FEASIBILITY STUDY OF A DISH/STIRLING SOLAR THERMAL POWER PLANT IN THE DOMINICAN REPUBLIC AND PUERTO RICO

By

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ABSTRACT

In this work we make the feasibility study of a 10 MW Dish/Stirling engine solar thermal plant for Juana Diaz, Puerto Rico, and Santo Domingo, Dominican Republic are done. The purpose of these studies is to determine the economic feasibility of this technology. Clearness index correlation by Erbs and the Collares-Pereira and Rabl equations are used to determine hourly estimations of direct solar radiation for Juana Diaz and Santo Domingo respectively. Realistic scenarios are developed by taking into account the renewable energy policies, financial parameters, incentives and cost for each location. These scenarios are simulated in Sola Advisor Model (SAM) obtaining the first year Power Purchase Agreement (PPA) price for an Internal Rate of Return (IRR) target of 7%. The first year PPA price was found to be 20.96c/kWh and 20.59c/kWh for Juana Diaz and Santo Domingo respectively.

RESUMEN

Este proyecto de tesis realiza un estudio de viabilidad de una planta de disco parabólico de 10 MW de capacidad para Juana Díaz, Puerto Rico y Santo Domingo, República Dominicana. El propósito de estos estudios es determinar el potencial económico de esta tecnología. Las correlaciones de Erbs del índice de índice de claridad y las ecuaciones de Collares-Pereira y Rabl se utilizan para determinar estimaciones horarias de la radiación solar directa de Juana Díaz y Santo Domingo, respectivamente. Escenarios realistas son desarrollados teniendo en cuenta las políticas de energías renovables, los parámetros financieros, incentivos y los costos para cada ubicación. Estos escenarios se simulan en SAM para obtener el precio del primer año de un contrato de compra de potencia (PPA) usando una taza de retorno de la inversión (IRR) de 7%. El primer año el precio del PPA resultó ser 20.96c/kWh y 21.59c/kWh para Juana Díaz y Santo Domingo, respectivamente.

DEDICATION

This thesis is dedicated to my parents Maria Cristina and Francisco Joaquin; my sisters, Claudine and Grace; my, brother Francisco; and my girlfriend Maribel De Los Santos for their endless support in every one of my endeavors. The enrollment and pursuance of graduate studies would have been impossible without their continuous encouragement and motivation.

Thanks for supporting me in this journey….

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1 INTRODUCTION

1.1 Motivation

Fossil fuels have been the predominant energy source since the Industrial Revolution. They are relatively easy to use to generate electric energy. However, there are important disadvantages to the use fossil fuels, noticeably their environmental impact. Not only does their extraction from the ground and underwater significantly alter the environment, but also their combustion leads to a great deal of air pollution. Burning fossil fuels generate carbon dioxide, which contributes to the "greenhouse effect", warming the Earth. Another issue is their cost. Their cost has been increasing over time and the fact that they are a finite resource makes this tendency unlikely to change.

These disadvantages are the main motivations for the study of other energy sources. The Dish/Stirling engine is a promising technology that uses solar power. This system converts the thermal energy of the sunrays to electricity. A parabolic dish made of mirrors concentrate the sunlight onto a receiver, thereby giving the thermal input to a Stirling engine that converts heat to mechanical energy. This mechanical energy is later converted to electricity by a generator.

1.2 Purpose

The purpose of this thesis project is to determine the economic feasibility of the Dish/Stirling systems.

1.3 Contents Outline

Chapter 1 - Introduction: the description of related works and how they are integrated in this thesis are presented in this chapter.

Chapter 2 - Dish/Stirling systems: Dish/Stiling systems components are discussed in detail in this chapter.

Chapter 3- Solar Radiation: the properties of extraterrestrial radiation, the types of solar radiation, solar radiation measurement, available solar radiation data, and solar radiation data processing are the topics of this chapter.

Chapter 4 – Analysis: The performance model, financial model, simulations, and results are discussed in this chapter.

Chapter 5 – Conclusions & Future Work: the conclusions and recommended future work are presented in this chapter.

1.4 *Literature Review*

1.4.1 Solar Resource

The solar radiation data from Santo Domingo was obtained from the "Programa Aprovechamiento de la Energía Solar en la Republica Dominicana" (PAES) [**1**]. The Dominican Institute of Industrial Technology (INDOTEC) in collaboration with the Central Bank of the Dominican Republic and Ohio State University measured the daily integrated values of global and diffuse solar radiation from January 1, 1983 to December 3, 1986.
Solar radiation from Juana Diaz was obtained from a project sponsored by the US Federal Emergency Management Agency (FEMA) where hourly solar radiation was computed from 5 minutes average measurements from January 2000 to March 2004. These solar radiation data sets were processed to obtain hourly global, direct, and diffuse solar radiation for a complete year. Then, the processed data is used as input for the Dish/Stirling system model. The data processing is explained in detail in Chapter 3.

1.4.2 The SunCatcher

Before choosing a Dish/Stirling system for our study, the Distal [**2**], the EuroDish [**2**], and SunCatcher [**3**] Dish/Stirling systems were analyzed. The SunCatcher was chosen because it has hundreds of thousands of hours of on-sun testing on each major subsystem, and on the whole system [**4**]. The SunCatcher uses efficient Stirling engine technology and was the only Dish/Stirling system in commercially use [**4**]. The characteristics of the SunCatcher are summarized in the following tables.

Table 1-1-1 SunCatcher Mirror Concentrator

Design	Parabolic Dish
Diameter	11.6 m
Intercept Area	89.2 m^2
Focal Length	3.65 m
Reflectivity (min)	95 %
Tracking	Dual Axis

Table 1-1-2 SunCatcher Power Conversion Unit (PCU)

Engine Type	4 Cylinder Stirling Engine
Working Gas	Hydrogen
Swept Volume	380 m^3
Electrical Generator	4 Pole Induction
Operating Speed	1800 rpm
Operating Voltage	575 V
Rated Output Power	25 kW

Table 1-3 Environmental Requirements

Direct Normal Irradiance (DNI)	350 – 1150 W /m^2
Operating Temperature - Max	50 C - 122 °F
Operating Temperature - Min	-10 C - 14 °F
Survivability Temperature - Max	80 C - 176 C
Survivability Temperature - Min	-30 C - -22 C
Wind Speed – Operability	22 m/s
Wind Speed – Survivability	40 m/s

Table 1-1-4 Site Requirements

Site Grade (Slope)	Max 5%
Geotechnical Limits	Seismic Zone 4
Altitude	Max 7,000 ft.
Design Life	30 years
Water Usage	Zero for Power Production

1.4.3 Modeling

Dish/Stirling systems are modeled using National Renewable Energy Laboratory NREL's System Advisor Model (SAM) [**5**]. SAM is a performance and economic modeling tool designed to facilitate decision making for people involved in the renewable energy industry.

SAM was developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories and in partnership with the U.S Department of Energy (DOE) Solar Energy Technologies Program (SETP). The SETP began developing SAM in 2004 for analysis to support the implementation of the SEPT Systems approach. Since then, SAM has evolved to model a range of renewable energy technologies and is used worldwide for planning and evaluating research.

SAM makes performance predictions for grid-connected solar, small wind, and geothermal power systems and economic estimates for distributed energy and central generation projects. The model calculates the cost of generating electricity based on information the user provides about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications.

SAM is based on an hourly simulation engine that interacts with performance, cost, and finance models to calculate energy output, energy costs, and cash flows. The software can also account for the effect of incentives on project cash flows. SAM's spreadsheet interface allows for exchanging data with external models developed in Microsoft Excel. The model provides options for parametric studies, sensitivity analysis, optimization, and statistical analyses to investigate impacts of variations and uncertainty in performance, cost, and financial parameters on model results.

SAM models system performance using TRNSYS [**6**]. TRNSYS is a time-series simulation program that can simulate the performance of photovoltaic, concentrating solar power, water heating systems, and other renewable energy systems using hourly resource data.

2 *DISH/STIRLING SYSTEMS*

A Dish/Stirling system is a type of concentrating solar power (CSP) system that consists of a parabolic dish-shaped collector, a receiver, a Stirling engine and a generator. The receiver, Stirling engine and generator come together as a unit called the Power Conversion Unit (PCU).

The system utilizes a parabolic dish-shaped collector equipped with dual-axis tracking to concentrate solar radiation onto a thermal receiver integrated in the Stirling engine. The receiver consists of a heat exchanger designed to transfer the absorbed solar energy to the working fluid, typically, hydrogen. The Stirling engine then converts the absorbed thermal energy into mechanical power by expanding the gas in a piston-cylinder in a manner similar to a gas or diesel engine. The linear motion is transformed into a rotary motion that turns a generator shaft to produce electricity. The systems can produce electricity from the sun with efficiencies up to 29 % [**7**]. The major components of a Dish/Stirling system are analyzed in this chapter.

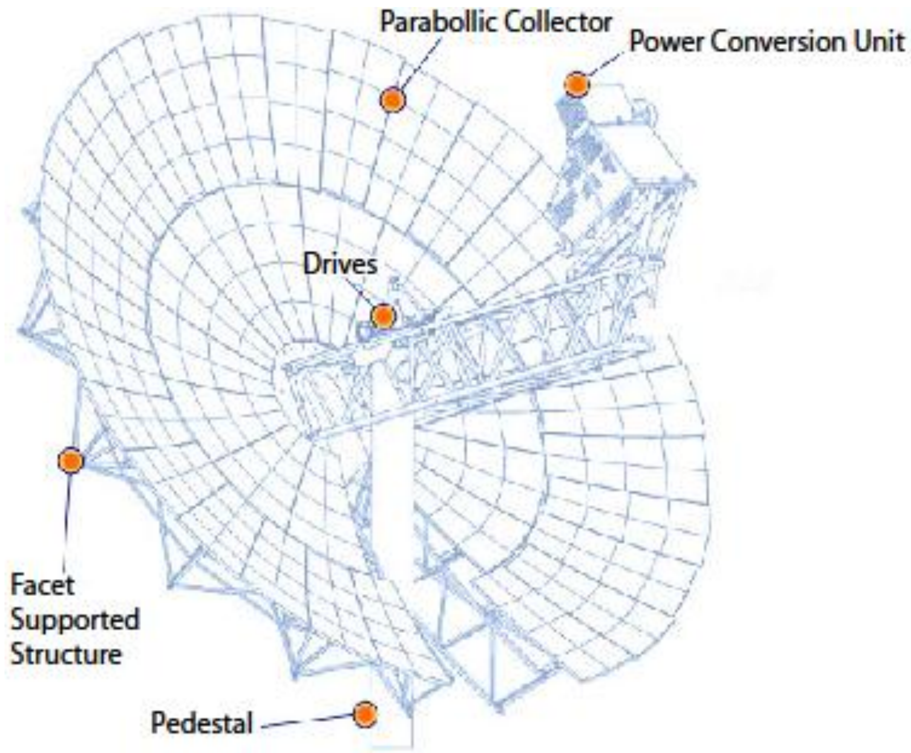

Figure 2-1 Dish/Stirling System Parts (Adapted from [8])

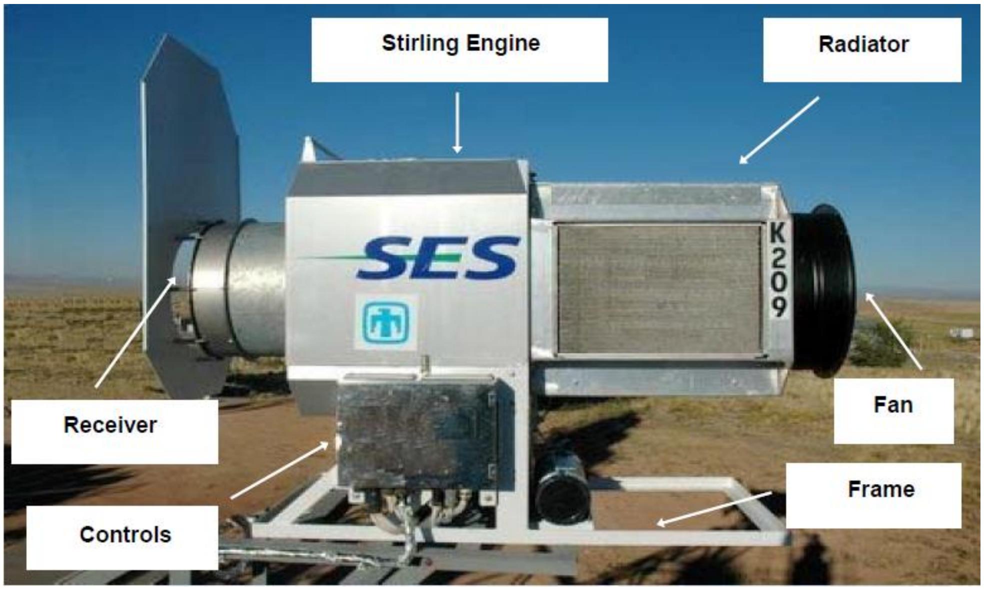

Figure 2-2 SunCatcher's Power Conversion Unit (PCU) [9]

2.1 Parabolic Concentrator

The parabolic concentrator reflects direct solar radiation to the receiver. The curved reflective surface can be manufactured by attached segments, by individual facets or by a stretched membrane shaped by films.

First-generation parabolic dishes were shaped with multiple, spherical mirrors supported by a trussed structure [**10**]. Though extremely efficient, this structure concept was costly and heavy. Large monolithic reflective surfaces can be obtained by using stretched membranes in which a thin reflective membrane is stretched across a rim or hoop. A second membrane is used to close off the space behind forming a partially evacuated plenum between them, giving the reflective membrane an approximately spherical shape. This concept was developed by the German SBP Company in the 1990s, and several prototypes have been tested at the "Plataforma Solar de Almería" (PSA) in Spain [**2**].

Figure 2-3 Distal I at PSA [11**]**

The concentrator for the Stirling dish systems uses parabolic mirrors mounted on a structure that tracks the sun by pivoting on two axes. The parabolic concentrator must be sized to deliver about four times more thermal energy than the rated electrical output due to an average net system efficiency of around 25 % [**12**]. Existing Stirling dish systems have been built to provide 10 kW and 25 kW with a parabolic dish of approximately 7.5 and 11 meters respectively [**8**].

The solar reflectance of the silvered mirrors ranges between 91-95 % for current Stirling dish systems [**13**]. The most durable mirror surfaces employ silver/glass mirrors. Attempts to produce low cost reflective polymer films have had limited success in the past [**14**]. ReflecTech has recently developed a polymer reflective film (ReflecTechTM) that has excellent optical properties with a 94.5 % mirror reflectivity and costs $1.30 per square foot in large volumes [**15**]. The most innovative parabolic mirrors use stretched-membranes where the reflective membrane is stretched across a hoop or rim and a second membrane is placed behind the first. A partial vacuum then pulls the first membrane into a parabolic shape.

The dual-axis solar tracking is accomplished through the use of a Tip-Tilt Dual Axis Tracker (TTDAT) or a Azimuth-Altitude Dual Axis Tracker (AADAT). The name of the Tip–tilt dual axis tracker comes from the fact that the parabolic collector is mounted on the tip of a long pole. Normally the east-west movement is driven by rotating the parabolic collector around the top of the pole. On top of the rotating bearing is a T- or H-shaped mechanism that provides both the vertical rotation and the main mounting points for the collector.

Figure 2-4 Using Tip-tilt dual axis tracker [16]

Azimuth–altitude dual axis tracker has its primary axis vertical to the ground. The secondary axis is then typically normal to the primary axis. They are similar to tip-tilt systems in operation, but they differ in the way the collector is rotated for daily tracking. Instead of rotating around the top of the pole, AADAT systems typically use a large ring mounted on the ground with the collector mounted on a series of rollers. The main advantage of this arrangement is that the weight is distributed over a portion of the ring, as opposed to the single loading point of the pole in the TTDAT. This allows AADAT to support much larger collectors [**16**]. Unlike the TTDAT, however, the AADAT system cannot be placed closer together than the diameter of the ring, which may reduce the system density, especially considering inter-tracker shading [**16**].

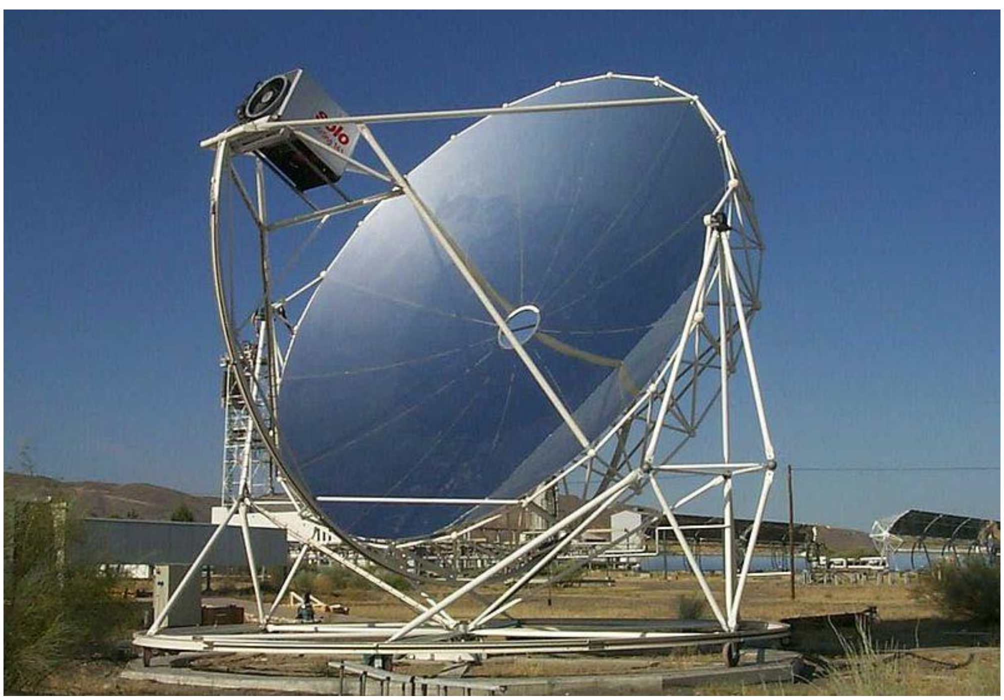

Figure 2-5 Azimuth-altitude dual axis tracker [17]

Figure 2-6 SunCatcher's Dish Controls

2.2 *Receiver*

The receiver of a Dish/Stirling system absorbs the thermal energy from the parabolic concentrator and transfers it to the working fluid in the Stirling engine, usually helium or hydrogen. Thermal fluid working temperatures are between 650C and 750C. This temperature strongly influences the efficiency of the engine. Because of the high operating temperatures, radiation losses strongly penalize the efficiency of the receiver.

A Stirling receiver consists of an aperture and an absorber. The aperture in a Stirling receiver is located at the focal point of the parabolic concentrator to reduce radiation and convection losses, and can have concentration ratios of over 13,000 [**18**]. The size of the aperture has diameters ranging from about 14 to 20 centimeters to ensure that an appropriate fraction of the concentrated solar energy is intercepted by the aperture [**18**].

The absorber in the Stirling receiver absorbs solar radiation and transfers the thermal energy to the Stirling engine. Current Stirling absorbers are typically Direct Illumination Receivers (DIR) or Indirect Illumination Receivers (IIR). In DIR receivers, the same fluid used inside the engine is externally heated in the receiver through a pipe bundle; Figure 2-7 shows a picture of a DIR. In IIR, an intermediate fluid is used to decouple solar flux and working temperature from the engine fluid. One such method is heat pipes, shown in Figure 2-8, which use a metal capillary wick impregnated with a liquid metal heated up through the receiver plate and vaporized. The vapor then moves across the receiver and condenses in a cooler section, transferring the heat to the engine. The phase change guarantees good temperature control, providing uniform heating of the Stirling engine [**19**].

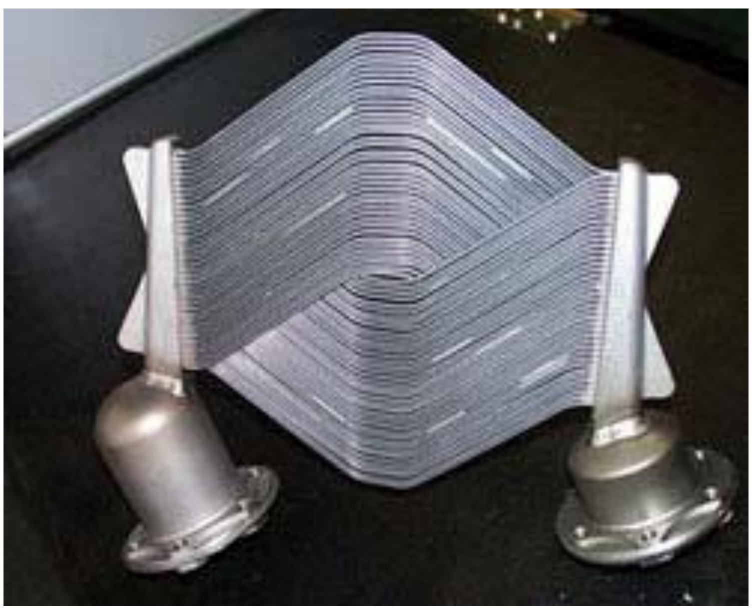

Figure 2-7 Stirling DRI Cavity Receiver [20**]**

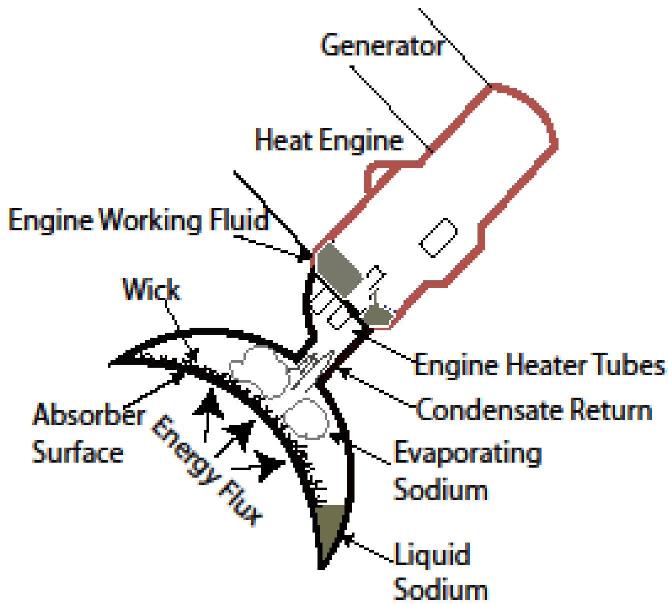

Figure 2-8 Heat Pipe Absorber for a Dish Receiver (Adapted from [14])

Volumetric receivers shown in Figure 2-9, are implemented in hybrid Stirling dish systems where natural gas is used to supplement solar energy.

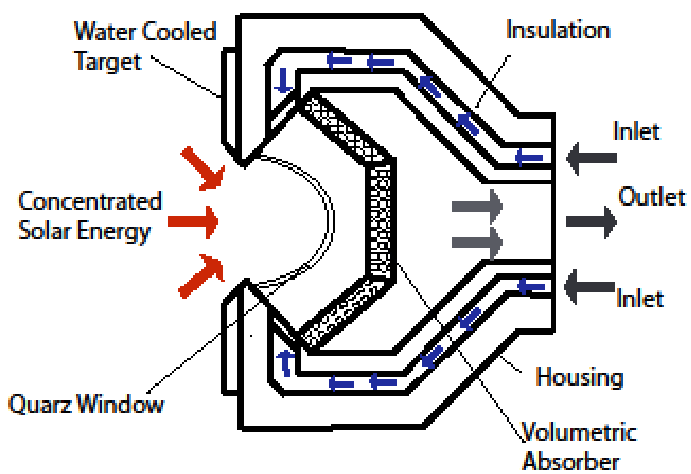

Figure 2-9 Volumetric Stirling Receiver Design (Adapted from [12])

2.2.1 Receiver Losses

The receiver of a Stirling dish system is responsible for most of the thermal losses that occur before the energy is converted into electricity. The collector losses due to the mirror reflectivity are of 37 % and 24 % of the thermal losses in the SES and WGA collectors respectively, the receiver intercept losses represent 12 % and 10 % of the total thermal losses for the SES and WGA systems, and the receiver thermal losses (conduction, convection, radiation) consist of 51 % and 66 % of the total thermal losses for the SES and WGA systems respectively [**13**].

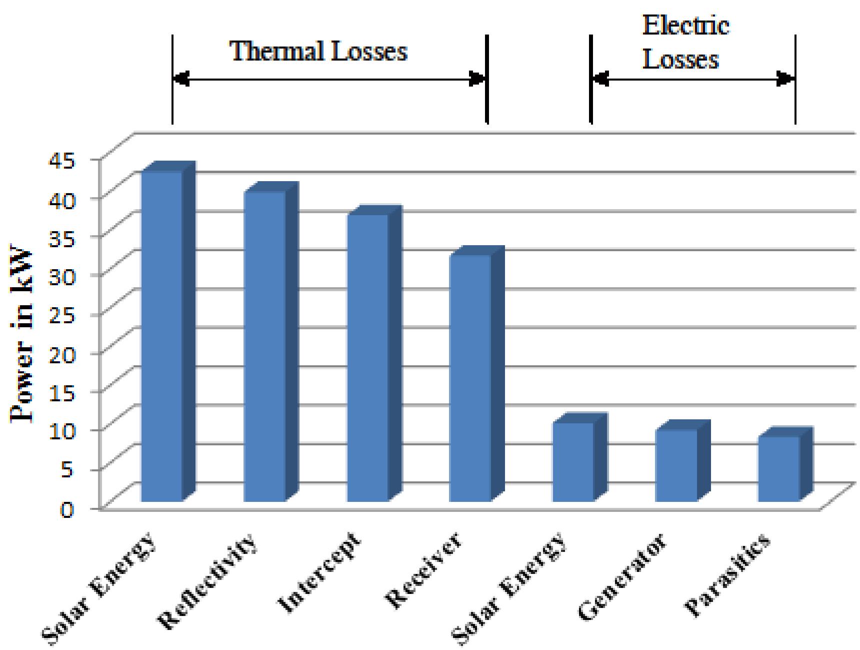

Figure 2-10 Energy Loss chart for the SBP system at 1000 [W/m2] [18**]**

2.2.1.1 Conduction Losses

The receiver conduction losses represent a small fraction of the receiver thermal losses. As the temperature of the absorber and receiver walls increase, conduction through the receiver housing to the ambient air occurs at a more rapid rate. Fourier.'s law describes conduction in Equation (2.1) [**21**].

$$q_{conduction} = -k \ . \ A \frac{dT}{dx} \tag{2.1}$$

Where k is the thermal conductivity of a material, A is the surface area perpendicular to the temperature gradient, and dT/dx is the change in temperature over the distance parallel to thermal flow. The losses due to conduction through the receiver housing are also dependent on the convective heat transfer on the exterior of the receiver housing, so a series resistance model can be used to obtain the total conductive losses. The total losses resulting from conduction is given by Equation (2.2).

$$q_{conduction} = \frac{T_w - T_{amb}}{R_{cond} + R_{conv}} \tag{2.2}$$

2.2.1.2 Natural Convection Losses

The convective losses in the receiver represent a significant fraction of the total losses in a Stirling dish system. Experimental tests performed at Sandia National Labs indicate that convection losses may represent about 25 % of receiver losses during noon, and about 40 % during the morning and evening hours in the middle of October in Albuquerque, New Mexico [**22**]. In one parabolic collector and receiver system tested [**23**], the receiver losses were determined to be 11 % of the total solar radiation entering the receiver on a clear day at noon;

this percentage increases in the morning, evening, winter and at lower insolation levels due to an increase in convection losses. It is apparent that convective losses represent a large fraction of the total Stirling dish system losses and the receiver losses, and are very dependent on aperture orientation.

