141
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	700474	1.05E+06	1.38E+06	1.59E+06	1.64E+06	1.66E+06	1.55E+06	1.41E+06	1.24E+06	949242	688088	767419
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	684594	1.07E+06	1.45E+06	1.67E+06	1.72E+06	1.71E+06	1.58E+06	1.45E+06	1.28E+06	981728	703061	790545
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.3 Tracking error=1 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	689749	980711	1.29E+06	1.46E+06	1.52E+06	1.53E+06	1.46E+06	1.31E+06	1.17E+06	890524	644389	722006
{Rated cycle conversion efficiency=0.43 Washes per year=63 Tank loss coeff=0.6 Tracking error=0.9 Row spacing=20 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	619919	1.04E+06	1.43E+06	1.66E+06	1.70E+06	1.67E+06	1.52E+06	1.41E+06	1.23E+06	939344	664912	753634
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=0.9 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	680585	1.01E+06	1.35E+06	1.55E+06	1.60E+06	1.62E+06	1.52E+06	1.36E+06	1.20E+06	924905	680490	743899

{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=0.8}	662421	1.04E+06	1.41E+06	1.62E+06	1.68E+06	1.68E+06	1.54E+06	1.41E+06	1.23E+06	940291	671256	758716
{Rated cycle conversion efficiency=0.43 Tank loss coeff=0.6 Washes per year=63 Row spacing=20 Tracking error=1 Piping thermal loss coefficient=0.6 Dirt on mirror=1}	671931	956020	1.26E+06	1.43E+06	1.49E+06	1.50E+06	1.43E+06	1.28E+06	1.14E+06	875795	621818	702355