Convective losses are a function of cavity temperature and geometry, aperture orientation and diameter, wind velocity, and the effectiveness of the wind skirt. Convection losses are greatest in the morning and evening, and become less significant during the middle of the day depending of the latitude of the systems. This dependency results from the orientation of the receiver while tracking the sun. At noon, the receiver is pointed more vertically (with the receiver aperture facing down towards the ground) than during the early morning and late afternoon, when orientation is more horizontal; thereby, creating a more stable convective situation. These losses also depend on the time of the year and the location, since the angle between the sun and a horizontal surface changes with respect to these, and therefore affects the orientation of the receiver aperture.

2.2.1.3 Forced Convection Losses

The convective losses are a function of the aperture orientation and density of the air, but are also highly dependent on the velocity of the wind. If the wind is directed towards the aperture opening, the convection losses will increase significantly, whereas the convection losses will not be as large if the wind is not oriented towards the aperture [**24**]. Total convection losses have been measured to be up to four times that of natural convection with a 4.5 m/s wind directly facing the aperture opening [**24**].

An experimental setup to test the effect of forced convection using a receiver from the Shanandoah Project was constructed by [**25**]. These receivers had an aperture diameter of 46 cm which is larger than the 20 cm and 14 cm aperture diameters in the SES and WGA systems respectively. Data were recorded with the receiver aperture oriented at 15 or 30 degree intervals between facing horizontal until vertically down. A 4.’x4.’x14.’ wind machine generated wind speeds at 6, 8, and 20 miles per hour for side-on tests (wind parallel to the aperture opening plane) and additional speeds of 15 and 24 miles per hour were tested for head-on tests (wind perpendicular to the aperture opening) [**25**]. An organic fluid was passed through the heater tubes to measure the temperature drop and corresponding convective losses with a nominal receiver temperature of 530ºF. Tests were conducted to determine the natural convection losses in the receiver for six alternative setups, and the data were consistent with Stine and McDonald’s natural convection correlation. It is assumed that forced convection is independent of natural convection in the receiver, so the total convection losses can be represented as the sum of the natural and forced convection losses given by Equation (2.3) with the total convection coefficient expressed in Equation (2.4) [**25**].

$$q_{total,convection} = q_{natural} + q_{forced} \tag{2.3}$$

$$h_{total,convection} = h_{natural} + h_{forced} \tag{2.4}$$

2.2.1.4 Radiation Losses

The radiation losses in the receiver represent a significant fraction of the total losses in the receiver and in the total Stirling dish system. Experimental data obtained at Sandia National Labs indicate that radiation losses may represent about 60 % of receiver losses during the morning and evening, and about 75 % at noon in the middle of October in Albuquerque, New Mexico since convective losses vary throughout the day [**22**]. Unlike convection losses, radiation losses are relatively constant throughout the day once a steady state temperature has been reached for the heater head temperature.

2.3 Stirling Engine

The Stirling engine is an external heat engine that converts heat from the absorber to mechanical power in a manner similar to internal combustion engines. Unlike internal combustion engines, however, heat is applied externally to the piston heater head. Because the Stirling engine relies on an external source for heat input, the cycle itself operates as a closed system since the working fluid is contained within the cylinders and not vented to atmosphere like exhaust gases from internal combustion engines. The addition of a regenerator into a Stirling engine improves the efficiency of the engine by pre-cooling the working fluid as it moves from the expansion space to the compression space, and pre-heating the working fluid as it moves from the compression space into the expansion space. The working fluid is often hydrogen which is heated to over 700°C with a maximum pressure around 20 MPa yielding a thermal-to-mechanical efficiency of approximately 40 % [**14**]. The compression space is cooled by a refrigeration loop that makes a secondary fluid circulate through a common automotive radiator with forced air cooling provided by a fan.

The Stirling engines used in dish systems include the SOLO 161 11 kW engine from Germany, the Kockums (previously United Stirling) 4-95 25 kW engine from Sweden, and the Stirling Thermal Motors STM4-120 25 kW engine from the United States [**14**]. The SOLO engine has been used for cogeneration projects and in the Euro/Enviro dish research. The Kockums 4-95 engine is the power unit for the Stirling Energy Systems (SES), and it is shown in Figure 2-11.

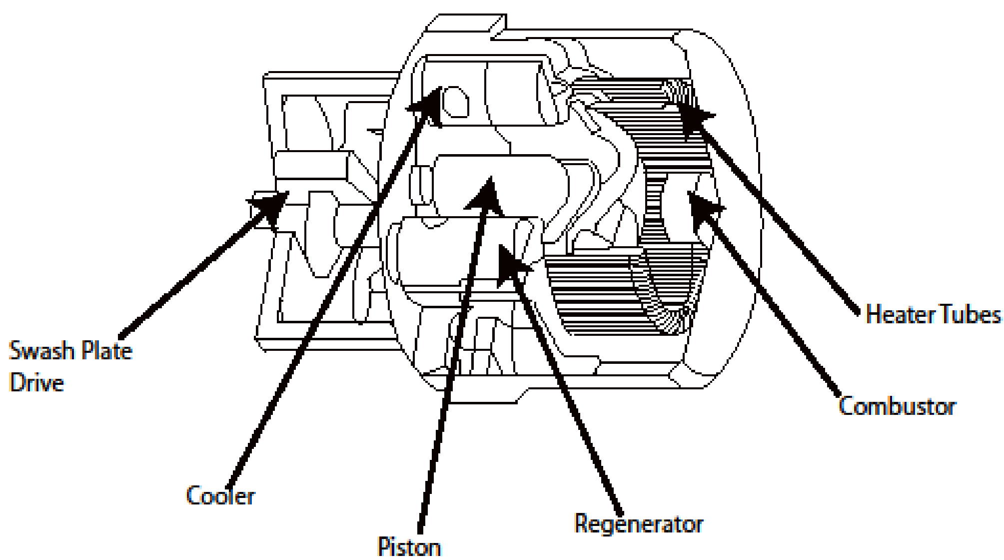

Figure 2-11 Kockums 4-95 Stirling Engine (Adapted from [26**])**

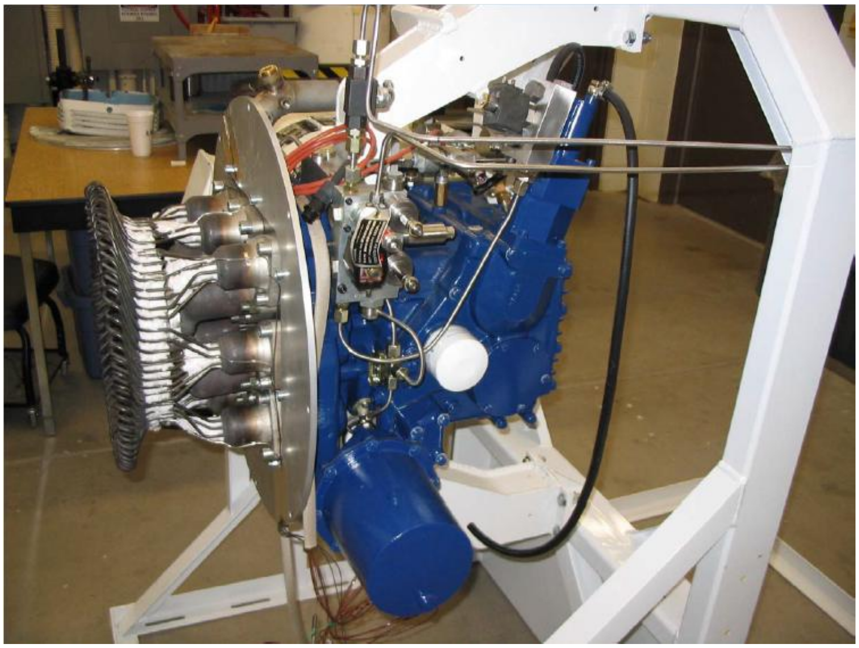

Figure 2-12 SunCatcher's Stirling Engine [9**]**

2.3.1 Stirling Engine Types

There are two common types of Stirling engines that have been used for power production: the kinematic and the free-piston engine. These are shown in Figure 2-11 and Figure 2-13 respectively. Kinematic engines have the power piston connected to the crankshaft by a connecting rod, which is attached to a cross-head to eliminate lateral forces against the cylinder walls [**27**]. A linear seal is used between the cross-head and piston to seal the region between high and lower pressures, allowing the bearing surfaces to remain lubricated in the low-pressure area while preventing fouling of the heat exchanger surface in the high-pressure region [**27**].

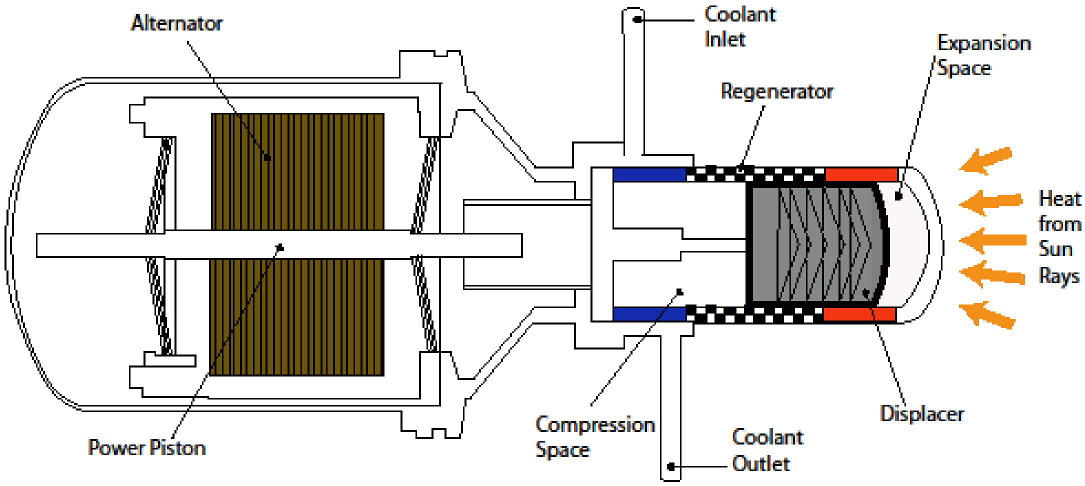

Figure 2-13 Free-Piston Stirling Engine (Adapted from [28**])**

Free-piston Stirling engines do not have the power piston connected to a crankshaft, but rather cycle back and forth between the working fluid and a spring which is often another gas [**27**]. The displacer is allowed to bounce on gas or mechanical springs, which are incorporated into the Beale free-piston design. The spring and mass system control the frequency, piston stroke, and timing between the two pistons. Power is generated by attaching a magnet to the power piston and moving it past stationary coils that act as a linear alternator, or the engine can be used to drive a hydraulic pump. Free piston Stirling engines only have two moving parts, no dynamic seals are required to seal the high and low pressure region since electricity is generated internally, and oil lubrication is not required [**27**].This enables the free-piston engines to have a lower cost, longer life, and minimal maintenance with respect to kinematic Stirling engines.

2.3.2 Power Control

For most Stirling engines, the engine power is controlled by varying the mean pressure within the expansion and compression space by varying the mass of the working fluid. This is accomplished by pumping gas in or out of the engine from an external tank [**29**]. To increase the power from the Stirling engine, a system of valves is used to move high pressure gas from an external tank to the engine, and to decrease power, the working fluid is compressed back into the external tank [**27**].

Another method to control the Stirling engine power is to change the volume within the piston cylinders with a variable stroke engine such as the SAIC (STM 4-120) Stirling [**29**]. This method of power control can be accomplished by using a variable angle swash plate drive which allows the stroke to be controlled [**27**]. This method effectively alters the displaced volume during each cycle and therefore changes the output power.

2.3.3 Regenerator

A regenerator consisting of many metal mesh disks is often used in Stirling engines to improve the efficiency of the engine [**30**]. Thermal energy is absorbed by the regenerator when working fluid passes from the expansion space to the compression space, cooling working fluid before entering the compression space. Thermal energy is transferred from the regenerator to the working fluid and is pre-heated when the working fluid moves from the compression to the expansion space. The regenerator in a Stirling engine can reach efficiencies greater than 98 %, which indicates that the working fluid will exit the regenerator with temperature close to the one of the space it occupies [**31**].

2.3.4 Stirling Engine Working Fluids

Working fluids commonly used in Stirling engines consist of air, helium, or hydrogen. The selection of a specific working fluid is based on the following fluid properties: thermal conductivity, specific heat, density, and viscosity. A working fluid with a higher thermal conductivity, density and higher specific heat will improve the heat transfer capabilities of the gas and improve the efficiency of the heat exchangers. A working fluid with a lower density and viscosity will reduce the pressure drop through the regenerator, working space, and dead space and consequently improve the engine efficiency [**27**].

2.4 Generator

The mechanical to electrical conversion device used in dish/engine systems depends on the engine and application. Induction generators are used on kinematic Stirling engines tied to an electric-utility grid. Induction generators synchronize with the grid and can provide single or three-phase power of either 230 or 460 volts. Induction generators are off-the-shelf items and convert mechanical power to electricity with an efficiency of about 94% [**4**].

Alternators in which the output is conditioned by rectification (conversion to DC) and then inverted to produce AC power are sometimes used to handle mismatches in speed between the engine output and the electrical grid. The high speed output of a gas turbine, for example, is converted to very high frequency AC in a high speed alternator, converted to DC by a rectifier, and then converted to 60 hertz single or three-phase power by an inverter. This approach can also represent advantages on the operation of the engine [**4**].

2.5 *Cooling System*

The cooling system for a Stirling dish system rejects the thermal losses from the Stirling engine in order to reduce the compression space temperature and improve the efficiency of the engine. The most common cooling system configuration for a Stirling dish system is a radiator and fan with a pump and cooling fluid loop [**32**].

2.5.1 Radiator Heat Exchanger

All of the current Stirling dish systems use a fan and plate-finned radiator to reject the thermal load from the cooler into the atmosphere using a cooling fluid loop. The radiator and fan act as a cross-flow heat exchanger with the cooling fluid moving through the radiator, and ambient air passing across the radiator perpendicular to the flow of the cooling fluid [**21**].

2.5.2 Stirling Engine Cooler

The Stirling engine utilizes a cooler to reduce the temperature of the compression space and improve the engine performance. Many Stirling engine coolers use a shell-and-tube heat exchanger with the hydrogen working fluid in the tube-side and a secondary fluid in the shellside [**30**]. The SES engine, for instance, uses 400 - 3 mm diameter tubes for each of the four coolers in every cylinder with hydrogen passing within the tubes [**30**]. The shell-and-tube heat exchanger operates on a counter flow heat exchange regime with hydrogen flowing from the regenerator into the compression space; it also, acts as a parallel-flow heat exchanger when hydrogen moves from the compression space back through the regenerator at a rate of thirty times per second.

2.5.3 Cooling System pump

A water pump is used in the cooling fluid loop to pump the cooling fluid through the cooler and radiator. The pump must overcome frictional losses in the cooling fluid loop resulting from friction against the pipe walls, and also from form losses resulting due to bends, valves, or locations in the pipe that have a larger or smaller diameter [**33**].

2.5.4 Radiator Fan

A fan is used on the radiator to dissipate energy from the cooling fluid and reduce the temperature of the engine compression space. The fan and radiator cooling loop is comparable to one in a vehicle with a Stirling engine in place of a gas or diesel engine. The fan typically consumes the greatest fraction of the parasitic power. The operating speed should be optimized to improve the net output power from the system [**33**].

3 *SOLAR RADIATION*

Solar radiation is the fuel for the Dish/Stirling systems and all the concentrating solar power generation technologies. Like any other generation source, knowledge of the quality and reliability of the fuel is essential to accurate analysis of the system performance and financial viability.

The topics in this chapter are the properties of extraterrestrial radiation, the types of solar radiation, solar radiation measurement, available solar radiation data, and solar radiation data processing.

3.1 The Sun

The sun is the star at the center of our solar system. It is an average sized star of average age located in one of the spiral arms of the Milky Way Galaxy. It is a main sequence star of spectral class G [**34**]. Table 4-1 shows the physical characteristics of the sun.

Table 3-1 Physical characteristics of the sun [35]

Mean diameter	1.392×10^6 km
Equatorial radius	6.955×10^5 km
Equatorial circumference	4.379×10^6 km
Surface area	6.0877×10^12 km^2
Volume	1.412×1018 km^3
Mass	1.9891×10^30
Average Density	1.408×10^3 kg/m^3
Temperature (center)	~ 1.57×10^7 K
Temperature (corona)	~5×10^6 K
Temperature (Photosphere)	5,778 K
Luminosity	3.846×10^26 W
Mean intensity	2.009×10^7 W·m^−2·sr^−1

3.2 Extraterrestrial Solar Radiation

Any object with a temperature above absolute zero emits radiation. With an effective temperature of approximately 6000 K, the sun emits radiation over a wide range of wavelengths, commonly labeled from high energy shorter wavelengths to lower energy longer wavelengths as gamma ray, x-ray, ultraviolet, visible, infrared, and radio waves. These are called spectral regions and are shown in Figure 3-1. 97% of solar radiation is in the wavelength range of 290 nm to 3000 nm [**35**]. Future references to broadband solar radiation refer to this spectral range.

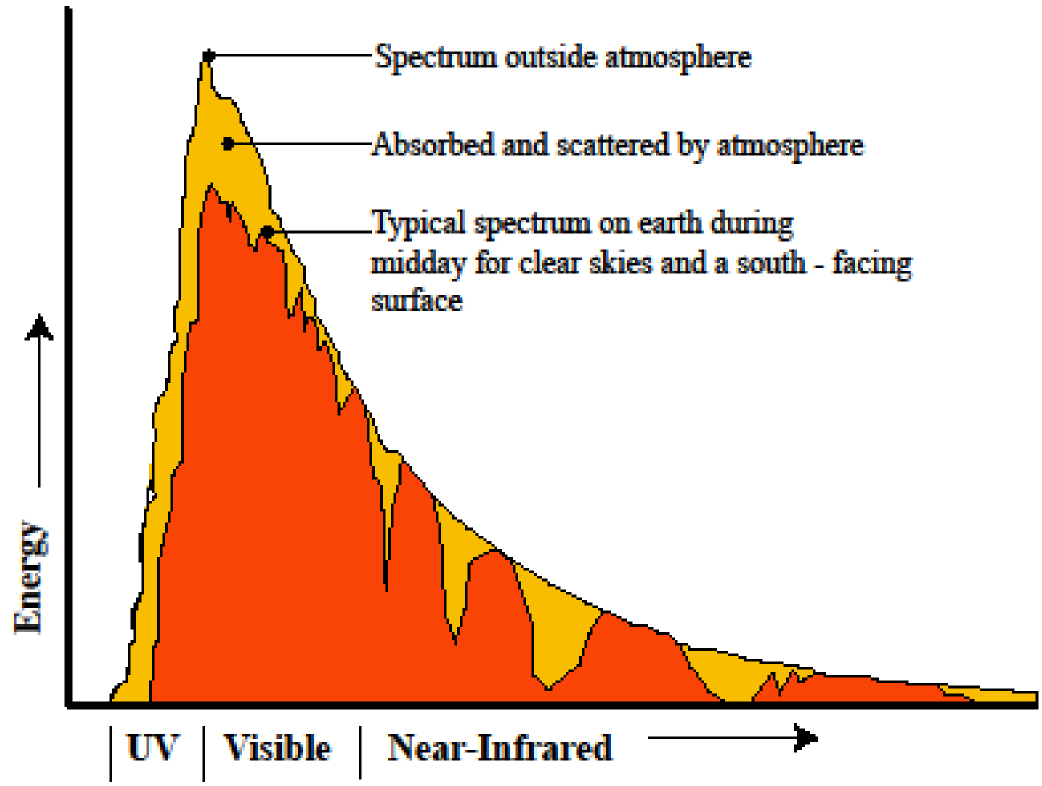

Figure 3-1 Spectral Distribution (Adapted from [1])

Sunlight is Earth's primary energy source. The distance between the sun and the earth varies 1.7% by the elliptical way that the earth orbits the sun [**35**]. Although not a constant, 1367 W/m^2, is the mean extraterrestrial irradiance normal to the solar beam outside the earth atmosphere and it is called "the solar constant" [**35**]. Since the distance between the sun and the earth varies, also does the value of the solar constant by ± 3.4% during the year [**35**].

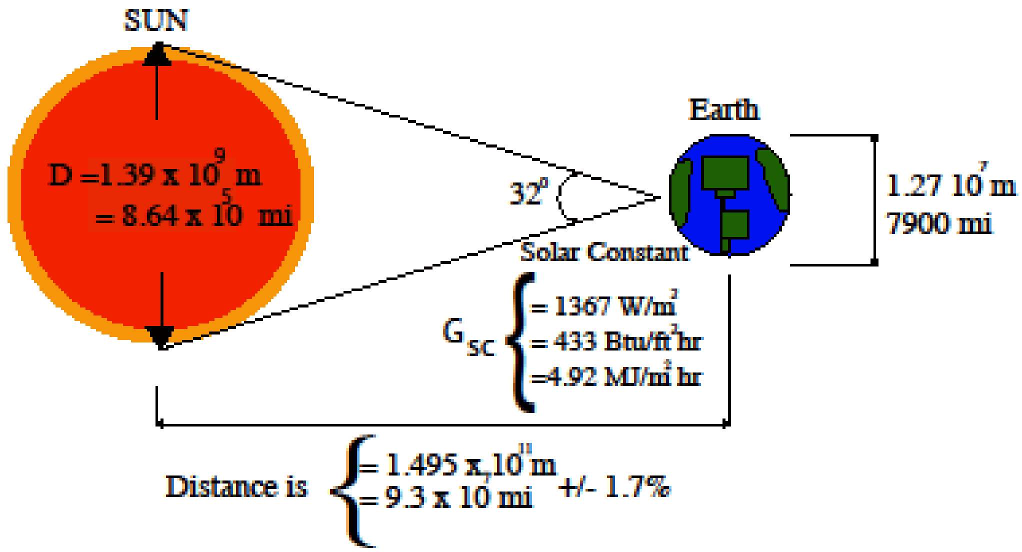

Figure 3-2 Sun-Earth Relationships

The hourly extraterrestrial solar radiation (I_0) is used in the following sections. Equation (3.1) shows the calculation of (I_0).

$$I_0 = \frac{12 \times 3,600}{\pi} G_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365} \right) \right] \times \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1 \right) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin\phi \sin\delta \right] \quad (3.1)$$

Where,

G_{sc} = the solar constant = 1,367 w/m^2

n = day number, n=1 corresponds to January 1st.

φ = the latitude of the location

ω = the hour angle (angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative, afternoon positive)

δ = the declination angle (angular position of the sun at solar noon with respect to the plane of the equator, north positive; $-23.45^0 \leq \delta \leq 23.45^0$

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \tag{3.2}$$

3.3 *Solar Radiation Types*

Complex interactions of the Earth's atmosphere with solar radiation result in three fundamental broadband components of interest to solar energy conversion technologies:

Direct Normal Irradiance (DNI) - the quantity of direct solar radiation per unit area that is intercepted by a flat surface that is at all times pointed in the direction of the sun. This quantity is of particular interest to concentrating solar installations and installations that track the position of the sun.

Diffuse Horizontal Irradiance (DHI) – the quantity of diffuse solar radiation per unit area that is intercepted by a flat, horizontal surface that is not subject to any shade or shadow and does not arrive on a direct path from the sun.

Global Horizontal Irradiance (GHI) - the quantity of the total solar radiation per unit area that is intercepted by a flat, horizontal surface. This value is of particular interest to photovoltaic installations. It includes both direct radiation and diffuse radiation

These basic solar components are reacted to the zenith angle by the expression,

$$GHI = DNI \times \cos(\theta_z) + DHI \tag{3.3}$$

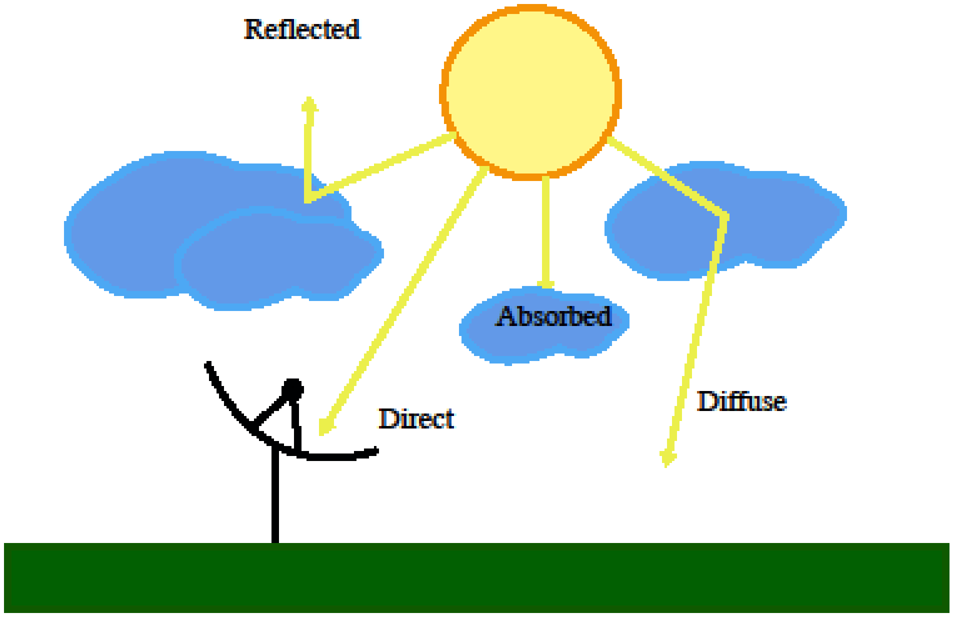

Figure 3-3 Solar Radiation Types

3.4 Solar Radiation Measurement

Accurate measurements of solar radiation are essential to CSP project design and implementation. Instruments designed to measure any form of radiation are called radiometers. Pyrheliometers and pyranometers are the most commonly used radiometers. Their ability to receive solar radiation from two distinct portions of the sky distinguishes their designs.

Pyrheliometer - an instrument using a collimated detector for measuring direct solar radiation from the sun at normal incidence. Fig.3-4 shows a pyrheliometer.

Figure 3-4 Pyrheliometer [36**]**

Pyranometer – an instrument for measuring global radiation from the sun on horizontal surfaces. If shaded from the direct radiation by a shade ring or disc, it can be used to measure diffuse radiation. Fig.3-5 Shows a pyranometer.

Figure 3-5 Pyranometer [37**]**

In addition, the terms solarimeter and actinometer are encountered. A solarimeter can generally be interpreted to mean the same as a pyranometer, and an actinometer usually refers to a pyrheliometer.

3.5 Available Solar Radiation Data

Solar radiation data was obtained from Santo Domingo, Dominican Republic and Juana Díaz, Puerto Rico respectively, Figure 3-6 and 3-7 show both locations.

Figure 3-6 Santo Domingo, Dominican Republic (left) and Juana Diaz, Puerto Rico I [38]

Figure 3-7 Santo Domingo, Dominican Republic (left) and Juana Diaz, Puerto Rico (Right) II [39**]**

Solar radiation from Santo Domingo was obtained from two different sources, the "Programa Aprovechamiento de la Energía Solar en la República Dominicana" (PAES) [**1**] and from a study from 3Tier called ¨Site Climate Variability Analysis 13-Year Record Date from Santo Domingo, Dominican Republic¨ [**40**].

During PAES a solar radiation measuring station equipped with two Hollis MR-1 pyranometers gathered 3 years of integrated daily values of global and diffuse solar radiation data. The units of measurement were W-h/m^2. The diffuse radiation was recorded using one of the pyranometers with a shade band to exclude the direct component of solar radiation.

The study from 3Tier is based on the past 13+ years (January 1997 through June 2010) of half hourly high-resolution (roughly 1 km) visible satellite imagery from GOES satellite data. The satellite imagery has been processed to create 13+ years of hourly values of Global Horizontal Irradiance, Direct Normal Irradiance and Diffuse Horizontal Irradiance from Santo Doming, Dominican Republic [**40**].

The solar radiation from Juana Diaz was obtained from a project sponsored by the US Federal Emergency Management Agency (FEMA) where hourly solar radiation was computed from 5 minutes averages measurements from January 2000 to March 2004. A pyranometer measured and collected the average global solar radiation in W/ m^2. Table 4-2 shows a summary of the available solar radiation data while Figure 4-5 and Figure 4-6 are maps showing the locations of Santo Domingo, Dominican Republic and Juana Diaz, Puerto Rico.

Table 3-2 Summary of the available solar radiation data

	Santo Domingo	**Juana Díaz**
Types	GHl and DHI	GHI
Period of the Data	3 years	3 years and 2 months
Method of Obtention	Measured	Measured
Format	Integrated daily values	5 minutes averages

3.6 Solar Radiation Data Processing

SAM is used to model the Dish/Stirling system. In SAM, the user must provide solar radiation data of the desired location in a specific format. The program only accepts columns of 8,760 elements (the number of hours in a year) for each solar radiation type, the global horizontal irradiation (GHI), the direct normal irradiation (DNI) and the diffuse horizontal irradiation (DHI). Therefore, solar radiation data gathered in Santo Domingo and Juana Díaz was processed using an excel worksheet to obtain estimates of hourly values for a complete year to be used as input in SAM.

The next two subsections are dedicated to explain the solar radiation data processing from both locations to meet SAM´s input format. Note that the Dish/Stirling systems only use the direct fraction of the global solar radiation.

3.6.1 Estimation of the Hourly Direct Radiation from Juana Diaz

The first step into the processing of the available solar radiation data from Juana Díaz is to determine the hourly average of the global solar radiation from the 5 minutes averages of measured data. This is done by averaging all the measurements made 30 minutes before and after the hour in question.

Next, we estimate I_D by correlating the hourly diffuse radiation fraction (I_D/I) with the hourly clearness index (k_T). Several correlations of this type can be used with similar outcomes, equations (3.4) refers to the Erbs correlation [**41**], while equations (3.5) to the Orgill and Hollands correlation [**42**]. The hourly clearness index is given by:

$$\frac{I_D}{I} = \begin{cases} 1-0.09k_T & for\, k_T \le 0.22 \\ 0.9511-0.1604\, k_T + 4.388\, k_T^2 & for\, 0.22 < k_T \le 0.8 \\ 0.165 & for\, k_T > 0.8 \end{cases} \quad (3.4)$$

$$\frac{I_D}{I} = \begin{cases} 1-0.249k_T & for\, k_T \le 0.35 \\ 1.557-1.84\, k_T & for\, 0.35 < k_T \le 75 \\ 0.177 & for\, k_T > 0.75 \end{cases} \quad (3.5)$$

The k_T most be known before using these correlations. For the k_T to be known the calculation of the extraterrestrial radiation (I_0) is made using equation (3.1)

$$I_0 = \frac{12 \times 3,600}{\pi} G_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365} \right) \right] \times \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1 \right) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin\phi \sin\delta \right]$$

Where,

G_{sc} = the solar constant = 1,367 w/m^2

n = day number, when n=1 corresponds to January 1st

φ = the latitude of the location

ω = the hour angle (angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative, afternoon positive)

δ = the declination angle (angular position of the sun at solar noon with respect to the plane of the equator, north positive; $-23.45^0 \le \delta \le 23.45^0$

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

With I_0, k_T is:

$$k_T = \frac{I}{I_o} \tag{3.6}$$

With the k_T, the Erbs and the Orgill and Hollands correlation can now be used to find the hourly diffuse radiation fraction of the global solar radiation, $\frac{I_D}{I}$.

Now with the hourly diffuse radiation fraction I_D, I_B is given by (3.7):

$$I_B = \frac{I - I_D}{\cos(\theta_z)} \tag{3.7}$$

Where,

$$\cos\theta_z = \cos\varphi.\ \cos\delta\ .\ cos\omega + sin\varphi\ .\ \sin\delta \tag{3.8}$$

3.6.1.1 Example of the Hourly Direct Radiation Estimations from Juana Díaz

This section shows an example of the hourly direct radiation estimations from Juana Díaz. For this example we estimate the hourly direct radiation from January 1st at 12:00 PM.

The first step is to determine the hourly average of the global solar radiation from the 5 minutes averages of measured data. This is done by averaging all the measurements made 30 minutes before and after the hour in question.

Time	Global Radiation (W/m^2)
11:30 A.M.	833.94
11:35 A.M.	811.22
11:40 A.M.	819.97
11:45 A.M.	827.95
11:50 A.M.	824.77
11:55 A.M.	830.39
12:00 P.M	832.09
12:05 P.M.	832.41
12:10 P.M.	816.14
12:15 P.M.	818.48
12:20 P.M.	816.53
12:25 P.M.	815.64

$I = 823.29$ W/m^2 $I = 823.29 W / m^2$

The following step is the calculation of I_0 using (3.1)

$$I_0 = \frac{12 \times 3,600}{\pi} G_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365} \right) \right] \times \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1 \right) + \frac{\pi(\omega_2 - \omega_1)}{180} \sin\phi \sin\delta \right]$$

Where,

G_{sc}= 1,367 w/m^2

n = 1

φ = 18.05° (Juana Díaz´s latitude)

$\delta = 23.45\ sin\left(360\ \frac{284+1}{365}\right)$ = - 23.0

$$\delta = 23.45 sin\left(360 \frac{284+1}{365} \right) = -23^{\circ}$$

$$I_0 = \frac{12 \times 3,600}{\pi}(1,367)\left[1 + 0.033\cos\left(\frac{360(1)}{365}\right)\right]...$$

$$...\left[\cos(18.05)\cos(-23)\left(\sin(7.5) - \sin(-7.5)\right) + \frac{\pi((7.5)-(-7.5))}{180}\sin(18.05)\sin(-23)\right]$$

$$= 3.82(MJ) = 1,061(W - h / m^2)$$

The clearness index is given (3.6):

$$k_T = \frac{819}{1061} = 0.761$$

Now, the Erbs correlation can be used:

$$\frac{I_D}{I} = \begin{cases} 1 - 0.09k_T & for\, k_T \le 0.22 \\ 0.9511 - 0.1604\, k_T + 4.388\, k_T^2 & for\, 0.22 < k_T \le 0.8 \\ 0.165 & for\, k_T > 0.8 \end{cases}$$

$$\frac{I_D}{I} = 0.9511 - 0.1604(0.761) + 4.388(0.761)^2 - 16.638(0.761)^3 + 12.336(0.761)^4$$

$$I_D = 0.175(823.29)$$

$$I_D = 144W / m^2$$

Finally, I_B is obtained using (3.3):

$$\cos\theta_z = \cos(18.05)\cos(-23)cos(0) + sin\ (18.05).\ \sin(-23) = 0.956$$

$$I_B = \frac{823.29 - 144}{0.956} = 710.49(W / m^2)$$

3.6.2 *Estimation of the Hourly Direct Radiation from Santo Domingo*

The processing of measured data from Santo Domingo consists of three parts: the estimation of the hourly global horizontal radiation (I). The second part is the estimation of the hourly diffuse horizontal radiation (I_D). The third and final part is the calculation of the hourly direct normal radiation (I_B).

1) The estimation of the hourly global horizontal radiation (I) from the daily global horizontal irradiation (H)

To estimate I from H we need to calculate the ratio of hourly global horizontal radiation to daily global horizontal radiation (r_t) using the equations by Collares-Pereira and Rabl [**43**]:

$$r_t = \frac{I}{H} = \frac{\pi}{24}\left(a + b\cos w\right)\frac{\cos w - \cos w_s}{\sin w_s - \frac{\pi w_s}{180}\cos w_s} \quad (3.9)$$

Where;

$$a = 0.409 + 0.5016\sin(w_s - 60) \quad (3.10)$$

$$b = 0.660 - 0.4767\sin(w_s - 60) \quad (3.11)$$

ω = hour angle in degrees (i.e. the midpoint of the hour for which the calculation is made)

w_s = sunset hour angle

$$w_s = Cos^{-1}(-\tan\phi\tan\delta) \quad (3.12)$$

δ = the declination angle

n = day number

With H and r_t, I is given from (3.9):

$$I = r_t.H$$

2) The estimation of the hourly diffuse radiation (I_D)

The estimation of I_D is made using a similar process as the estimation of I. The ratio of hourly diffuse horizontal radiation to daily diffuse horizontal radiation (r_d) is calculated using the following equation by Collares-Pereira and Rabl [**43**]:

$$r_d = \frac{\pi}{24}.\frac{\cos w - \cos w_s}{\sin w_s - \frac{\pi w_s}{180}\cos w_s} \quad (3.13)$$

3) The calculation of the hourly direct radiation (I_B)

Equation (3.3) can now be used for the calculation of I_B:

$$I_B = \frac{I - I_D}{\mathrm{Cos}(\theta_z)}$$

3.6.2.1 *Example of the Hourly Direct Radiation Estimations from Santo Domingo*

This section shows an example of the hourly direct radiation estimations from Santo Domingo. For this example we estimate the hourly direct radiation from January 1st at 12:00 PM. The integrated daily values of the global and diffuse solar radiation for January 1st are:

$$H = 4,644(W - H/m\wedge 2)$$

$$H_D = 1,385(W - H/m\wedge 2)$$

1) Calculate the ratio of hourly global to daily global radiation (r_t) for 12:00 P.M. using (3.3).

$$r_t = \frac{\pi}{24}(a + b\cos w)\frac{\cos w - \cos w_s}{\sin w_s - \frac{\pi w_s}{180}\cos w_s}$$

The coefficients a and b are given by:

$$a = 0.409 + 0.5016\sin(w_s - 60)$$

$$b = 0.660 - 0.4767\sin(w_s - 60)$$

Where,

$W = 0$ (for 12 P.M)

$$W_s = Cos^{-1}(-\tan\varphi\tan\delta)$$

φ = 18.5 (Santo Domingo's latitude)

The declination angle for January1st, which corresponds to the first day of the year (n=1) is obtained by:

$$\delta = 23.45\ sin\left(360\ \frac{284 + 1}{365}\right)$$

$$\delta = -23.0$$

$$W_s = Cos^{-1}(-\tan(18.5°)\tan(-23°)) = 81.84°$$

$$a = 0.409 + 0.5016\sin(81.84 - 60) = 0.5956$$

$$b = 0.660 - 0.4767\sin(81.84 - 60) = 0.4836$$

$$r_t = \frac{\pi}{24}\left(0.5956 + 0.4836\cos(0)\right)\frac{\cos(0) - \cos(81.84°)}{\sin(81.84°) - \frac{\pi\ (81.84°)}{180}\cos(81.84°)} = 0.154$$

Finally, I is given from (3.9)

$$I = r_t.H$$

$$I = (0.154).(4,644) = 715.18(W / m^2)$$

2) Calculate the ratio of hourly diffuse to daily diffuse radiation (r_d) using (3.14):

$$r_d = \frac{\pi}{24}.\frac{\cos w - \cos w_s}{\sin w_s - \frac{\pi\, w_s}{180}\cos w_s}$$

$$r_d = \frac{\pi}{24}.\frac{\cos(0) - \cos(81.84)}{\sin(81.84) - \frac{\pi\ (81.84)}{180}\cos(81.84)} = 0.1427$$

$$I_d = (0.1427).(1,385) = 197.63(W / m^2)$$

3) Calculate the hourly direct radiation from the hourly global and diffuse radiation using (3.3):

$$I_B = \frac{I - I_D}{\mathrm{Cos}(\theta_z)}$$

$$\cos\theta_z = \cos(18.5).\ \cos(-23)\ .\ cos(0) + sin\ (18.5)\ .\ \sin(-23) = 0.749$$

$$I_B = \frac{715.18 - 197.63}{0.749} = 690.99(W\ /\ m^2)$$

3.6.2.2 Validation

The relationship between hourly and daily radiation can also be represented by the following curves by Liu-Jordan [**44**].

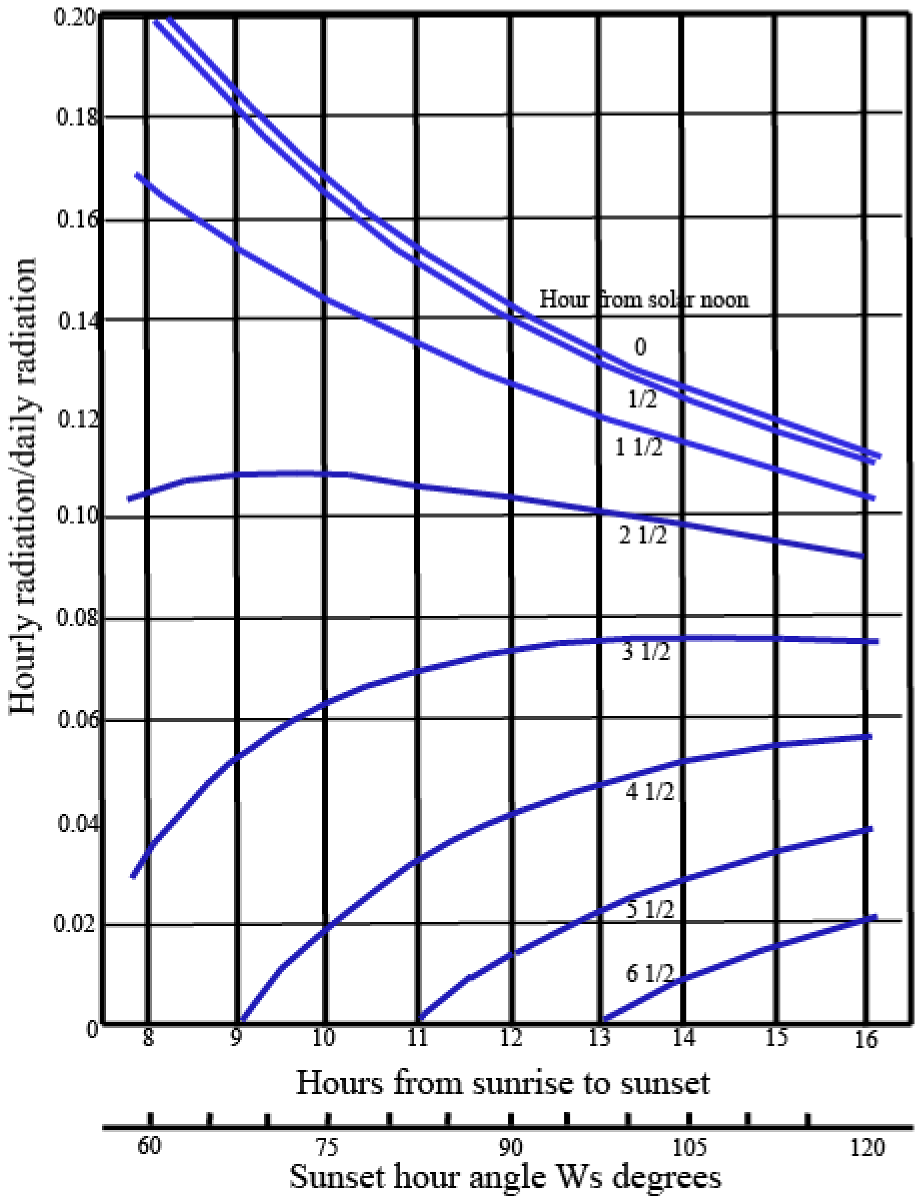

Figure 3-8 Relationship between hourly and daily global radiation on a horizontal surface as a function of day length (Adapted from [35])

The hours are designated by the time for the midpoint of the hour, and days are assumed to be symmetrical about solar noon. A curve for the hour centered at noon is also shown. Day length can be calculated from equation (3.14). Thus, from knowledge of day length and daily total radiation, the hourly total radiation for symmetrical days can be estimated.

$$N = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \qquad (3.14)$$

Figure 3-9 shows a Liu-Jordan chart created with the processed hourly global horizontal solar radiation from Santo Domingo. This chart was created for validation purposes. Since Figure 3-9 and figure 3-8 yield the same results, we can be certain that the estimations are correct.

Note that Figure 3-8 has a wider range of lengths of day than Figure 3-9, which may give the impression that the graphics do not match.

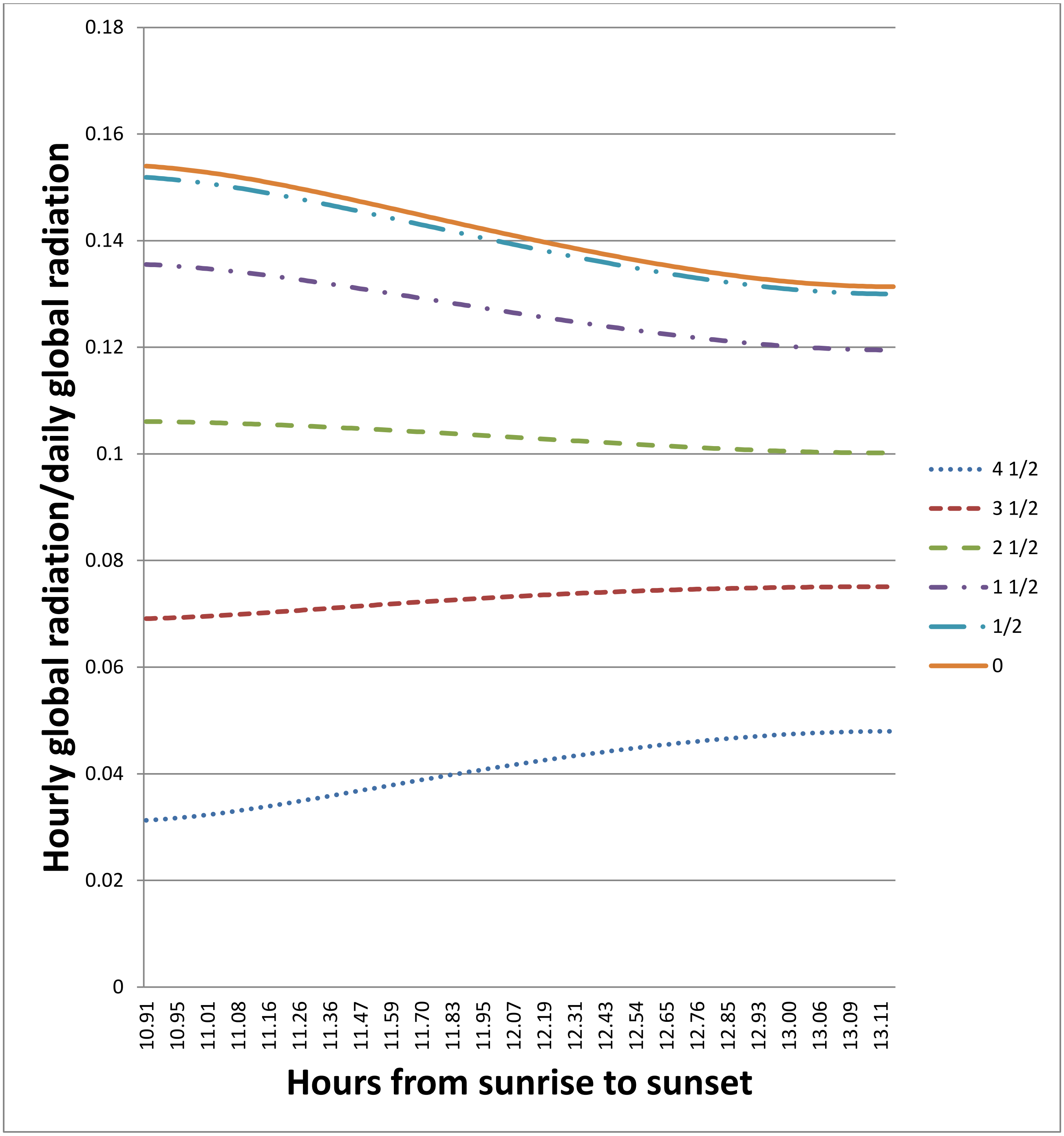

Figure 3-9 Liu-Jordan Chart extracted from the hourly global radiation from Santo Domingo

The same validation process is repeated with success for the hourly diffuse horizontal radiation:

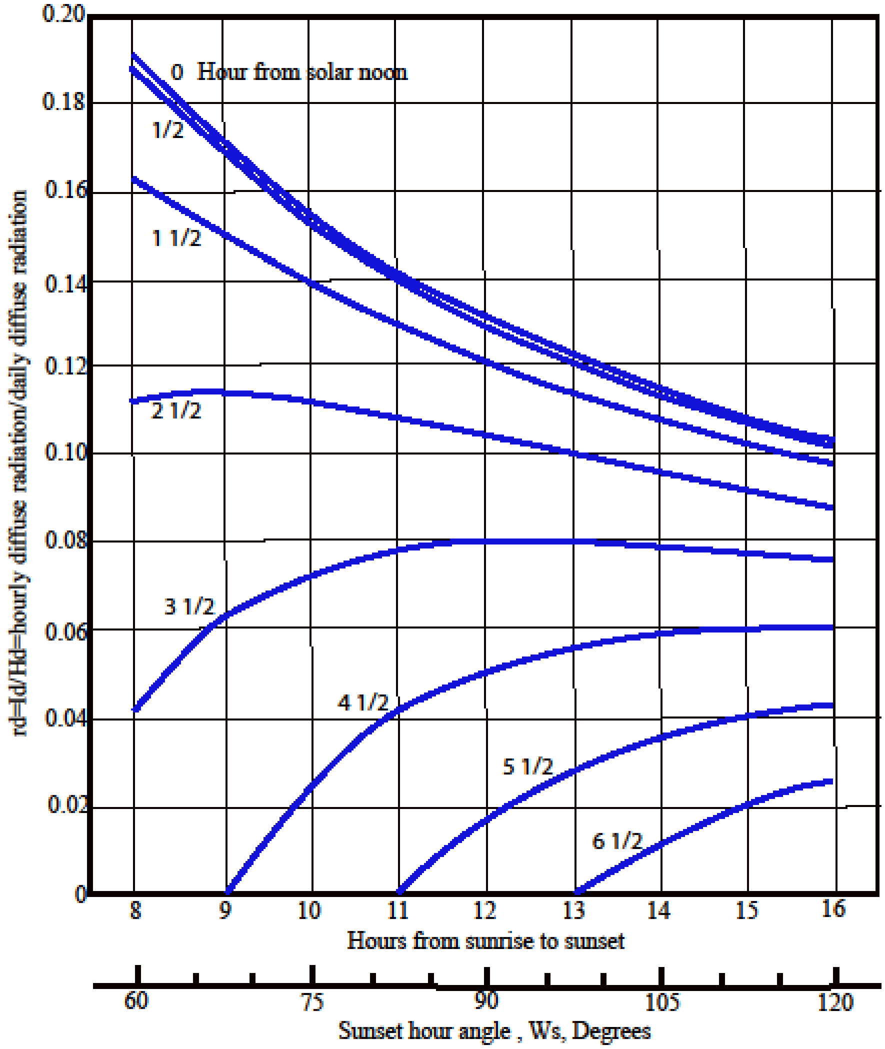

Figure 3-10 Relationship between hourly and daily diffuse radiation on a horizontal surface as a function of day length (Adapted from [35**])**

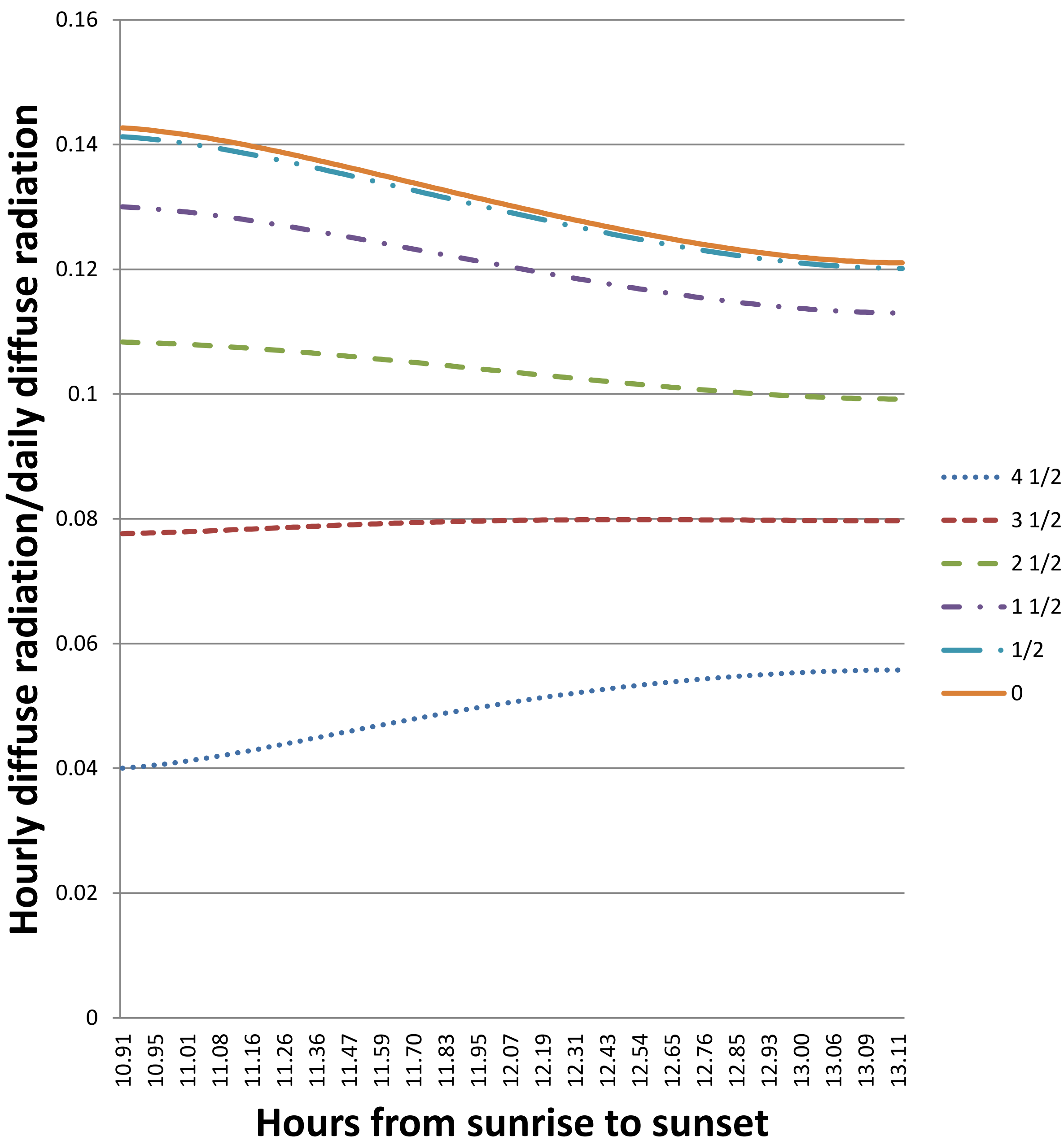

Figure 3-11 Liu-Jordan Chart extracted from the hourly diffuse radiation from Santo Domingo

3.7 Solar Radiation Data Processing Results

The results of the data processing are presented in this section using graphs of monthly and annual profiles.

The monthly profile graphs are set of line graphs showing the average daily profile for each month and for the entire year. The annual profile graphs show the average daily profile graph for the complete year.

Solid lines represent the global horizontal solar radiation, dashed lines represent the direct normal radiation and the dotted lines represent the diffuse horizontal radiation.

3.7.1 Estimations of Hourly Solar Radiation from Juana Diaz

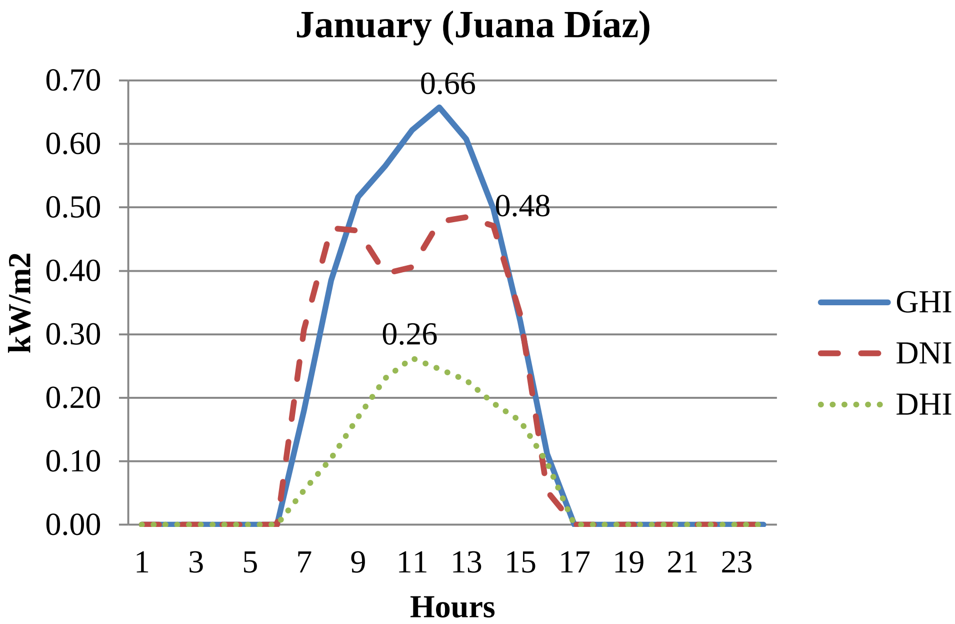

Figure 3-12 Average Hourly Solar Radiation for January (Juana Díaz)

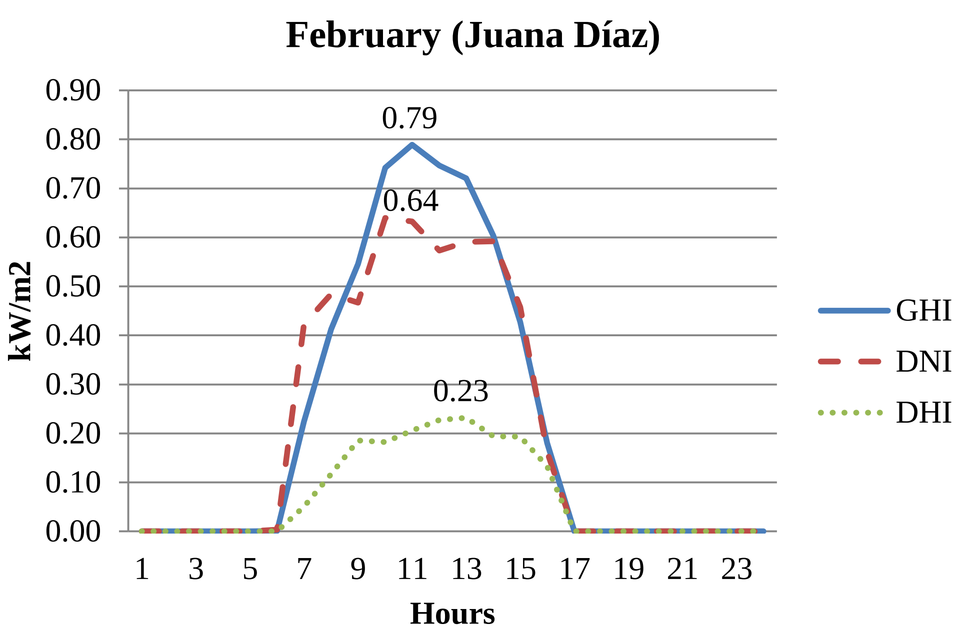

Figure 3-13 Average Hourly Solar Radiation for February (Juana Díaz)

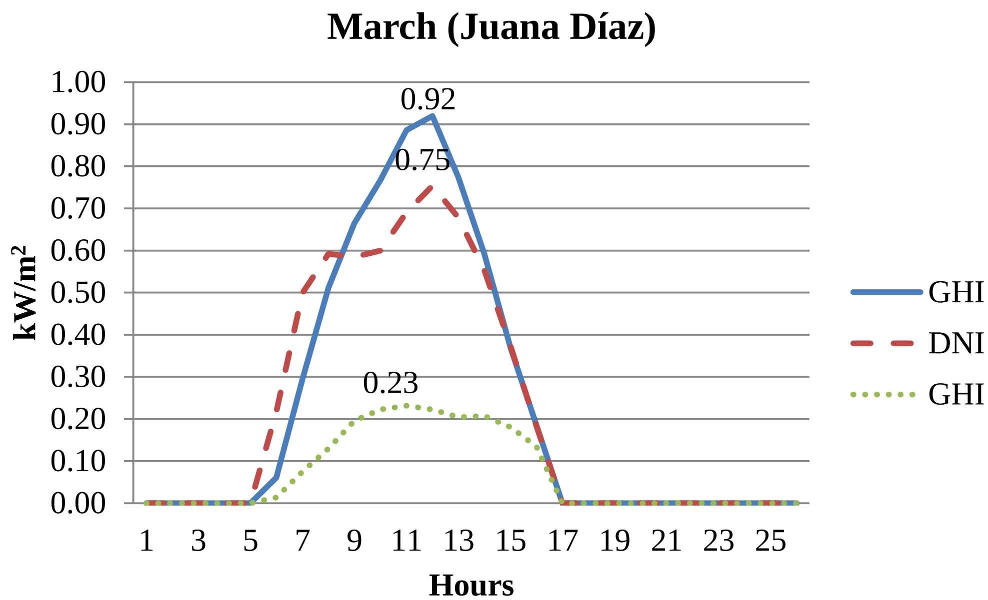

Figure 3-14 Average Hourly Solar Radiation for March (Juana Díaz)

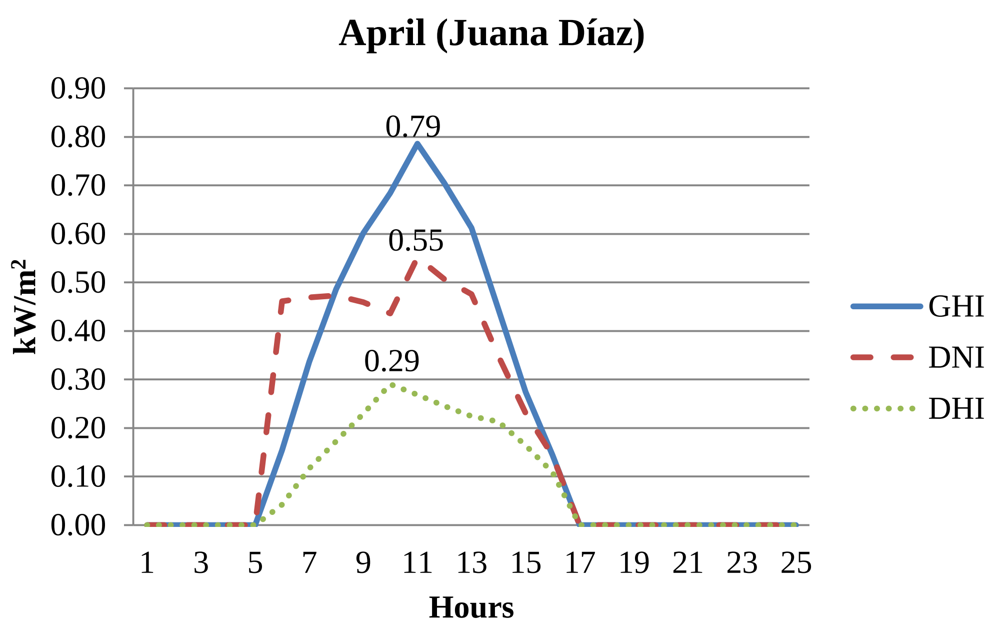

Figure 3-15 Average Hourly Solar Radiation for April (Juana Díaz)

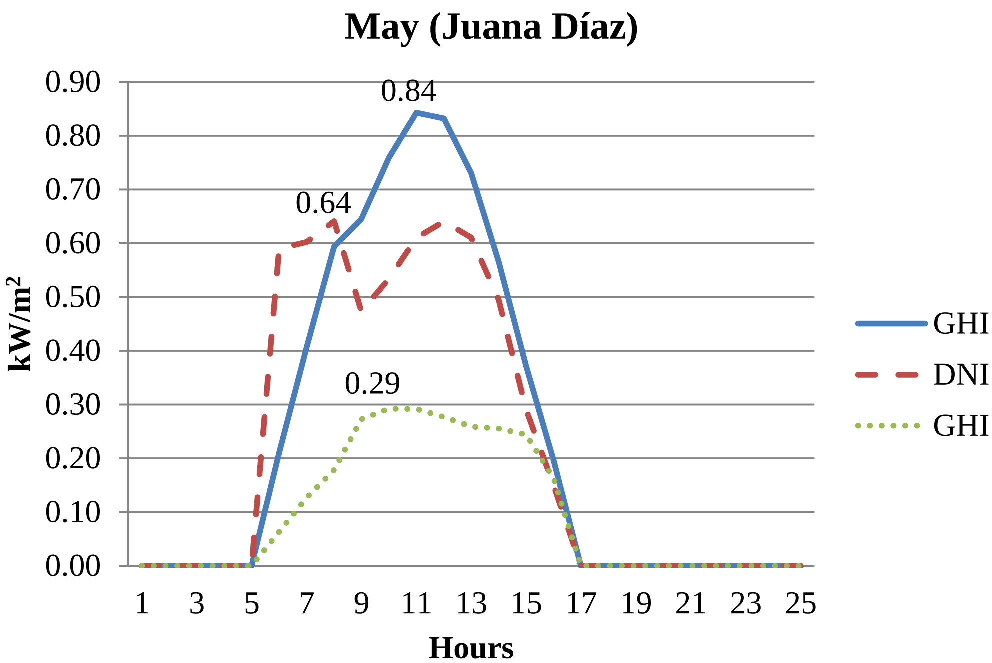

Figure 3-16 Average Hourly Solar Radiation for May (Juana Díaz)

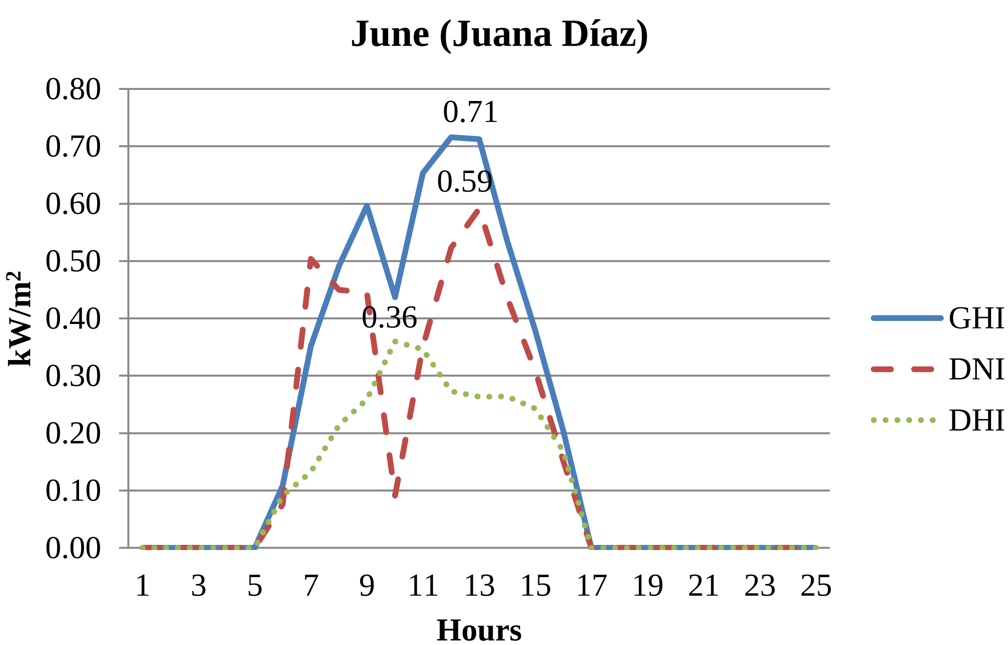

Figure 3-17 Average Hourly Solar Radiation for June (Juana Díaz)

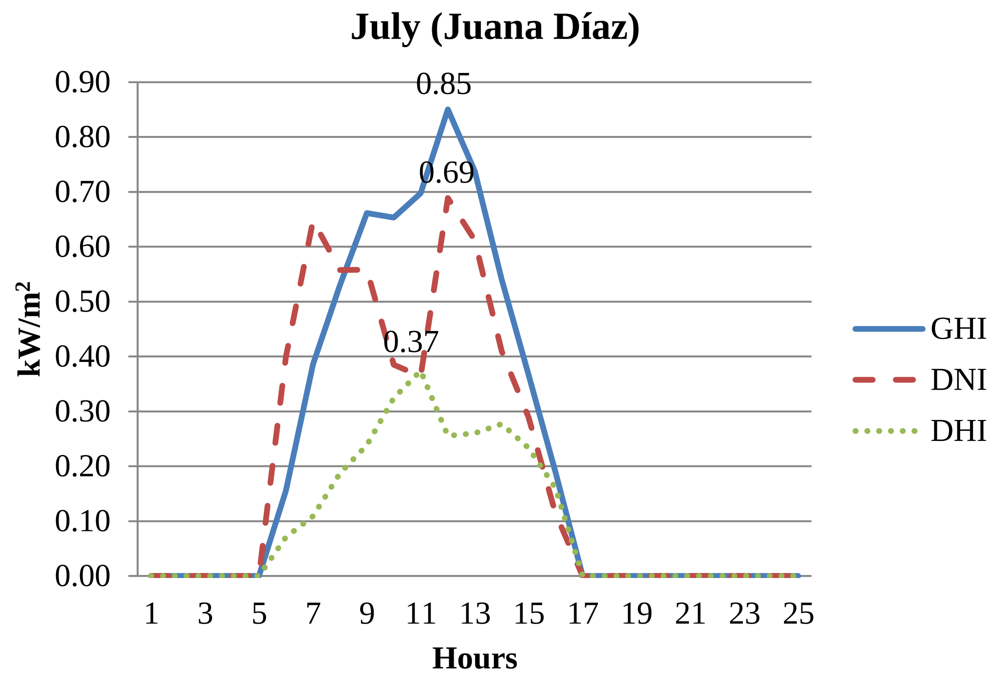

Figure 3-18 Average Hourly Solar Radiation for July (Juana Díaz)

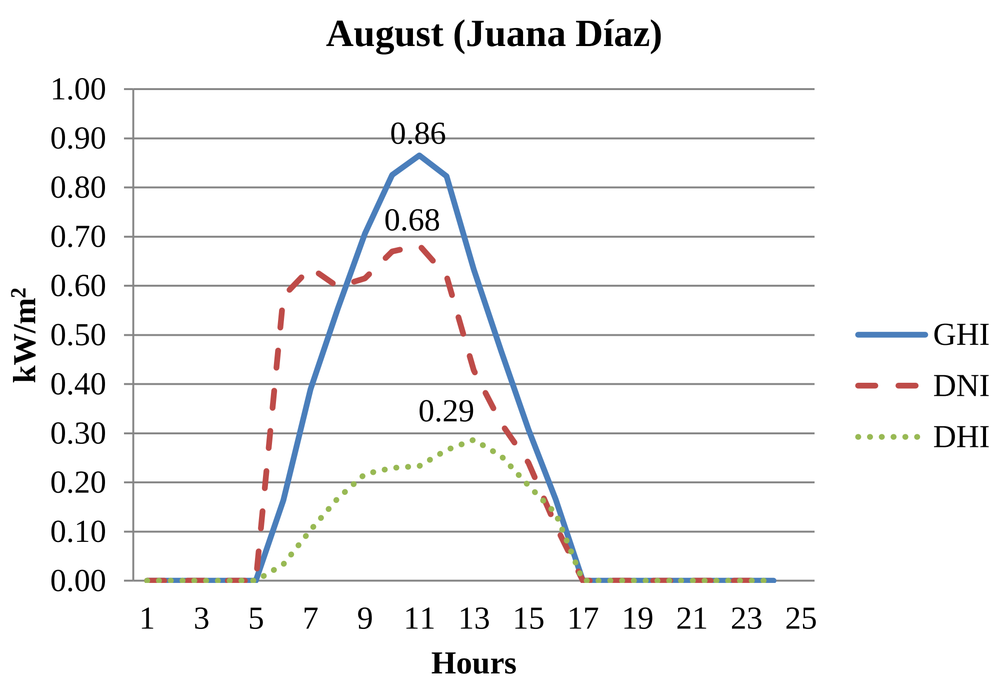

Figure 3-19 Average Hourly Solar Radiation for August (Juana Díaz)

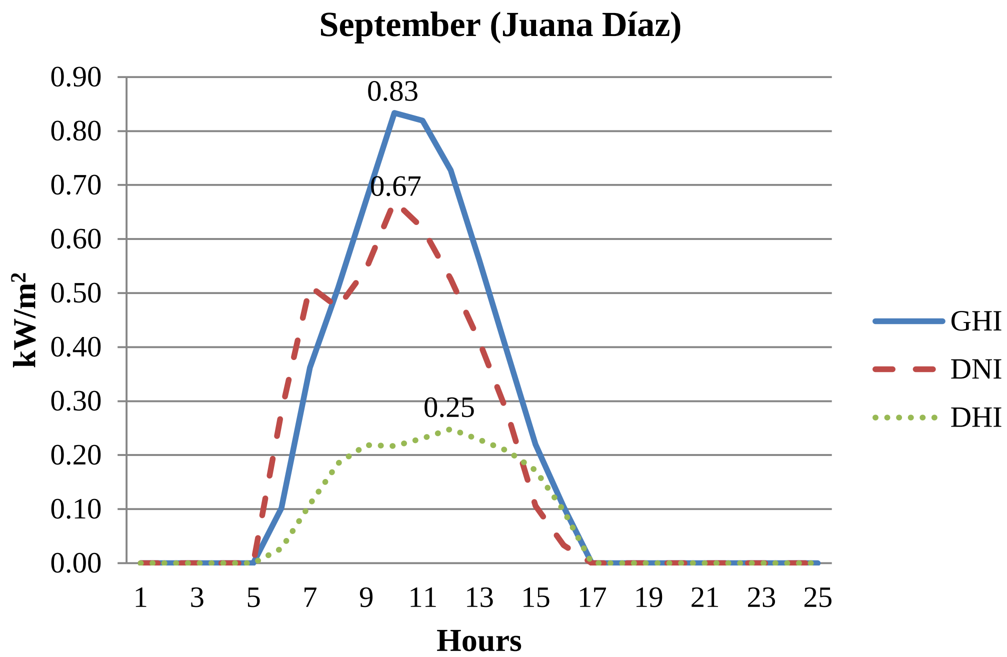

Figure 3-20 Average Hourly Solar Radiation for September (Juana Díaz)

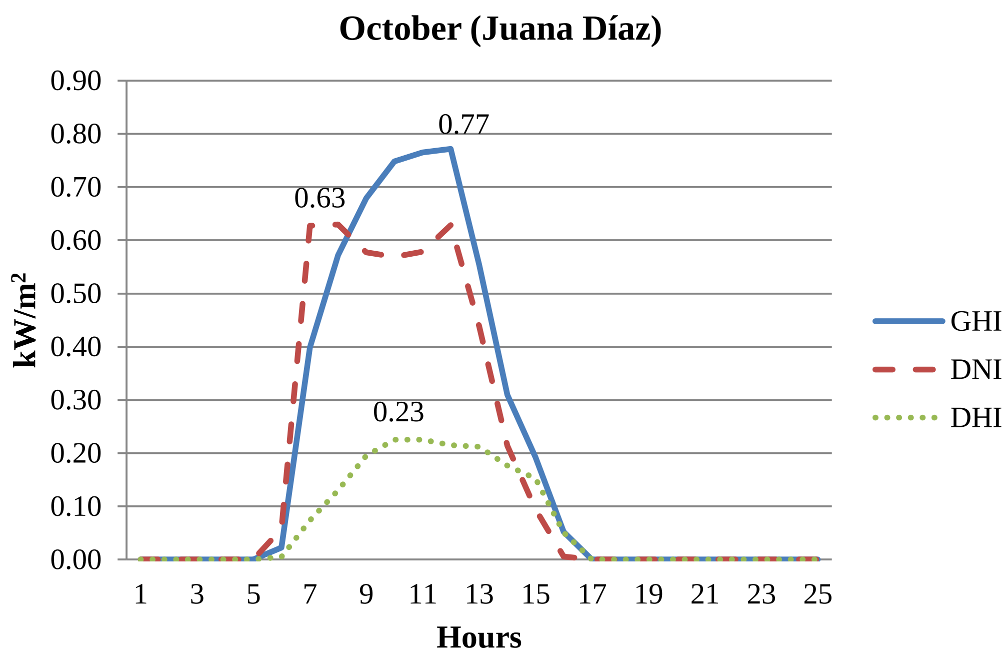

Figure 3-21 Average Hourly Solar Radiation for October (Juana Díaz)

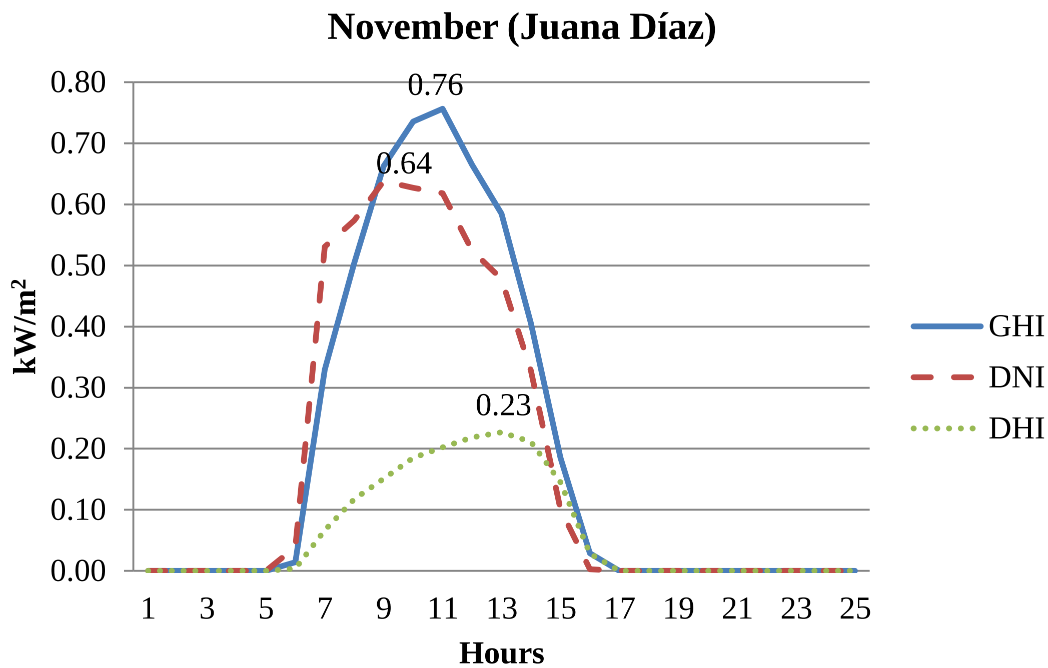

Figure 3-22 Average Hourly Solar Radiation for November (Juana Díaz)

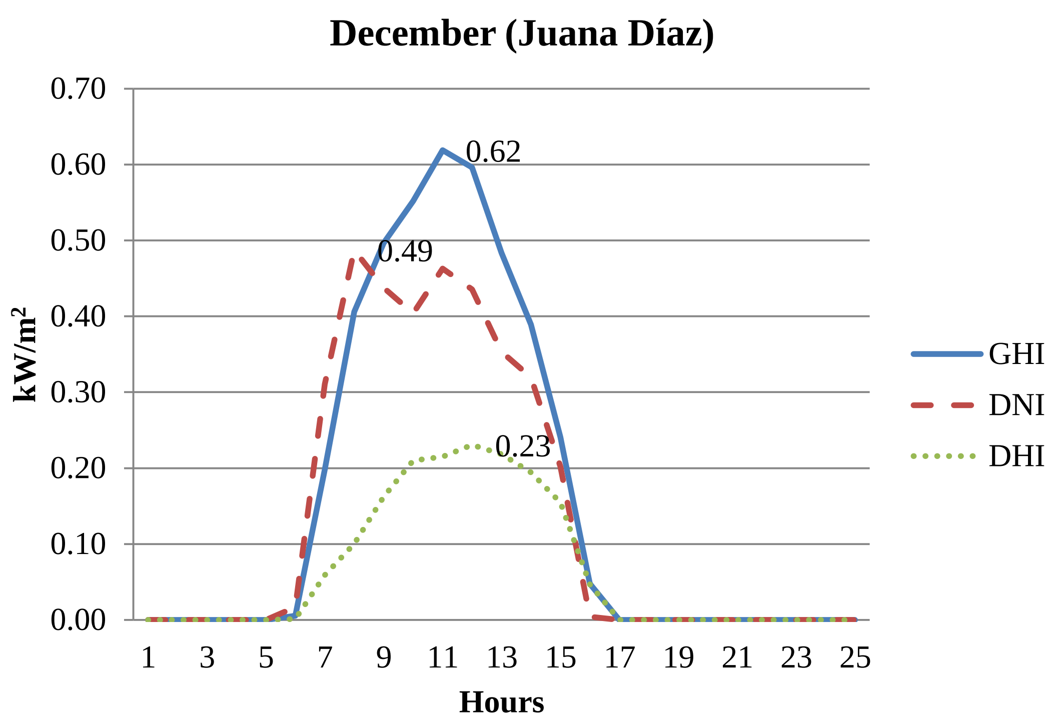

Figure 3-23 Average Hourly Solar Radiation for December (Juana Díaz)

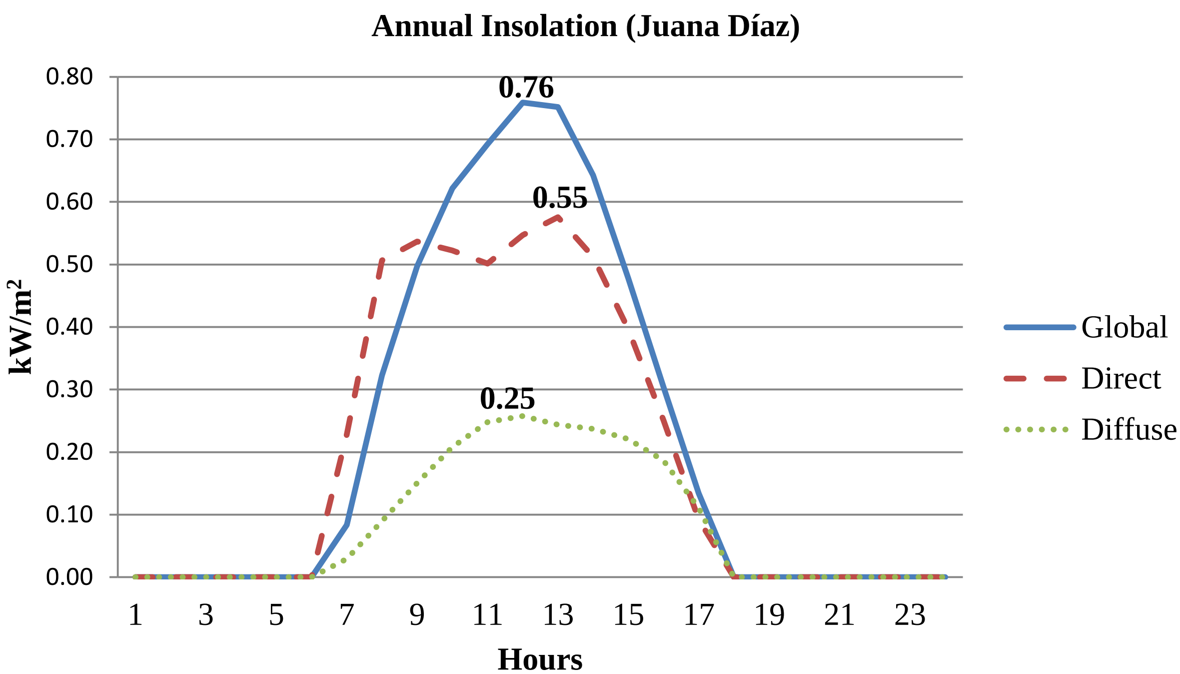

Figure 3-24 Annual profile for Juana Diaz

3.7.2 Estimation of the Hourly Solar Radiation Results from Santo Domingo

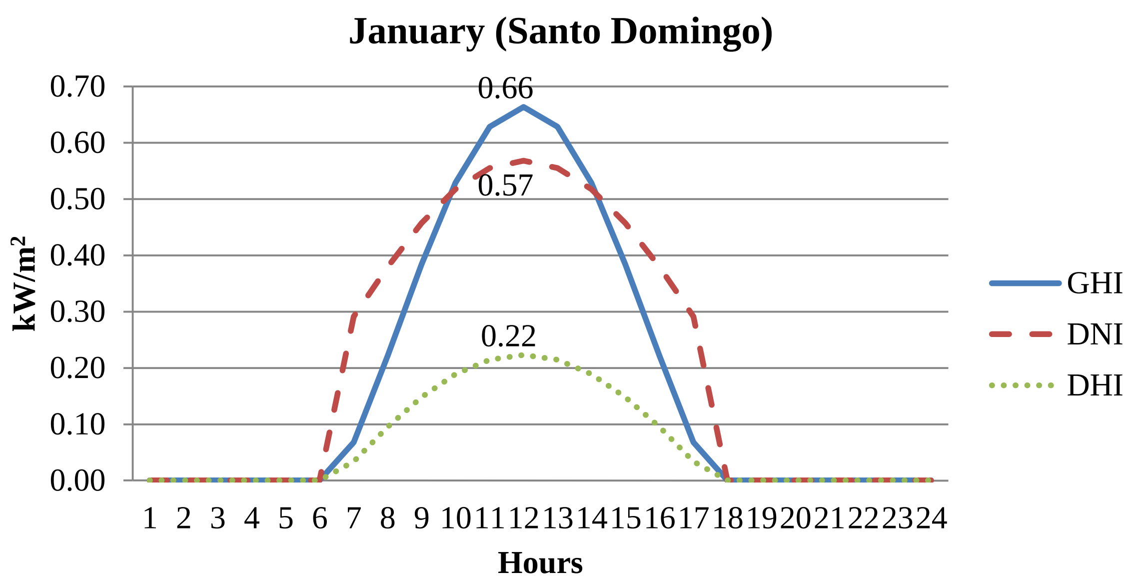

Figure 3-25 Average Hourly Solar Radiation for January (Santo Domingo)

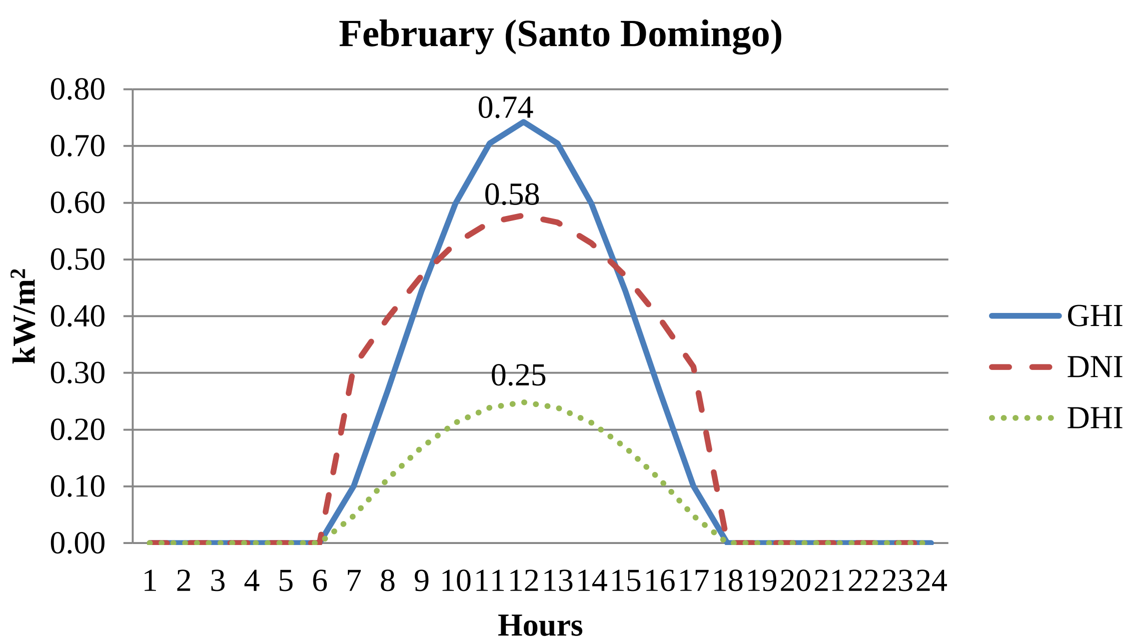

Figure 3-26 Average Hourly Solar Radiation for February (Santo Domingo)

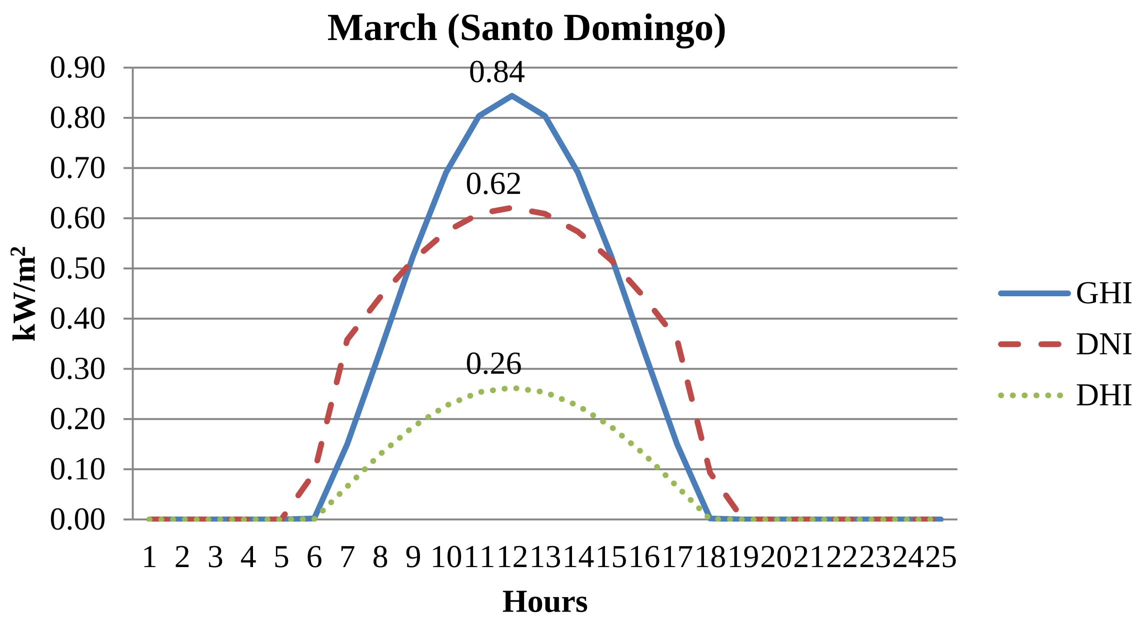

Figure 3-27 Average Hourly Solar Radiation for March (Santo Domingo)

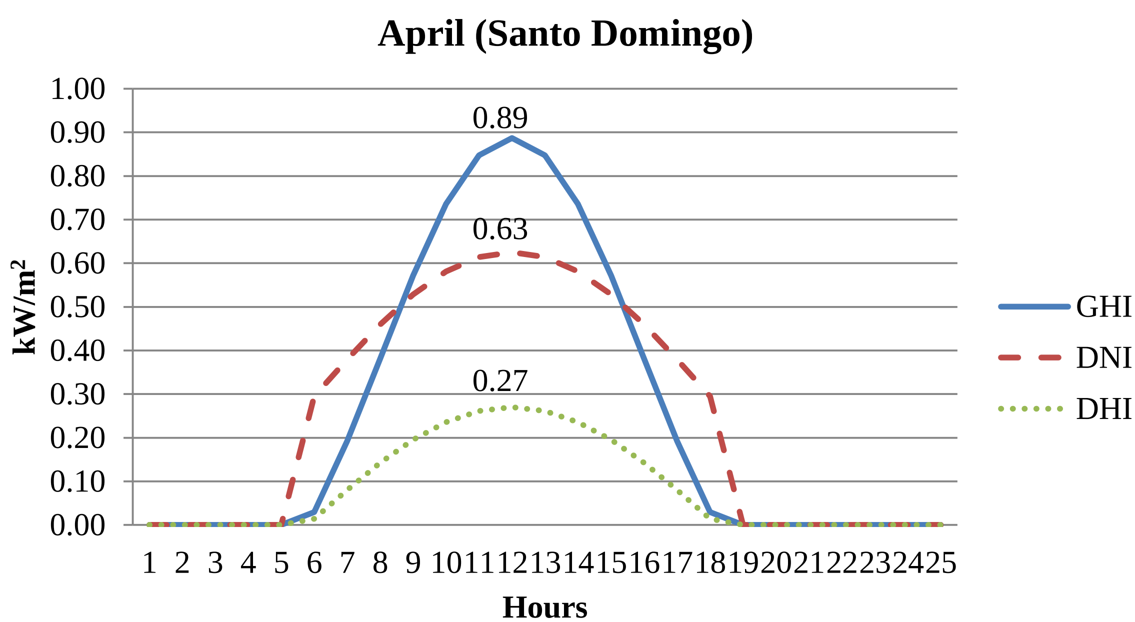

Figure 3-28 Average Hourly Solar Radiation for April (Santo Domingo)

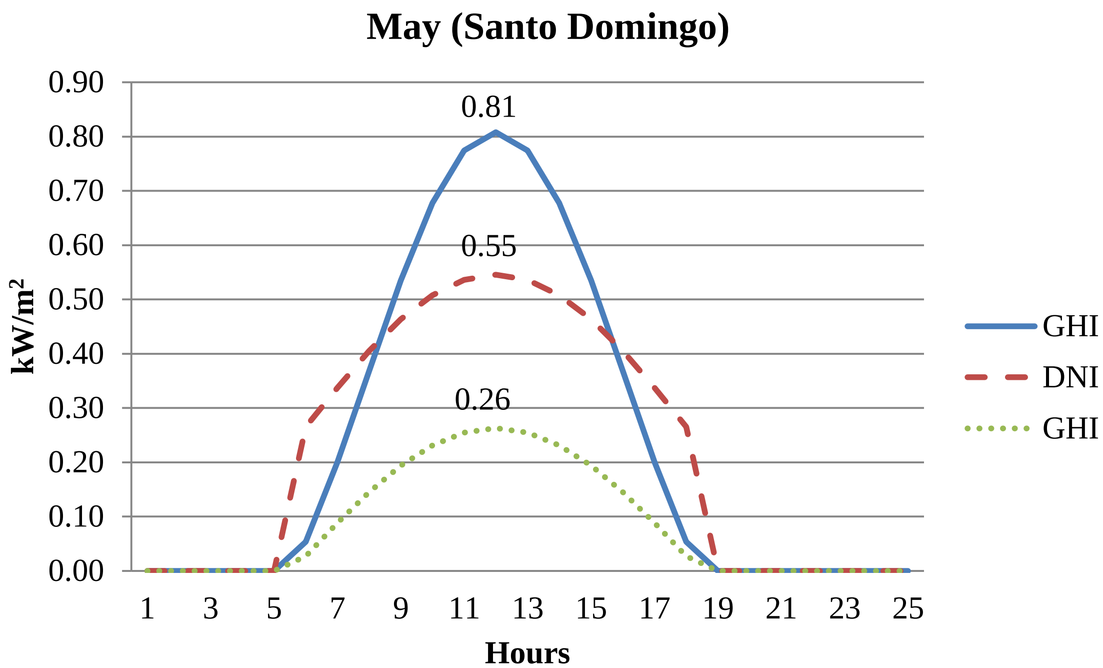

Figure 3-29 Average Hourly Solar Radiation for May (Santo Domingo)

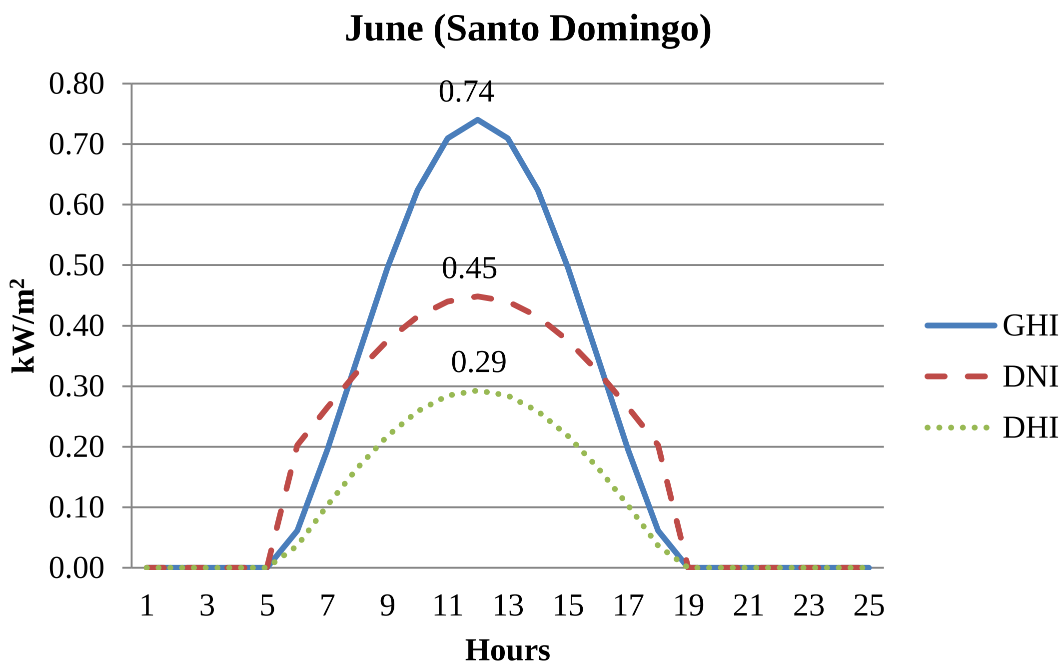

Figure 3-30 Average Hourly Solar Radiation for June (Santo Domingo)

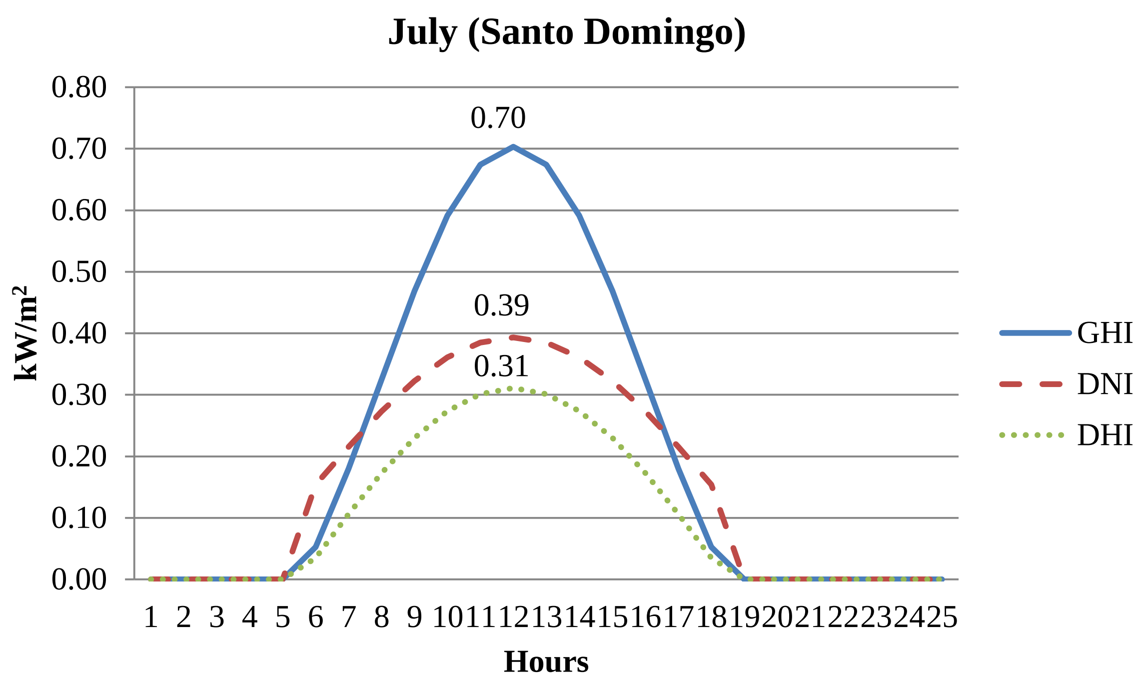

Figure 3-31 Average Hourly Solar Radiation for July (Santo Domingo)

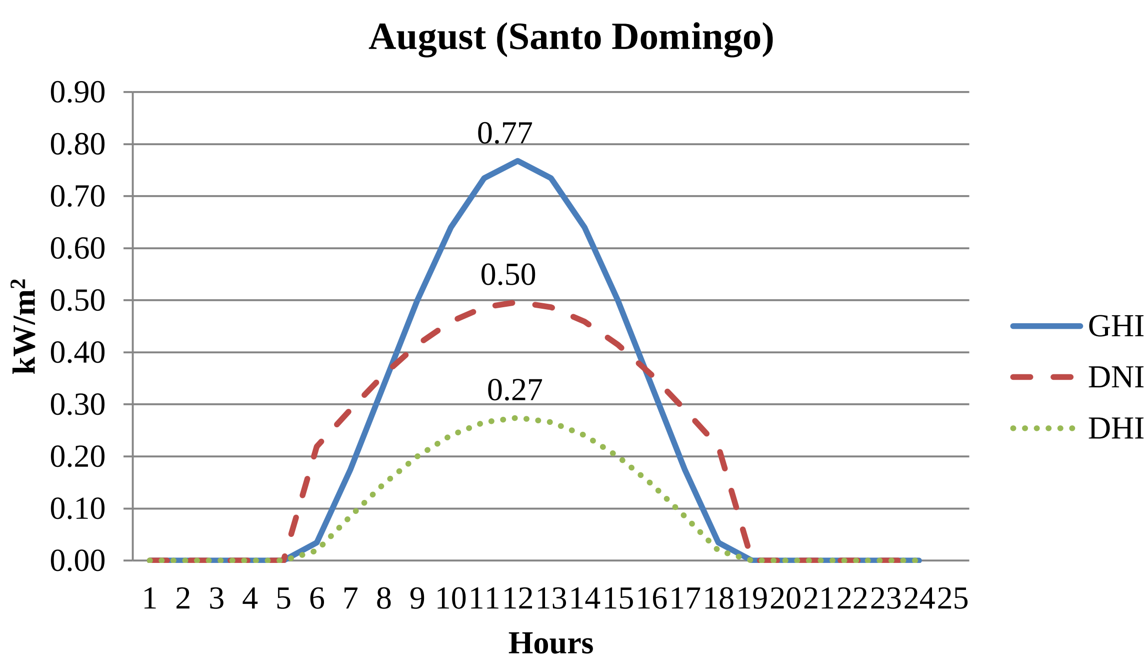

Figure 3-32 Average Hourly Solar Radiation for August (Santo Domingo)

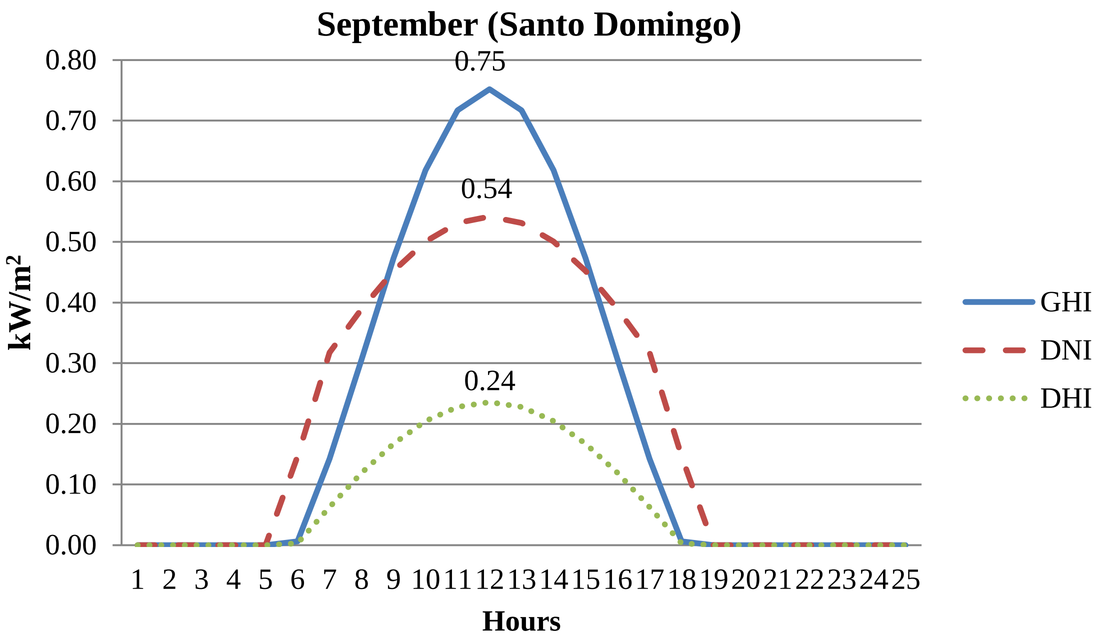

Figure 3-33 Average Hourly Solar Radiation for September (Santo Domingo)

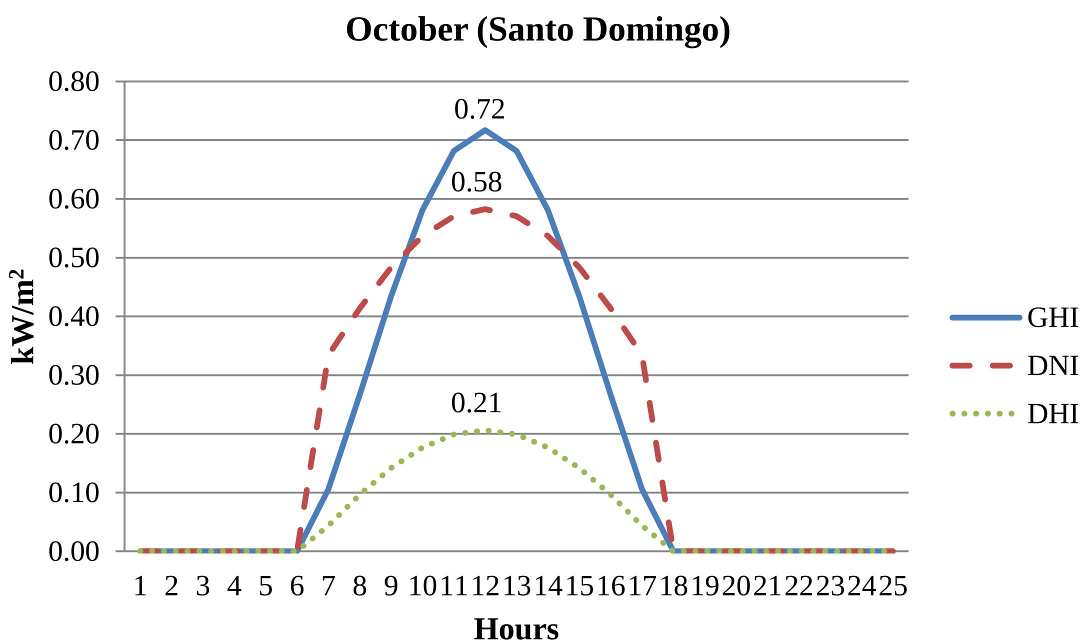

Figure 3-34 Average Hourly Solar Radiation for October (Santo Domingo)

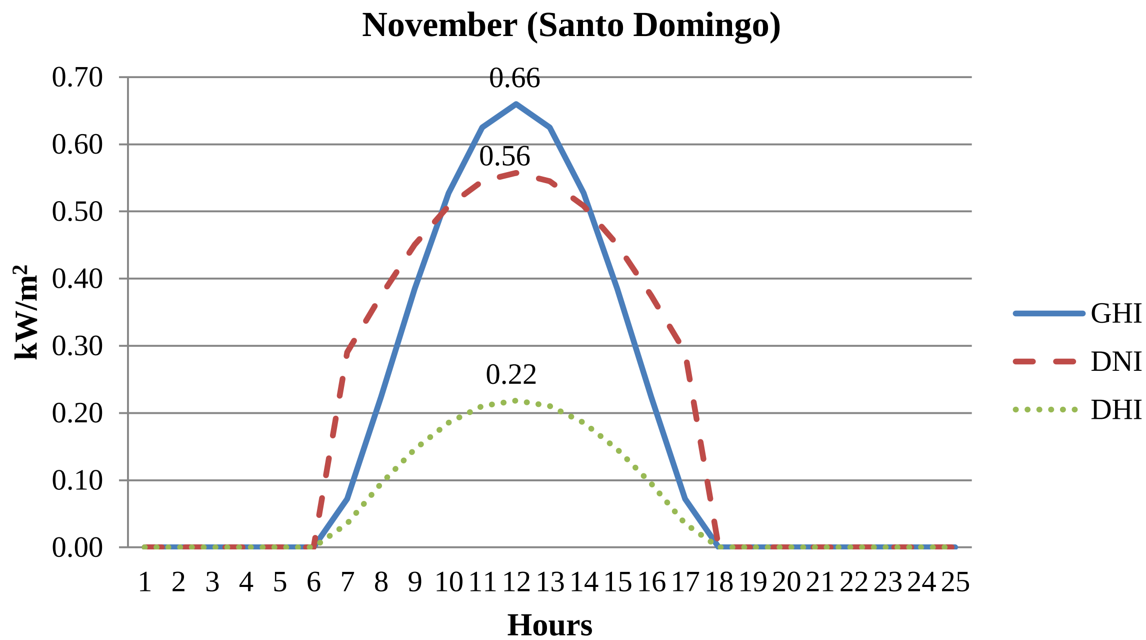

Figure 3-35 Average Hourly Solar Radiation for November (Santo Domingo)

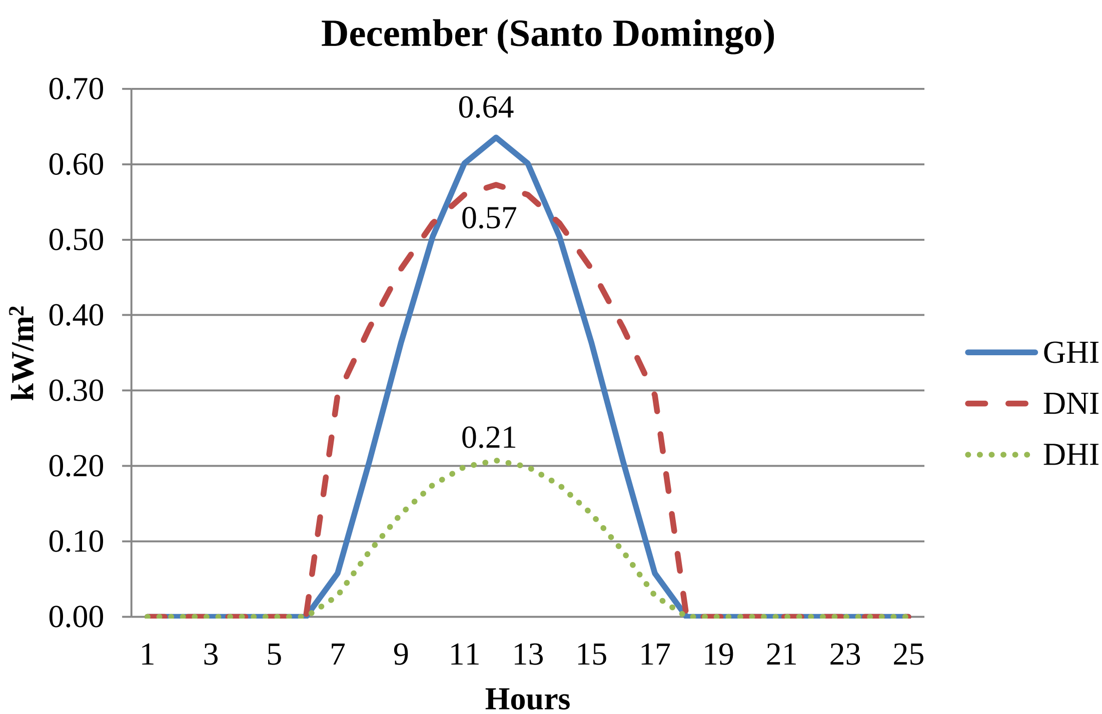

Figure 3-36 Average Hourly Solar Radiation for December (Santo Domingo)

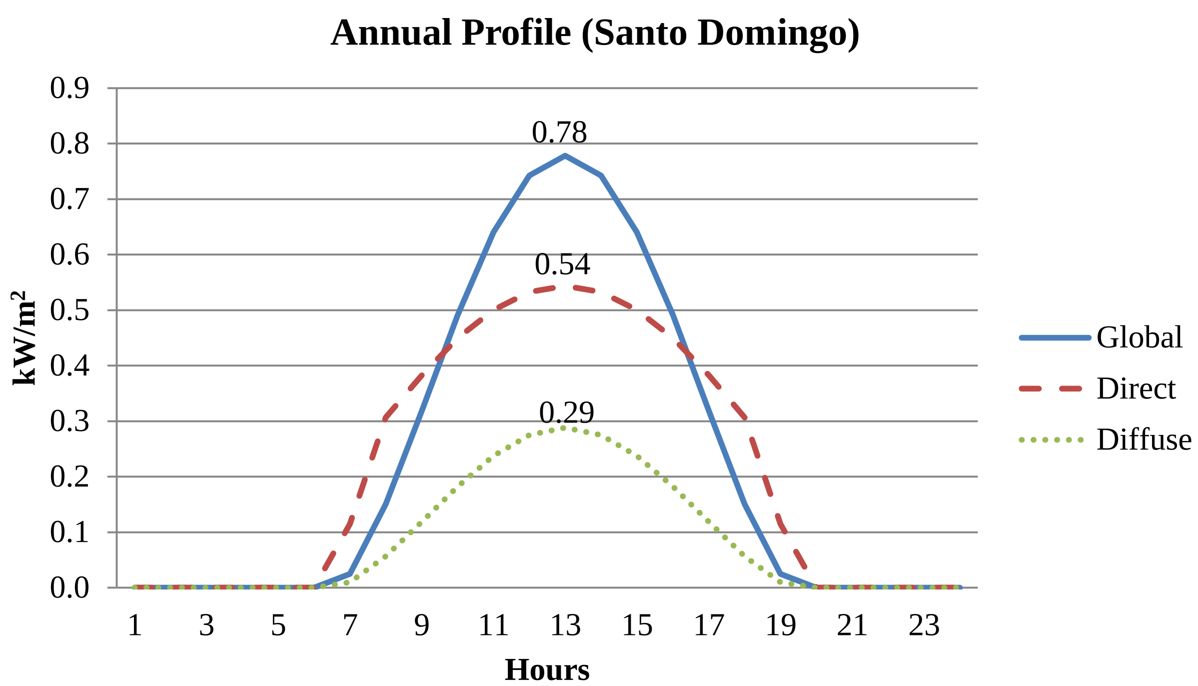

Figure 3-37 Annual profiles for Santo Domingo

Measured daily data was processed to make the hourly estimations for Santo Domingo. This is not an exact process. For example, daily radiation values can arise from various circumstances, such as intermittent heavy clouds, continuous light clouds, or heavy cloud cover for part of the day. There is no way to determine these circumstances from the daily totals. Therefore, monthly and annual profiles of Santo Domingo look different to those of Juana Diaz.

3.7.3 Direct Normal Irradiation Monthly Comparison

Figure 3-38 shows the monthly direct normal irradiation comparison between Juana Diaz and Santo Domingo. Santo Domingo shows more direct normal irradiation that Juana Diaz in most months, with the exception of May, July and August.

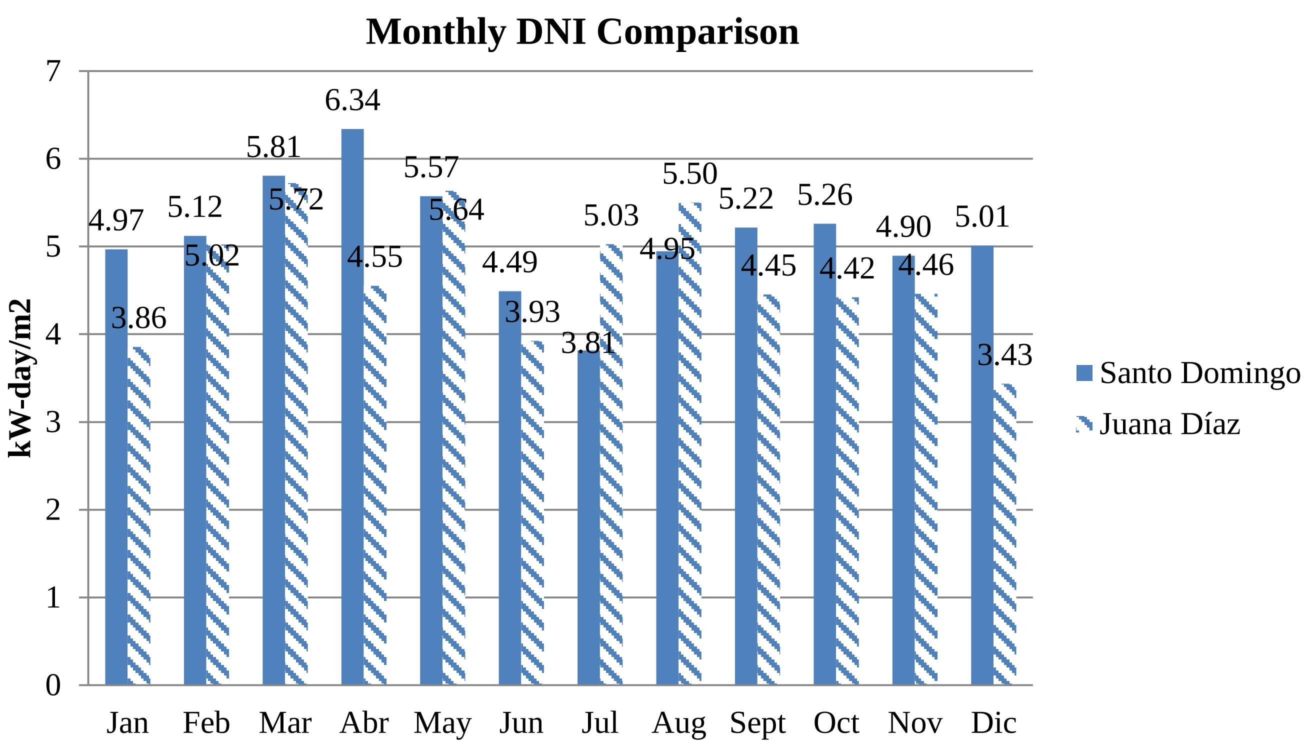

Figure 3-38 Monthly DNI Comparison

4 ANALYSIS

Economics is arguably the most important part in the implementation of any project. The cost of energy at which Dish/ stirling systems becomes a profitable project in Puerto Rico and the Dominican Republic are estimated in this chapter. The performance model, financial model, simulations, and results are discussed as well.

4.1 SAM Overview

The Solar Advisor Model (SAM) is the performance and financial modeling tool used. It makes performance predictions and cost of energy estimates for grid connected power projects based on installation, operating costs and system design parameters specified as inputs to the model. Fig. 4-1 shows a general overview of SAM.

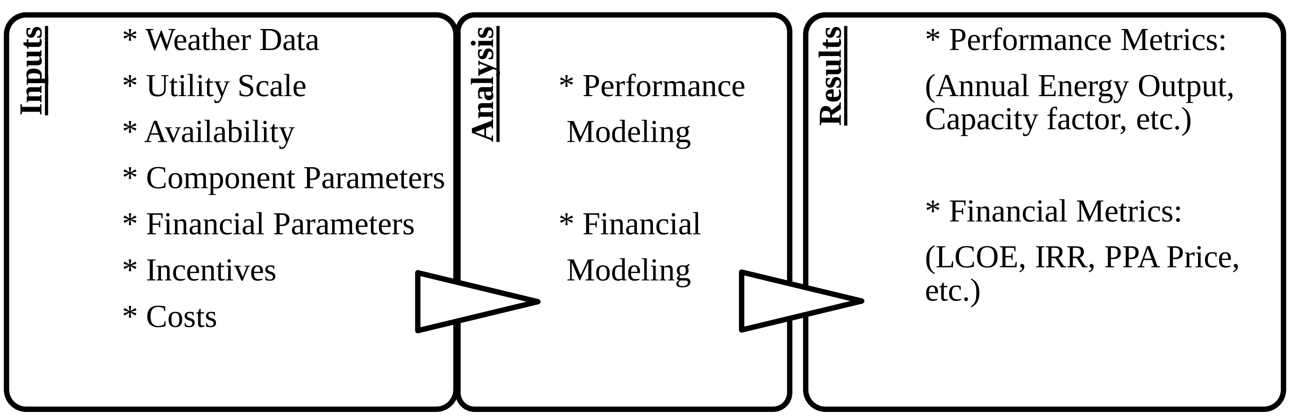

Figure 4-1 General Overview of SAM

The first step in creating a SAM file is to choose a technology and financing method for the project. Next, the weather file, the cost of installing and operating the system, and the financial parameters and incentives are provided.

Once all the inputs are set, the simulations are run, and the results of the performance and financial model are presented. In the next section the performance and financial modeling are discussed in detail.

4.2 *Performance Model*

The performance model calculates the hourly system electrical output over the analysis period. Figure 4-2 shows an overview of the performance modeling process by SAM.

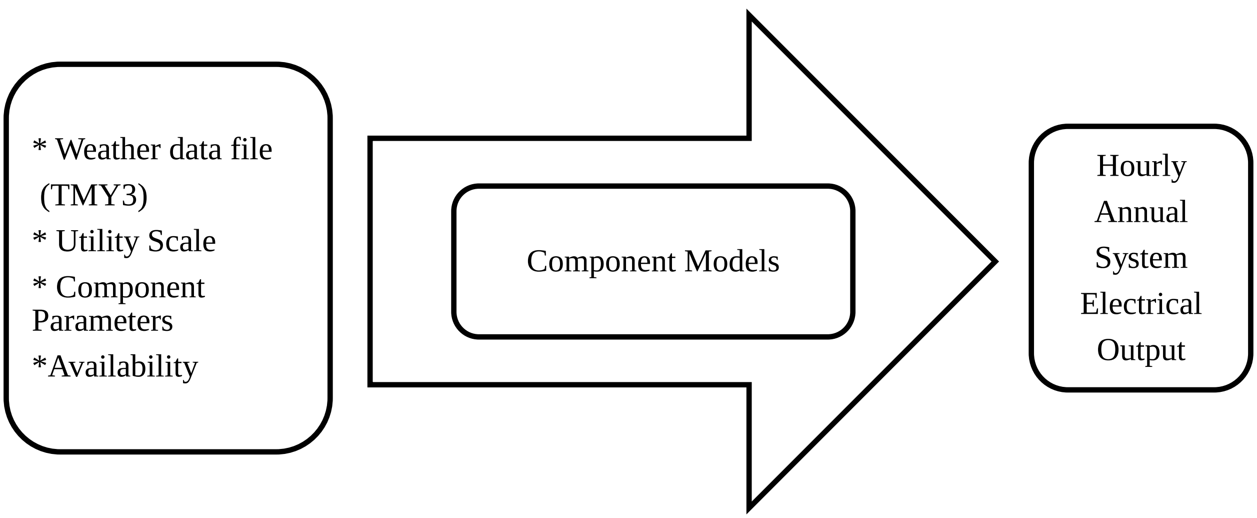

Figure 4-2 Performance Modeling Overview

4.1.1 Performance Inputs

As seen is Figure 4-2 the weather file, component parameters, and availability are the inputs of the performance model. Performance inputs are discussed in this section.

4.1.1.1 Weather file

SAM requires the weather file to be in Meteorological Year 3 (TMY3) format. TMY3s are data sets of hourly values of solar radiation and meteorological elements for a 1year period.

The processed solar radiation data in TMY3 format is used as the weather file input for each location.

4.1.1.2 Component Parameters

Separate components models for the parabolic collector, receiver, Stirling engine, and the parasitic power are used. These models are described in Appendix C. The models can be interchanged to have different manufacturers for every component. Another option is to input custom variables for every parameter that are not characteristic of a specific system. Tables 4-1, 4-2, 4-3 and 4-4 show the parameters for the collector, receiver, stirling engine and parasitic loss respectively. The values on these tables are from the SunCatcher, the Dish/Stiling system used in this thesis project [**45**].

Table 4-1 Collector Parameter Values (SES)

Parameter	Units
Projected Mirror Area	87.7 m^2
Total Mirror Area	91 m^2
Insolation Cut In	200 W/m^2
Wind Stow Speed	16 m/s
Receiver Aperture Diameter for Reference	0.184 m
Reference Intercept Factor	0.995
Reference Focal Length of Mirror	7.45 m

Table 4-2 Receiver Parameter Values (SES)

Parameter	Units
Absorber Absorptance	0.9
Absorber Surface Area	0.6 m^2
Cavity Wall Absorptance	0.6
Cavity Wall Surface Area	0.6 m^2
Internal Diameter of the Cavity Perpendicular to the Receiver Aperture	0.46 m
Internal Depth of the Cavity Perpendicular to the Aperture	0.46 m
Receiver Insulation Thickness	0.075 m
Insulation Thermal Conductivity	0.06 W/mK
Delta Temp. for DIR Receiver	90° Kelvin

Table 4-3 Stirling Engine Parameter Values (SES)

Parameter	Units
Heater Head Set Temperature	993° Kelvin
Heater Head Lowest Temperature	973° Kelvin
Engine Operating Speed	1800 rpm
Displaced Engine Volume	$3.80 \times 10^{-4}\ m^3$
Beale Constant Coefficient	4.247×10^{-2}
Beale First-order Coefficient	1.682×10^{-5}
Beale Second-order Coefficient	-5.105×10^{-10}
Beale Third-order Coefficient	7.07260×10^{-15}
Beale Fourth-order Coefficient	-3.586×10^{-20}
Pressure Constant Coefficient	6.58769×10^{-1}
Pressure First-order Coefficient	2.34963×10^{-4}

Table 4-4 Parasitic Loss Parameter Values (SES)

Parameter	Units
Pump Parasitic Power	150 W
Pump Speed	1800 rpm
Cooling Fluid Type	50% EG
Cooling Fluid Temperature	288 °Kelvin
Cooling Fluid Volumetric Flow Rate	9 gal/min
Cooling System Fan Test Power	1000 W
Cooling System Fan Test Speed	890 rpm
Fan Air Density	1.2 kg/m3
Fan Volumetric Flow Rate	6000 CFM

4.1.1.3 Availability (%)

The availability factor accounts for downtimes due to forced and scheduled outages. SAM suggests 96 % of availability for Dish/Stirling systems [**9**]. Therefore, an availability rate of 96% is chosen for both lacations.

4.1.2 Component Models

The performance model runs hourly simulations to calculate the sum of simulation values. That is the system's total annual electrical output equal to the sum of the values calculated by the performance model (8,760 values for hourly simulations). For these simulations mathematical models for every component of the Dish/Stirling system (i.e. collector, receiver, stirling engine, generator) are used [**32**]. The component models are presented in Appendix C.

4.1.3 Performance Results

The performance model results are the annual hourly energy values for every year of the analysis period. SAM adjusts that value of Year-One as described below using the availability to account for expected system downtime for maintenance, and degradation of system performance over time.

For year one, the performance model calculates the total annual energy by:

$$Total\ energy\ in\ year\ one\ =\ Sum\ of\ \ Simulation\ Values\ x\ Availability \tag{4.1}$$

For Years 2 and later:

$$Energy\ in\ Year\ n>1\ =\ Energy\ in\ Year\ n-1\ \times\ \left(1\ -\ Degradation\ Rate\right) \qquad (4.2)$$

Where,

Energy in Year n-1 is the previous year's energy value (with the year-one value adjusted by the availability factor).

4.2 Financial Model

The financial model calculates the project's annual cash flows for each year of the analysis period specified. The commercial Power Purchase Agreement (PPA) is the financial structure used. The inputs, results and the PPA itself are discussed in this chapter. Figure 4-3 shows an overview of the financial modeling process.

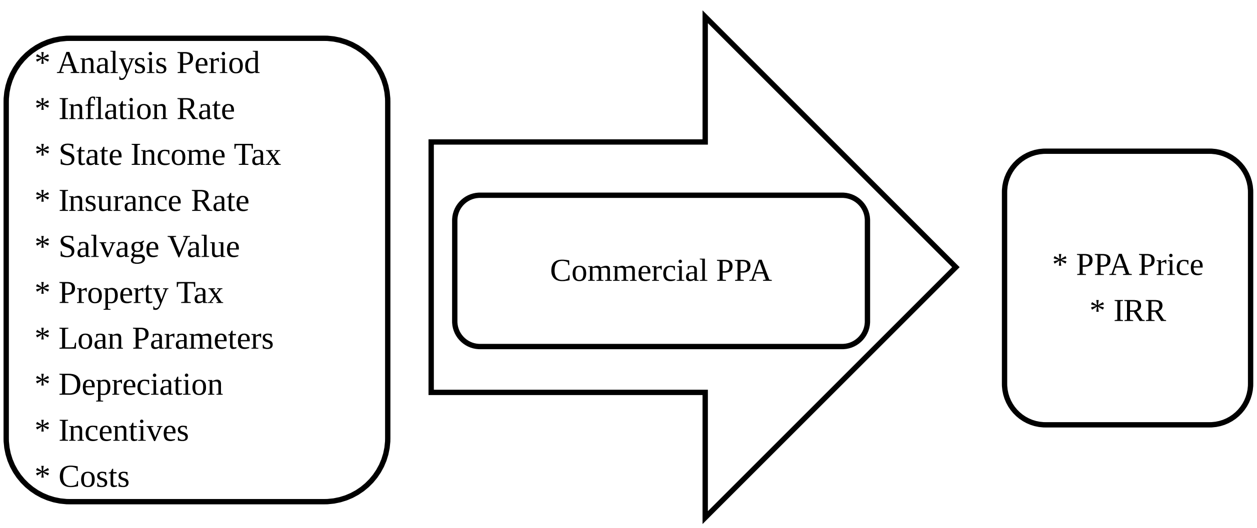

Figure 4-3 Financial Modeling Overview

4.2.1 Financial Parameters

The financial parameters considered in the financial model are discussed in this section.

4.2.1.1 Analysis Period

It is the number of years covered by the analysis. The analysis period determines the number of years in the project cash flow.

The design life of the SunCatcher's is 30 years [**8**]. Therefore, a 30 years analysis period is chosen for both locations.

4.2.1.2 Inflation Rate

Costs and revenues can be expressed either in "current" or "future" money. Current money cash flows will change over time because of inflation (or deflation). Therefore, the inflation rate is the annual rate of change of costs.

An inflation rate of 3.6% is chosen for Puerto Rico. This value is the average inflation rate for 2011 [**46**].

An inflation rate of 6.2% is chosen for the Dominican Republic. This value is the average inflation rate from 2001 to 2011 [**46**].

4.2.1.3 State Tax

State tax refers to the direct tax levied on the profits made by the project.

Law 73 classifies a CPS project as a novel pioneering activity in Puerto Rico. The clause (3) of section (3) of this law fixes the state income tax at 1% [**47**].

Law 57-17 excludes renewable energy projects from state income tax for the first 10 years in the Dominican Republic [**48**]. After the first 10 years the state income tax is fixed to 25%.

4.2.1.4 Sales Tax

Both Puerto Rico and the Dominican Republic have 100 % exemption of sales taxes for renewable energy projects. This is stated in the law 248 for Puerto Rico [**49**], and in law 57-17 for the Dominican Republic [**48**].

4.2.1.5 Insurance

This is the annual insurance rate and it applies to the total installed cost of the project.

SAM uses 1 % insurance rate as the default value for Dish/Stirling systems. We believe this to be a realistic cost. Therefore, 1% insurance rate is selected for both locations.

4.2.1.6 Salvage Value

The salvage value is a project income in the final year of the project cash flow, and is a percentage of the total installed cost of the project.

For example, if you specify a 10% salvage value for a project with a 30-year analysis period, and total installed cost of $1 million, an income in Year 30 of $100,000 = $1,000,000 × 0.10 is included.

SAM uses 10 % salvage value as the default for Dish/Stirling systems. We selected 10 % salvage value for both locations.

4.2.1.7 Property Tax

Property tax is a levy on property that the owner is required to pay. The tax is levied by the governing authority of the jurisdiction in which the property is located.

Law 248 determines an exemption of 100 % from property taxes for solar and renewable energy equipment in Puerto Rico [**49**].

Law 11-92 determines a 1% property tax rate for the Dominican Republic [**50**].

4.2.1.8 Loan Parameters

Debt Fraction - percentage of the total installed cost to be borrowed. The debt fraction assumed for both locations is 80%.

Loan Term- number of years required to repay a loan. The loan term assumed for both locations is 20 years.

Loan Rate- the annual loan interest rate. The loan rate for renewable energy projects is fixed at 5% in the Dominican Republic by Law 57-17. For Puerto Rico the loan rate is assumed to be 7%.

4.2.1.9 Depreciation

The depreciation inputs represent the decrease in value of project assets over the analysis period. Depreciation reduces the state taxable income by adding the depreciation as an expense of the project.

5-Year Modified Accelerated Cost Recovery System (MACRS)

5-Year (MACRS) is the depreciation method used in Puerto Rico. The MACRS establishes prescribed depreciation rates, called recovery allowance percentages, for all assets within a specified class. Table 4.5 shows the MACRS depreciation schedule with it recovery allowance percentages.

Table 4-5 5-Year MACRS Depreciation Schedule

Year	Recovery Allowance Percentage
1	20%
2	32%
3	19.20%
4	11.52%
5	11.52%

Straight Line Depreciation

The straight-line is the depreciation method used in the Dominican Republic. It assumes that a constant amount is depreciated each year over the life of the asset. The Annual Depreciation Deduction (ADD) percentage is calculated dividing the value to be depreciated by the analysis period:

$$ADD = [(Total\ installed\ costs\ - SV_N)\ /\ Analysis\ period]\ \% \qquad (4.3)$$

Where,

SV_N, is the salvage value of the project.

The straight line depreciation schedule is 3% for every year of the project life for Santo Domingo.

4.2.2 Incentives

Puerto Rico - Renewable Energy Certificates (RECs)

The emission trading system used in Puerto Rico is the renewable energy certificates (RECs). Renewable energy providers get issued one REC for each 1,000 kWh of energy it produces. Entities required to comply with a Renewable Portfolio Standard (RPS) from other states or companies with corporate social responsibility can buy RECs from green energy sources in Puerto Rico [**51**]. REC prices will fluctuate according to demand and supply dynamics of the RPS Compliance Market. Figure 4-4 shows the variation of RECs prices in the compliance market from January 2008 to January 2012.

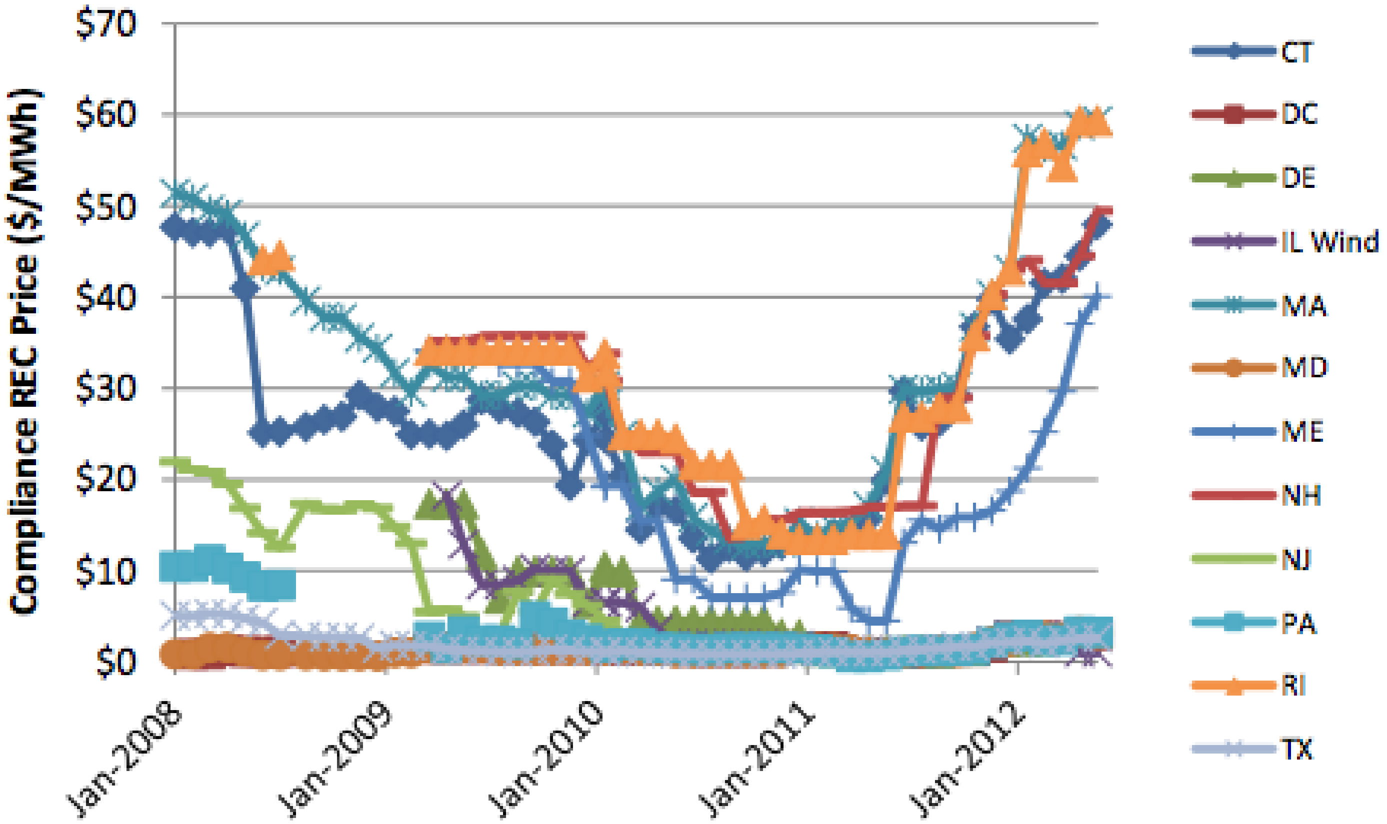

Figure 4-4 REC Price Chart [**52**]

The average RECs price from all states is 15 $/MWh [**52**]. Therefore, a production based incentive of 15 $/MWh with the same escalation rate as the inflation rate of Puerto Rico is chosen.

Dominican Republic

Although the Dominican Republic in part of the Kyoto protocol agreement, there is no emission trading system in place.

4.2.3 Costs

In this section the system costs, the operation and maintenance costa, and the land costs are discussed.

4.2.3.1 System Costs

The values of the system costs used in this work are from SAM's default data. These cost default data are meant to be realistic. The system costs are the same for both locations.

Site Improvements ($/$m^2$) - Account for expenses related to site preparation. Site improvement costs are 20 $/$m^2$.

Collector Cost (Projected Area) ($/$m^2$) - Account for expenses related to installation of the collectors, including labor and equipment. Collector costs are 400 $/$m^2$.

Receiver Cost ($/kW) - Account for expenses related to installation of the receiver, including labor and equipment. Receiver costs are 250 $/kW.

Stirling Engine Cost ($/kW) - Account for expenses related to installation of the Stirling engine components, including labor and equipment. Stlirng engine costs are $500 per kW of engine rated capacity.

Contingency (%) – The percentage of the sum of the site improvements and power plant costs to account for expected uncertainties in direct cost estimates. Contingency value is 7%

4.2.3.2 Operation and Maintenance Costs

Operation and Maintenance (O&M) costs represent annual expenditures on equipment and services that occur after the system is installed. O&M costs is a fixed annual cost proportional to rated or nameplate capacity of the system. An O&M cost of 65 $/kW-yr is selected for both locations.

4.2.3.3 Land Costs

Costs associated with land purchases. Land cost is calculated by averaging the price per acre of three properties for sale in October 2012. The price of these properties was obtained in the websites of real estate companies engaged in each location.

A Land cost of $96,000 per acre is used for Juana Diaz [**53**]. Land cost of $144,000 per acre is used for Santo Domingo [**54**].

4.2.4 Summary of the Financial Parameters for both Locations

Tables 4-7 and 4-8 summarize the financial parameters used in Base Case I for Juana Diaz and Santo Domingo respectively. While Tables 4-9 and 4-10 summarize the financial parameters used in Base Case II for Juana Diaz and Santo Domingo respectively.

Table 4-6 Financial Parameters for Juana Diaz (Base Case)

Financial Parameters	Juana Díaz Values
General	
Analysis Period	30
Inflation Rate	3.60%
Taxes and Insurance	
State Tax	1.00%
Property Tax	0.00%
Insurance	1.00%
Loan	
Loan (Debt) Percent	80.00%
Term	20
Rate	7 %
Depreciation	
Type	5-year MACRS
Salvage Value	
Net Salvage Value	10.00%
Power Purchase Agreement	
PPA Escalation	Inflation Rate

Table 4-7 Financial Parameters for Santo Domingo (Base Case)

Financial Parameters	Santo Domingo Values
General	
Analysis Period	30
Inflation Rate	6.20%
Taxes and Insurance	
State Tax	25%
Property Tax	1.00%
Insurance	1.00%
Loan	
Loan (Debt) Percent	80.00%
Term	20
Rate	5%
Depreciation	
Type	Straight Line
Salvage Value	
Net Salvage Value	10.00%
Power Purchase Agreement	
PPA Escalation	Inflation Rate

4.3 Power Purchase Agreement (PPA)

PPA was used as the financing method. PPA projects sell electricity at a price negotiated through a power purchase agreement (PPA). SAM calculates a power purchase price given a target minimum internal rate of return (IRR). PPA calculations are discussed in detail on Appendix D.

4.4 *Base Case Simulations*

The Dish/Stirling power plant feasibility study is sized at 10 MW. The total installed power generation capacity for Puerto Rico is 5365 MW. Total installed power generation for the Dominican Republic is 3,394 MW. Therefore, the relatively small capacity of this Dish/Stirling system eliminates the risks of generation rejection.

An internal rate of return (IRR) of 7% is selected for the base case on both locations. Performance and financial results are presented in this section.

4.4.1 *Base Case Results*

Performance and financial results for the base case scenarios are shown in this section. Performance results consist in two figures, the monthly energy output and the system's electric loss diagram. The financial results are the first year PPA price and cash flows for each location.

4.4.1.1 Performance Model Results (Juana Diaz)

Figure 4-5 shows the monthly energy output for Juana Diaz.

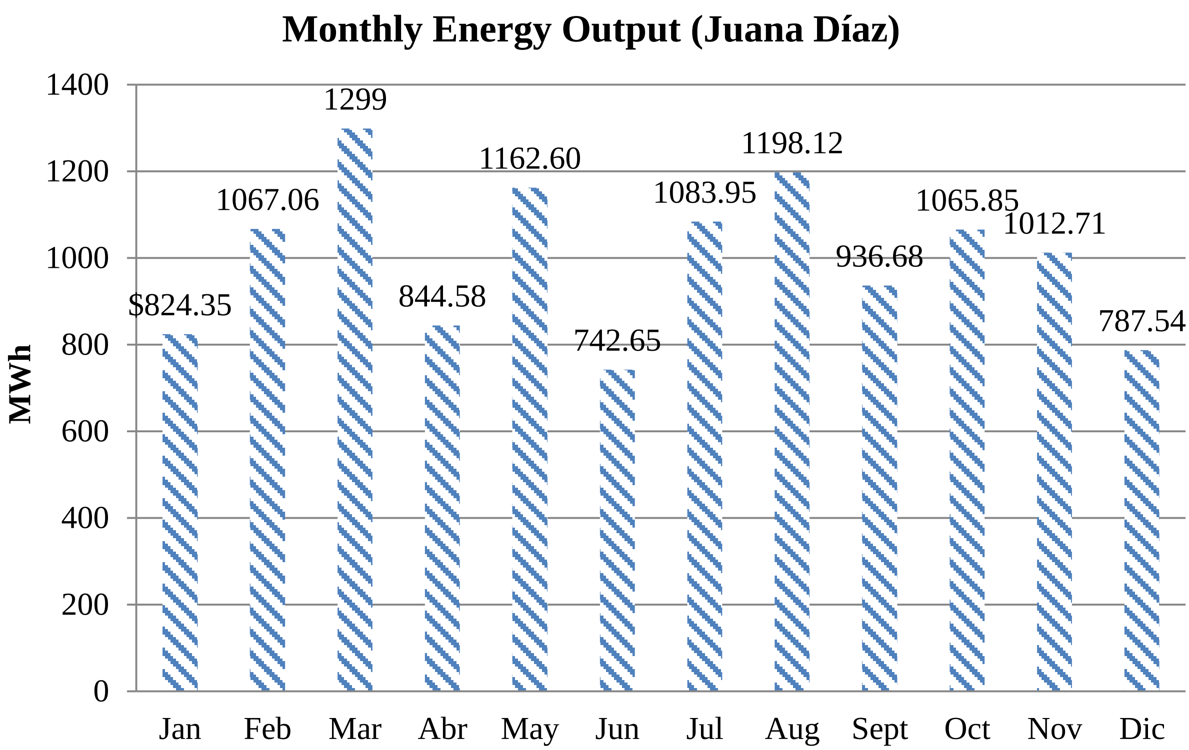

Figure 4-5 Monthly Energy Output (Juana Diaz)

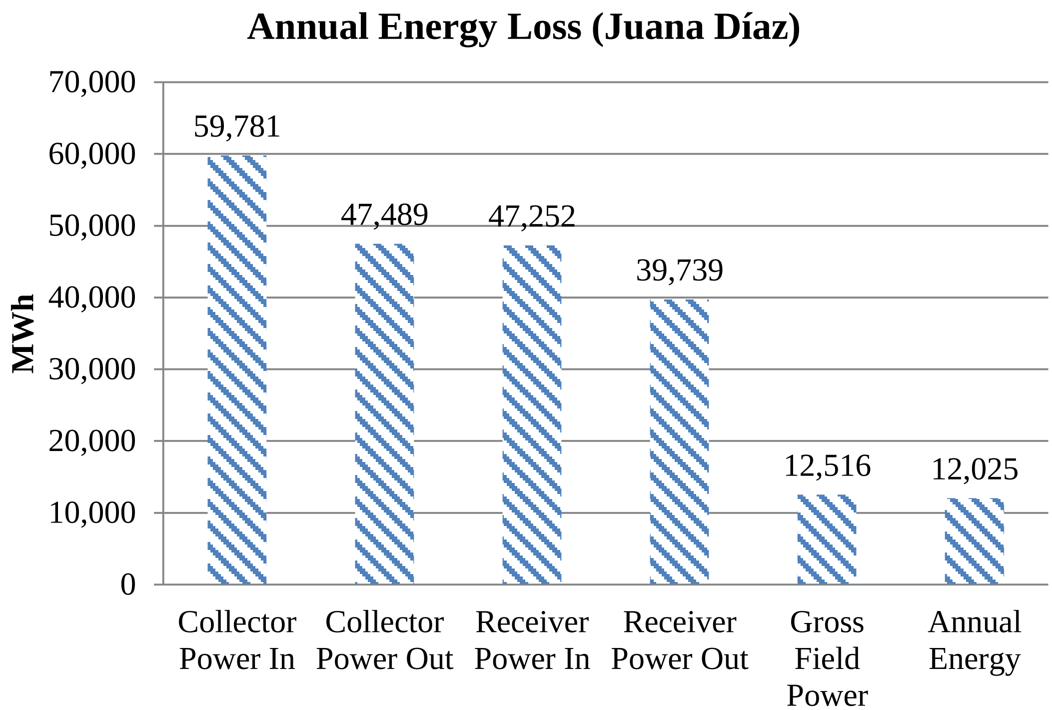

Figure 4-6 Energy Loss (Juana Diaz)

Figure 4-6 shows the energy loss chart for Juana Diaz. The receiver (15.90%) and PCU (68.50%) are the most significant source of energy loss in the system. The overall efficiency of the system is 24.3%.

4.4.1.2 Financial Model Results (Juana Diaz)

The First Year PPA price for Juana Diaz is 20.96 c/kWh. Figure 4-7 shows the Base Case cash flow chart for Juana Diaz. The Base Case cash flow summary is presented below from Table 4-13 to Table 4-17. In this case the project starts to make revenues in the 13th year and break-even in the 23rd year.

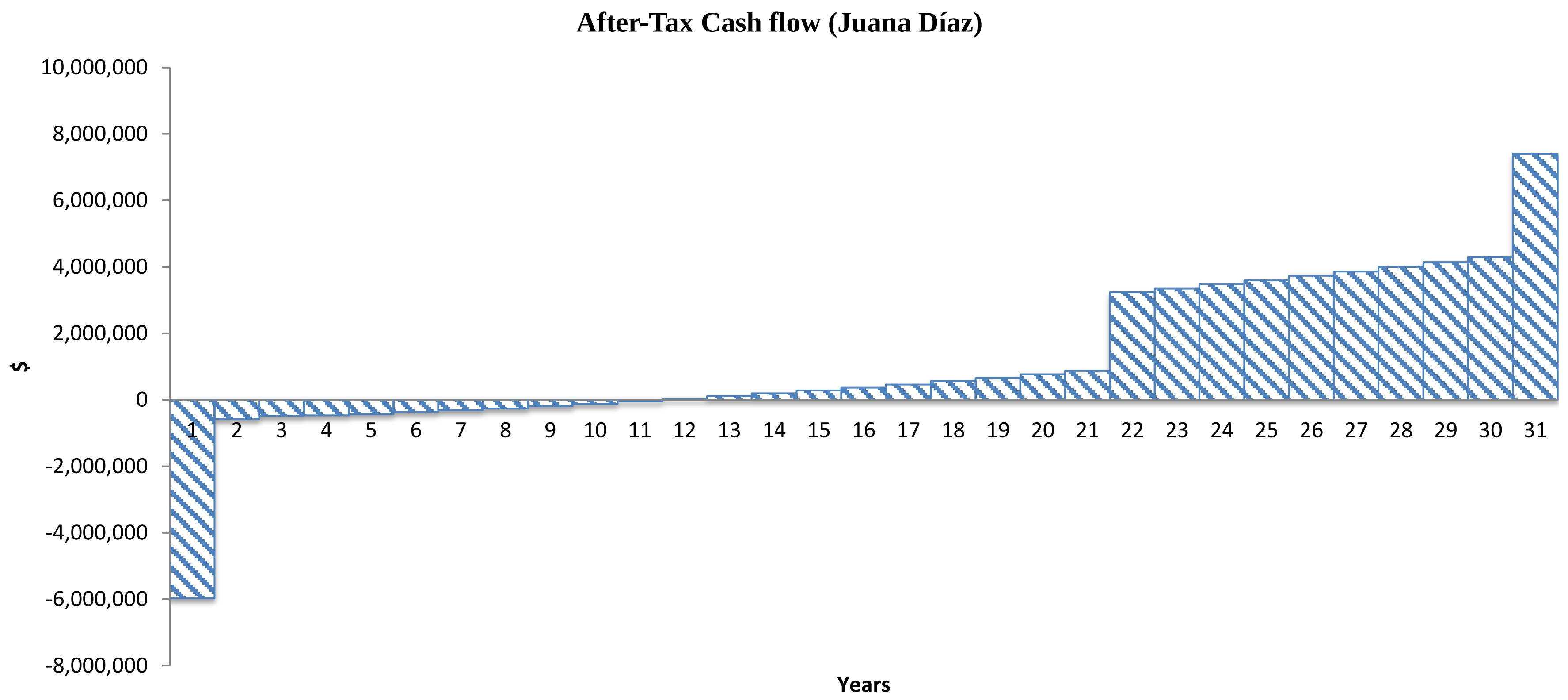

Figure 4-7 Juana Diaz Base Case Cash flow Chart

Table 4-8Juana Diaz Base Case Cash Flow

Year	0	1	2	3	4	5	6
Energy (kWh)	0	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102
Energy Price ($/kWh)	0	0.21	0.217	0.225	0.233	0.241	0.25
Energy Value ($)	0	2,419,616.23	2,506,722.41	2,596,964.42	2,690,455.14	2,787,311.52	2,887,654.74
Fixed O&M	0	650,000	673,400	697,642.40	722,757.53	748,776.80	775,732.76
Variable O&M	0	34,632.31	35,879.07	37,170.72	38,508.86	39,895.18	41,331.41
Insurance	0	298,464.07	309,208.78	320,340.29	331,872.54	343,819.95	356,197.47
Property Assessed Value	0	29,846,406.90	28,951,014.69	28,055,622.48	27,160,230.28	26,264,838.07	25,369,445.86
Property Taxes	0	0	0	0	0	0	0
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	0	983,096.38	1,018,487.84	1,055,153.41	1,093,138.93	1,132,491.93	1,173,261.64
Operating Income	0	1,436,519.85	1,488,234.57	1,541,811.01	1,597,316.21	1,654,819.59	1,714,393.10
Debt Balance	0	-23,877,125.52	-23,294,692.57	-22,671,489.31	-22,004,661.83	-21,291,156.42	-20,527,705.63
Debt Interest Payment	0	1,671,398.79	1,630,628.48	1,587,004.25	1,540,326.33	1,490,380.95	1,436,939.39
Debt Repayment	0	582,432.95	623,203.26	666,827.48	713,505.41	763,450.79	816,892.34
Debt Total Payment	0	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74
RECs	0	173,161.53	179,395.35	185,853.58	192,544.31	199,475.90	206,657.03
State Depreciation Schedule (%)	0	20	32	19.2	11.52	11.52	5.76
State Depreciation	0	5,969,281.38	9,550,850.21	5,730,510.12	3,438,306.07	3,438,306.07	1,719,153.04
State Income Taxes	0	-60,309.99	-95,138.49	-55,898.50	-31,887.72	-30,743.92	-12,350.42
State Tax Savings	0	60,309.99	95,138.49	55,898.50	31,887.72	30,743.92	12,350.42
After Tax Cashflow	-5,969,281.38	-583,840.36	-491,063.33	-470,268.65	-432,083.50	-368,792.33	-320,431.18

Table 4-9 Juana Diaz Base Case Cash Flow II

Year	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Energy (kWh)	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102
Energy Price ($/kWh)	0.259	0.268	0.278	0.288	0.299	0.309	0.32
Energy Value ($)	2,991,610.31	3,099,308.28	3,210,883.38	3,326,475.18	3,446,228.29	3,570,292.50	3,698,823.04
Fixed O&M	803,659.14	832,590.87	862,564.14	893,616.45	925,786.64	959,114.96	993,643.10
Variable O&M	42,819.34	44,360.83	45,957.82	47,612.31	49,326.35	51,102.10	52,941.77
Insurance	369,020.58	382,305.32	396,068.31	410,326.77	425,098.54	440,402.08	456,256.56
Property Assessed Value	24,474,053.65	23,578,661.45	22,683,269.24	21,787,877.03	20,892,484.83	19,997,092.62	19,101,700.41
Property Taxes	0	0	0	0	0	0	0
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	1,215,499.06	1,259,257.03	1,304,590.28	1,351,555.53	1,400,211.53	1,450,619.14	1,502,841.43
Operating Income	1,776,111.25	1,840,051.25	1,906,293.10	1,974,919.65	2,046,016.76	2,119,673.36	2,195,981.60
Debt Balance	-19,710,813.29	-18,836,738.49	-17,901,478.44	-16,900,750.20	-15,829,970.98	-14,684,237.21	-13,458,302.08
Debt Interest Payment	1,379,756.93	1,318,571.69	1,253,103.49	1,183,052.51	1,108,097.97	1,027,896.60	942,081.15
Debt Repayment	874,074.81	935,260.04	1,000,728.24	1,070,779.22	1,145,733.77	1,225,935.13	1,311,750.59
Debt Total Payment	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74
RECs	214,096.69	221,804.17	229,789.12	238,061.53	246,631.74	255,510.48	264,708.86
State Depreciation Schedule (%)	0	0	0	0	0	0	0
State Depreciation	0	0	0	0	0	0	0
State Income Taxes	6,104.51	7,432.84	8,829.79	10,299.29	11,845.51	13,472.87	15,186.09
State Tax Savings	-6,104.51	-7,432.84	-8,829.79	-10,299.29	-11,845.51	-13,472.87	-15,186.09
After Tax Cashflow	-269,728.31	-199,409.15	-126,579.31	-51,149.84	26,971.26	107,879.24	191,672.64

Table 4-10 Juana Diaz Base Case Cash Flow III

Year	14	15	16	17	18	19	20
Energy (kWh)	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102
Energy Price ($/kWh)	0.332	0.344	0.356	0.369	0.382	0.396	0.41
Energy Value ($)	3,831,980.66	3,969,931.97	4,112,849.52	4,260,912.10	4,414,304.94	4,573,219.92	4,737,855.83
Fixed O&M	1,029,414.25	1,066,473.17	1,104,866.20	1,144,641.38	1,185,848.47	1,228,539.02	1,272,766.42
Variable O&M	54,847.68	56,822.19	58,867.79	60,987.03	63,182.56	65,457.14	67,813.59
Insurance	472,681.79	489,698.34	507,327.48	525,591.27	544,512.55	564,115.01	584,423.15
Property Assessed Value	18,206,308.21	17,310,916	16,415,523.79	15,520,131.59	14,624,739.38	13,729,347.17	12,833,954.97
Property Taxes	0	0	0	0	0	0	0
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	1,556,943.72	1,612,993.70	1,671,061.47	1,731,219.68	1,793,543.59	1,858,111.16	1,925,003.16
Operating Income	2,275,036.94	2,356,938.27	2,441,788.05	2,529,692.42	2,620,761.35	2,715,108.75	2,812,852.67
Debt Balance	-12,146,551.49	-10,742,978.36	-9,241,155.10	-7,634,204.23	-5,914,766.79	-4,074,968.72	-2,106,384.80
Debt Interest Payment	850,258.60	752,008.48	646,880.86	534,394.30	414,033.68	285,247.81	147,446.94
Debt Repayment	1,403,573.13	1,501,823.25	1,606,950.88	1,719,437.44	1,839,798.06	1,968,583.93	2,106,384.80
Debt Total Payment	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74	2,253,831.74
RECs	274,238.38	284,110.96	294,338.96	304,935.16	315,912.82	327,285.69	339,067.97
State Depreciation Schedule (%)	0	0	0	0	0	0	0
State Depreciation	0	0	0	0	0	0	0
State Income Taxes	16,990.17	18,890.41	20,892.46	23,002.33	25,226.40	27,571.47	30,044.74
State Tax Savings	-16,990.17	-18,890.41	-20,892.46	-23,002.33	-25,226.40	-27,571.47	-30,044.74
After Tax Cashflow	278,453.42	368,327.09	461,402.81	557,793.51	657,616.03	760,991.24	868,044.17

Table 4-11 Juana Diaz Base Case Cash Flow IV

Year	21	22	23	24	25	26	27
Energy (kWh)	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102	11,544,102
Energy Price ($/kWh)	0.425	0.44	0.456	0.473	0.49	0.507	0.526
Energy Value ($)	4,908,418.64	5,085,121.71	5,268,186.09	5,457,840.79	5,654,323.06	5,857,878.69	6,068,762.33
Fixed O&M	1,318,586.01	1,366,055.11	1,415,233.09	1,466,181.49	1,518,964.02	1,573,646.72	1,630,298.01
Variable O&M	70,254.88	72,784.06	75,404.29	78,118.84	80,931.12	83,844.64	86,863.05
Insurance	605,462.38	627,259.03	649,840.35	673,234.60	697,471.05	722,580.01	748,592.89
Property Assessed Value	11,938,562.76	11,043,170.55	10,147,778.34	9,252,386.14	8,356,993.93	7,461,601.72	6,566,209.52
Property Taxes	0	0	0	0	0	0	0
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	1,994,303.28	2,066,098.20	2,140,477.73	2,217,534.93	2,297,366.19	2,380,071.37	2,465,753.94
Operating Income	2,914,115.36	3,019,023.52	3,127,708.36	3,240,305.87	3,356,956.88	3,477,807.32	3,603,008.39
Debt Balance	0	0	0	0	0	0	0
Debt Interest Payment	0	0	0	0	0	0	0
Debt Repayment	0	0	0	0	0	0	0
Debt Total Payment	0	0	0	0	0	0	0
RECs	351,274.42	363,920.30	377,021.43	390,594.20	404,655.59	419,223.19	434,315.23
State Depreciation Schedule (%)	0	0	0	0	0	0	0
State Depreciation	0	0	0	0	0	0	0
State Income Taxes	32,653.90	33,829.44	35,047.30	36,309	37,616.12	38,970.31	40,373.24
State Tax Savings	-32,653.90	-33,829.44	-35,047.30	-36,309	-37,616.12	-38,970.31	-40,373.24
After Tax Cashflow	3,232,735.89	3,349,114.38	3,469,682.49	3,594,591.06	3,723,996.34	3,858,060.21	3,996,950.38

Table 4-12 Juana Diaz Base Case Cash Flow V

Year	28	29	30
Energy (kWh)	11,544,102	11,544,102	11,544,102
Energy Price ($/kWh)	0.545	0.564	0.585
Energy Value ($)	6,287,237.77	6,513,578.33	6,748,067.15
Fixed O&M	1,688,988.73	1,749,792.33	1,812,784.85
Variable O&M	89,990.12	93,229.76	96,586.03
Insurance	775,542.23	803,461.75	832,386.37
Property Assessed Value	5,670,817.31	4,775,425.10	3,880,032.90
Property Taxes	0	0	0
Net Salvage Value	0	0	2,984,640.69
Total Operating Expenses	2,554,521.08	2,646,483.84	-242,883.43
Operating Income	3,732,716.69	3,867,094.49	6,990,950.58
Debt Balance	0	0	0
Debt Interest Payment	0	0	0
Debt Repayment	0	0	0
Debt Total Payment	0	0	0
RECs	449,950.58	466,148.80	482,930.15
State Depreciation Schedule (%)	0	0	0
State Depreciation	0	0	0
State Income Taxes	41,826.67	43,332.43	74,738.81
State Tax Savings	-41,826.67	-43,332.43	-74,738.81
After Tax Cashflow	4,140,840.59	4,289,910.85	7,399,141.93

4.4.1.3 Performance Model Results (Santo Domingo)

Figure 4-8 shows the monthly energy output for Juana Diaz.

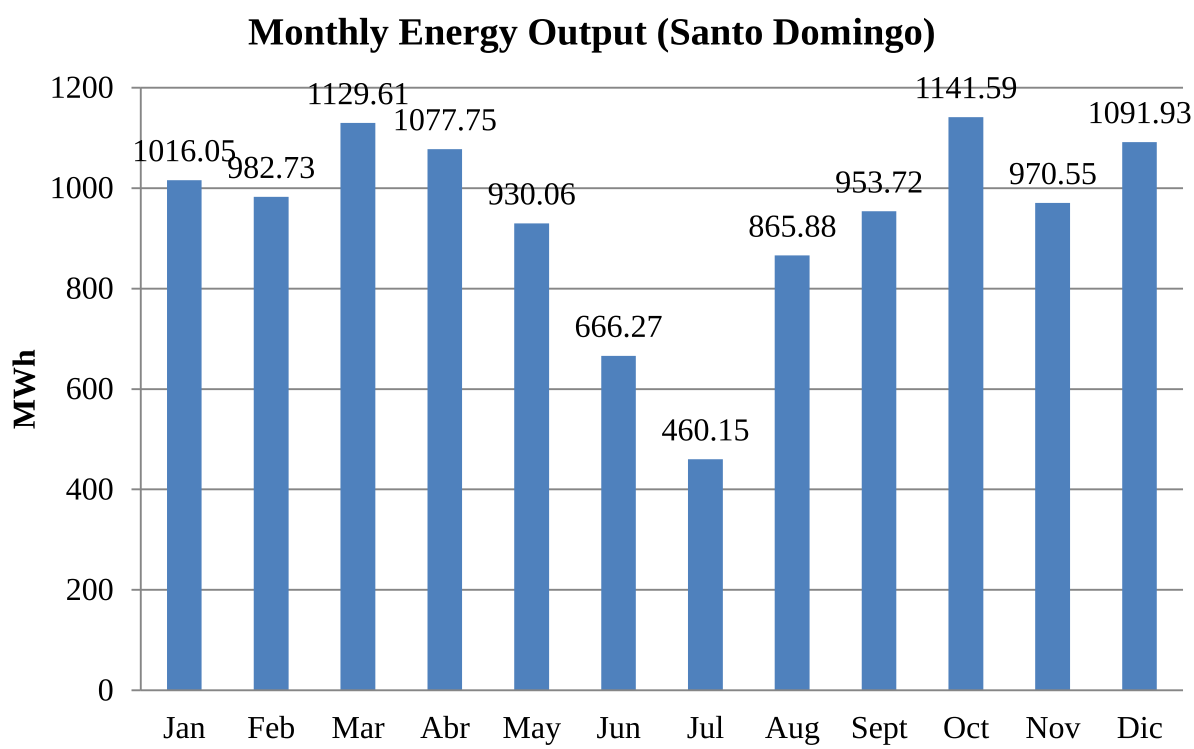

Figure 4-8 Monthly Energy Output (Santo Domingo)

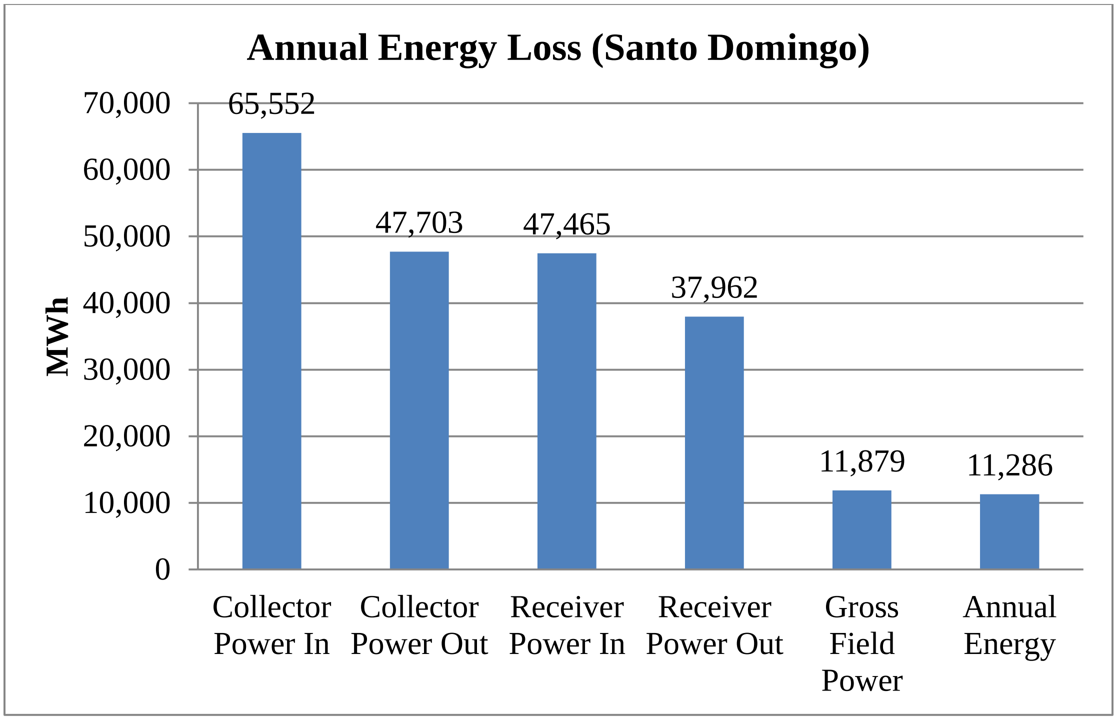

Figure 4-9 Energy Loss (Santo Domingo)

Figure 4-9 shows the energy loss chart for Santo Domingo. The receiver (20.02%) PCU (68.71%) are the most significant source of energy loss in the system. The overall efficiency of the system is 22.87%.

4.4.1.4 Financial Model Results (Santo Domingo)

The First Year PPA price for Juana Diaz is 20.59 c/kWh. Figure 4-10 shows the Base Case cash flow chart for Juana Diaz. The Base Case cash flow summary is presented below from Table 4-19 to Table 4-23. In this case the project starts to make revenues in the 13th year and break-even in the 23rd year.

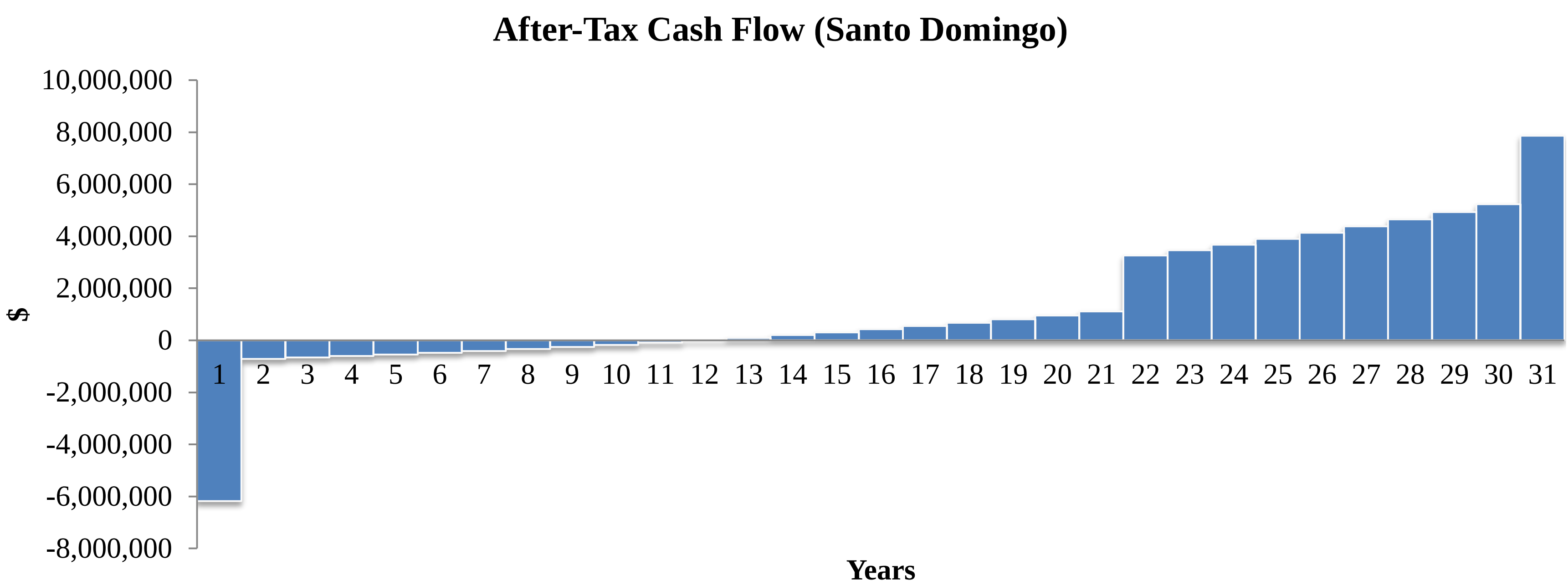

Figure 4-10 Santo Domingo Base Case Cash flow Chart

Table 4-13 Santo Domingo Base Case Cash Flow I

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Energy (kWh)	0	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817
Energy Price ($/kWh)	0	0.206	0.219	0.232	0.247	0.262	0.278
Energy Value ($)	0	2,231,009.19	2,369,331.76	2,516,230.33	2,672,236.61	2,837,915.28	3,013,866.02
Fixed O&M	0	650,000	690,300	733,098.60	778,550.71	826,820.86	878,083.75
Variable O&M	0	32,504.45	34,519.73	36,659.95	38,932.87	41,346.70	43,910.20
Insurance	0	309,139.02	328,305.64	348,660.59	370,277.55	393,234.76	417,615.31
Property Assessed Value	0	30,913,902.14	29,986,485.08	29,059,068.02	28,131,650.95	27,204,233.89	26,276,816.82
Property Taxes	0	309,139.02	299,864.85	290,590.68	281,316.51	272,042.34	262,768.17
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	0	1,300,782.49	1,352,990.22	1,409,009.82	1,469,077.64	1,533,444.65	1,602,377.43
Operating Income	0	930,226.70	1,016,341.54	1,107,220.51	1,203,158.97	1,304,470.62	1,411,488.60
Debt Balance	0	-24,731,121.72	-23,983,188.61	-23,197,858.85	-22,373,262.60	-21,507,436.54	-20,598,319.18
Debt Interest Payment	0	1,236,556.09	1,199,159.43	1,159,892.94	1,118,663.13	1,075,371.83	1,029,915.96
Debt Repayment	0	747,933.10	785,329.76	824,596.25	865,826.06	909,117.36	954,573.23
Debt Total Payment	0	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19
State Depreciation Schedule (%)	0	3	3	3	3	3	3
State Depreciation	0	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40
State Income Taxes	0	0.00	0.00	0.00	0.00	0.00	0.00
State Tax Savings	0	0.00	0.00	0.00	0.00	0.00	0.00
After Tax Cashflow	-6,182,780.43	-720,064.30	-664,827.33	-606,484.72	-544,838.33	-479,677.42	-410,777.90

Table 4-14 Santo Domingo Base Case Cash Flow II

Year	7	8	9	10	11	12	13
Energy (kWh)	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817
Energy Price ($/kWh)	0.295	0.314	0.333	0.354	0.376	0.399	0.424
Energy Value ($)	3,200,725.72	3,399,170.71	3,609,919.30	3,833,734.29	4,071,425.82	4,323,854.22	4,591,933.18
Fixed O&M	932,524.94	990,341.49	1,051,742.66	1,116,950.71	1,186,201.65	1,259,746.15	1,337,850.41
Variable O&M	46,632.63	49,523.85	52,594.33	55,855.18	59,318.20	62,995.93	66,901.68
Insurance	443,507.46	471,004.92	500,207.23	531,220.07	564,155.72	599,133.37	636,279.64
Property Assessed Value	25,349,399.76	24,421,982.69	23,494,565.63	22,567,148.57	21,639,731.50	20,712,314.44	19,784,897.37
Property Taxes	253,494	244,219.83	234,945.66	225,671.49	216,397.32	207,123.14	197,848.97
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	1,676,159.03	1,755,090.09	1,839,489.88	1,929,697.45	2,026,072.89	2,128,998.60	2,238,880.71
Operating Income	1,524,566.69	1,644,080.62	1,770,429.42	1,904,036.84	2,045,352.93	2,194,855.62	2,353,052.47
Debt Balance	-19,643,745.95	-18,641,444.05	-17,589,027.07	-16,483,989.23	-15,323,699.50	-14,105,395.28	-12,826,175.86
Debt Interest Payment	982,187.30	932,072.20	879,451.35	824,199.46	766,184.97	705,269.76	641,308.79
Debt Repayment	1,002,301.89	1,052,416.99	1,105,037.84	1,160,289.73	1,218,304.22	1,279,219.43	1,343,180.40
Debt Total Payment	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19
State Depreciation Schedule (%)	3	3	3	3	3	3	3
State Depreciation	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40
State Income Taxes	0	0.00	0.00	0.00	0.00	114,780.61	170,320.07
State Tax Savings	0	0.00	0.00	0.00	0.00	-114,780.61	-170,320.07
After Tax Cashflow	-337,901.50	-260,794.82	-179,188.44	-92,795.84	-1,312.40	95,585.81	198,243.21

Table 4-15 Santo Domingo Base Case Cash Flow III

Year	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Energy (kWh)	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817
Energy Price ($/kWh)	0.45	0.478	0.508	0.539	0.573	0.608	0.646
Energy Value ($)	4,876,633.04	5,178,984.29	5,500,081.31	5,841,086.35	6,203,233.71	6,587,834.20	6,996,279.92
Fixed O&M	1,420,797.14	1,508,886.56	1,602,437.53	1,701,788.66	1,807,299.55	1,919,352.13	2,038,351.96
Variable O&M	71,049.58	75,454.66	80,132.85	85,101.08	90,377.35	95,980.75	101,931.55
Insurance	675,728.98	717,624.18	762,116.88	809,368.12	859,548.95	912,840.98	969,437.12
Property Assessed Value	18,857,480.31	17,930,063.24	17,002,646.18	16,075,229.11	15,147,812.05	14,220,394.99	13,292,977.92
Property Taxes	188,574.80	179,300.63	170,026.46	160,752.29	151,478.12	142,203.95	132,929.78
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	2,356,150.51	2,481,266.03	2,614,713.72	2,757,010.15	2,908,703.97	3,070,377.80	3,242,650.41
Operating Income	2,520,482.53	2,697,718.26	2,885,367.60	3,084,076.20	3,294,529.74	3,517,456.40	3,753,629.51
Debt Balance	-11,482,995.46	-10,072,656.04	-8,591,799.65	-7,036,900.45	-5,404,256.28	-3,689,979.90	-1,889,989.71
Debt Interest Payment	574,149.77	503,632.80	429,589.98	351,845.02	270,212.81	184,499	94,499.49
Debt Repayment	1,410,339.42	1,480,856.39	1,554,899.21	1,632,644.17	1,714,276.38	1,799,990.20	1,889,989.71
Debt Total Payment	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19	1,984,489.19
State Depreciation Schedule (%)	3	3	3	3	3	3	3
State Depreciation	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40
State Income Taxes	228,967.34	290,905.51	356,328.55	425,441.94	498,463.38	575,623.50	657,166.65
State Tax Savings	-228,967.34	-290,905.51	-356,328.55	-425,441.94	-498,463.38	-575,623.50	-657,166.65
After Tax Cashflow	307,026	422,323.55	544,549.85	674,145.07	811,577.17	957,343.71	1,111,973.66

Table 4-16 Santo Domingo Base Case Cash Flow IV

Year	21	22	23	24	25	26	27
Energy (kWh)	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817	10,834,817
Energy Price ($/kWh)	0.686	0.728	0.773	0.821	0.872	0.926	0.984
Energy Value ($)	7,430,049.27	7,890,712.33	8,379,936.49	8,899,492.56	9,451,261.09	10,037,239.28	10,659,548.12
Fixed O&M	2,164,729.78	2,298,943.03	2,441,477.49	2,592,849.10	2,753,605.74	2,924,329.30	3,105,637.71
Variable O&M	108,251.31	114,962.89	122,090.59	129,660.20	137,699.14	146,236.48	155,303.15
Insurance	1,029,542.22	1,093,373.84	1,161,163.02	1,233,155.13	1,309,610.75	1,390,806.61	1,477,036.62
Property Assessed Value	12,365,560.86	11,438,143.79	10,510,726.73	9,583,309.66	8,655,892.60	7,728,475.54	6,801,058.47
Property Taxes	123,655.61	114,381.44	105,107.27	95,833.10	86,558.93	77,284.76	68,010.58
Net Salvage Value	0	0	0	0	0	0	0
Total Operating Expenses	3,426,178.92	3,621,661.19	3,829,838.37	4,051,497.53	4,287,474.55	4,538,657.15	4,805,988.07
Operating Income	4,003,870.35	4,269,051.13	4,550,098.12	4,847,995.03	5,163,786.54	5,498,582.13	5,853,560.05
Debt Balance	0	0	0	0	0	0	0
Debt Interest Payment	0	0	0	0	0	0	0
Debt Repayment	0	0	0	0	0	0	0
Debt Total Payment	0	0	0	0	0	0	0
State Depreciation Schedule (%)	3	3	3	3	3	3	3
State Depreciation	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40	1,030,463.40
State Income Taxes	743,351.74	809,646.93	879,908.68	954,382.91	1,033,330.78	1,117,029.68	1,205,774.16
State Tax Savings	-743,351.74	-809,646.93	-879,908.68	-954,382.91	-1,033,330.78	-1,117,029.68	-1,205,774.16
After Tax Cashflow	3,260,518.62	3,459,404.20	3,670,189.44	3,893,612.12	4,130,455.76	4,381,552.45	4,647,785.89

Table 4-17 Santo Domingo Base Case Cash Flow V

Year	**28**	**29**	**30**
Energy (kWh)	10,834,817	10,834,817	10,834,817
Energy Price ($/kWh)	1.045	1.11	1.178
Energy Value ($)	11,320,440.10	12,022,307.39	12,767,690.44
Fixed O&M	3,298,187.25	3,502,674.86	3,719,840.70
Variable O&M	164,931.94	175,157.72	186,017.50
Insurance	1,568,612.89	1,665,866.89	1,769,150.64
Property Assessed Value	5,873,641.41	4,946,224.34	4,018,807.28
Property Taxes	58,736.41	49,462.24	40,188.07
Net Salvage Value	0	0	3,091,390.21
Total Operating Expenses	5,090,468.50	5,393,161.72	2,623,806.70
Operating Income	6,229,971.60	6,629,145.67	10,143,883.74
Debt Balance	0	0	0
Debt Interest Payment	0	0	0
Debt Repayment	0	0	0
Debt Total Payment	0	0	0
State Depreciation Schedule (%)	3	3	3
State Depreciation	1,030,463.40	1,030,463.40	1,030,463.40
State Income Taxes	1,299,877.05	1,399,670.57	2,278,355.08
State Tax Savings	-1,299,877.05	-1,399,670.57	-2,278,355.08
After Tax Cashflow	4,930,094.55	5,229,475.10	7,865,528.66

4.4.2 DNI vs. Energy Output Comparison

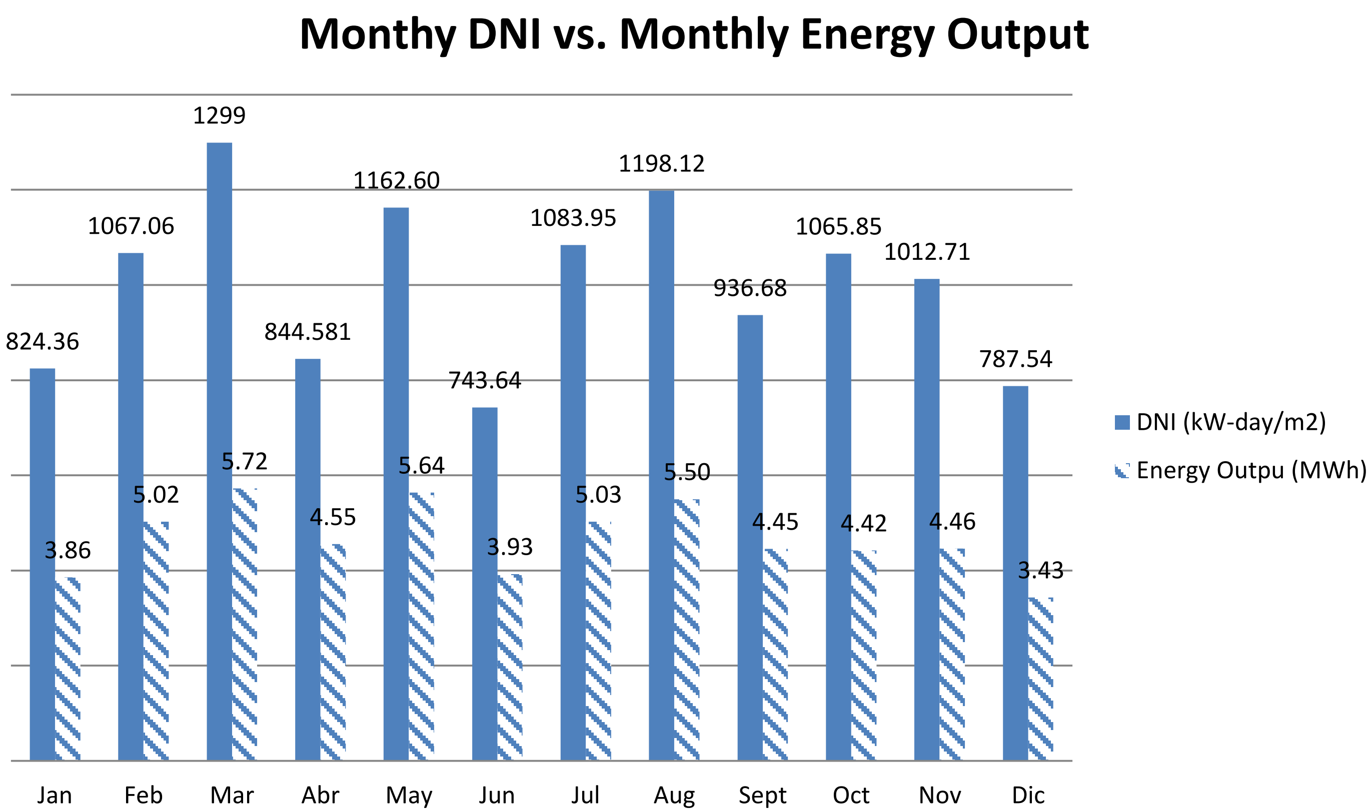

Figure 4-11 Monthly DNI vs. Monthly Energy Output for Juana Diaz

Figure 4-11 presents the monthly DNI vs. monthly energy output for Juana Diaz. The direct relationship between energy production and the amount of direct solar radiation received by the parabolic collector in a Dish/Stirling system is perceived in this bar chart.

4.4.3 Sensitivity Analysis

Single parameter sensitivity analysis is performed for each location. The objective of the sensitivity analysis is to observe how the first year PPA price changes when one of these parameters increases or decreases its value. The variable parameters are the inflation rate, loan parameters, debt fraction, land costs, and RECs (Utility PBI). These variables were selected because of their uncertainty. Figures 4-12 and 4-13 show the results of the sensitivity analysis.

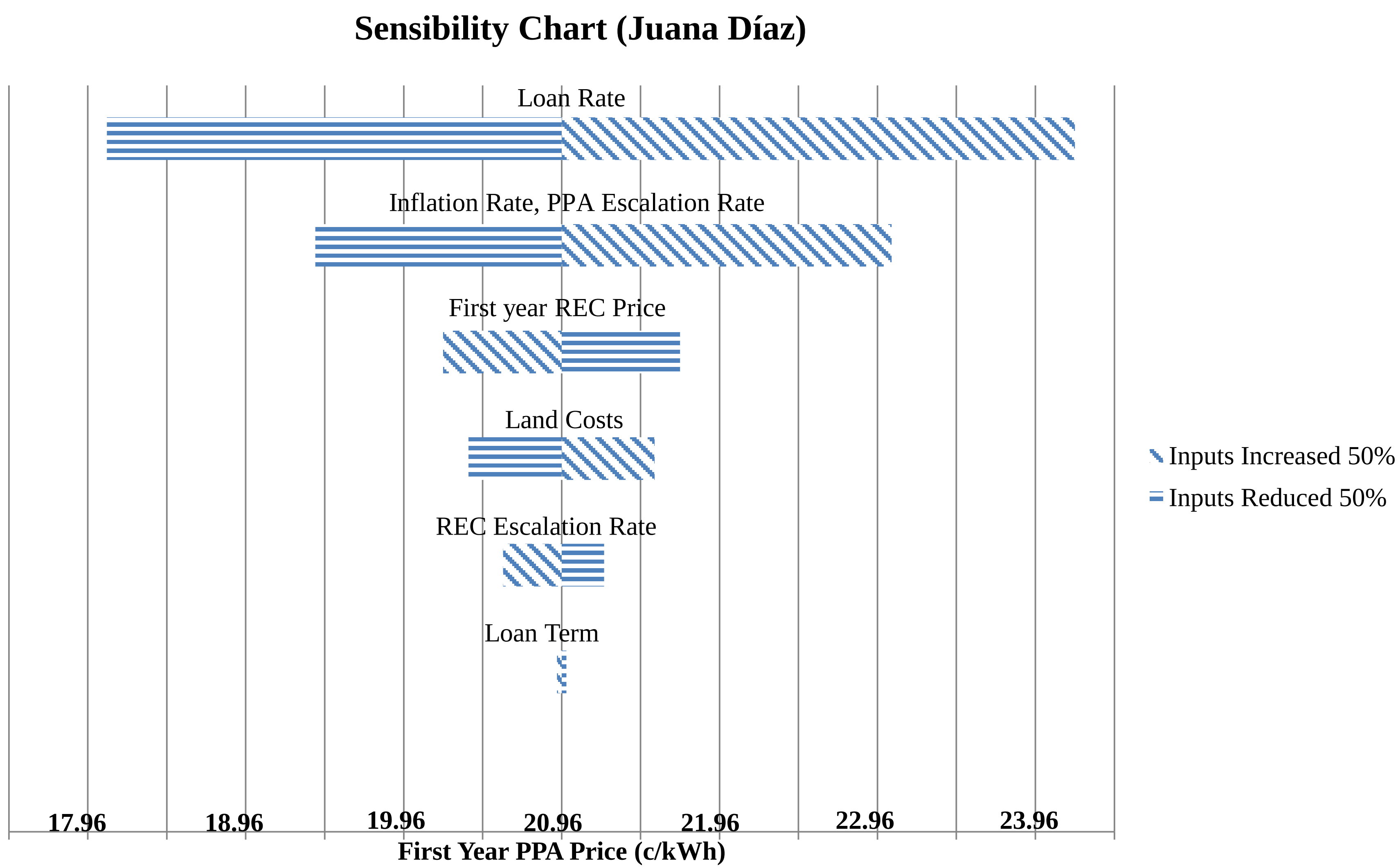

Figure 4-12 Sensitivity Analysis (Juana Diaz)

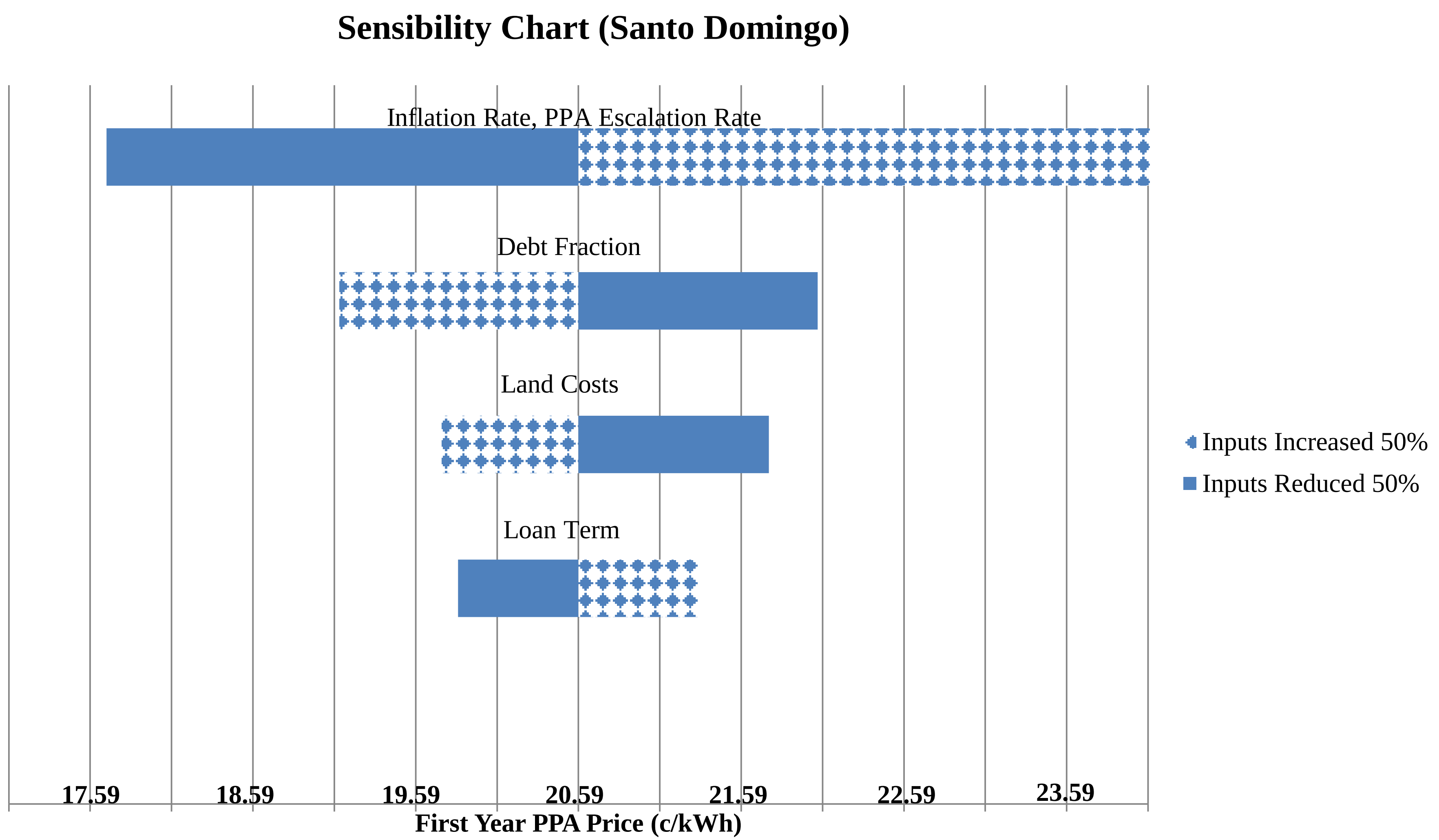

Figure 4-13 Sensitivity Analysis (Santo Domingo)

Figure 4-12 shows that the loan rate, inflation rate, RECs price, land cost and RECs escalation rate are the parameters that most affect the energy price in Juana Diaz. Figure 4-13 shows that the inflation rate, land cost, debt fraction and, loan term are the parameters that most affect the energy price in Santo Domingo.

Figure 4-12 shows the annual loan interest as the value with most influence over Juana Diaz's first year PPA price. However, this parameter is fixed at 5% for Santo Domingo due to law 57-17 [**48**]. This is an example of the power that energy policies can have over the feasibility of renewable energy technologies.

4.4.4 Parametric Analysis

Parametric simulation is performed for each location. The objective of these parametric analysis it to know the first year PPA price for different parameter inputs. The following figures show the result of the parametric analysis.

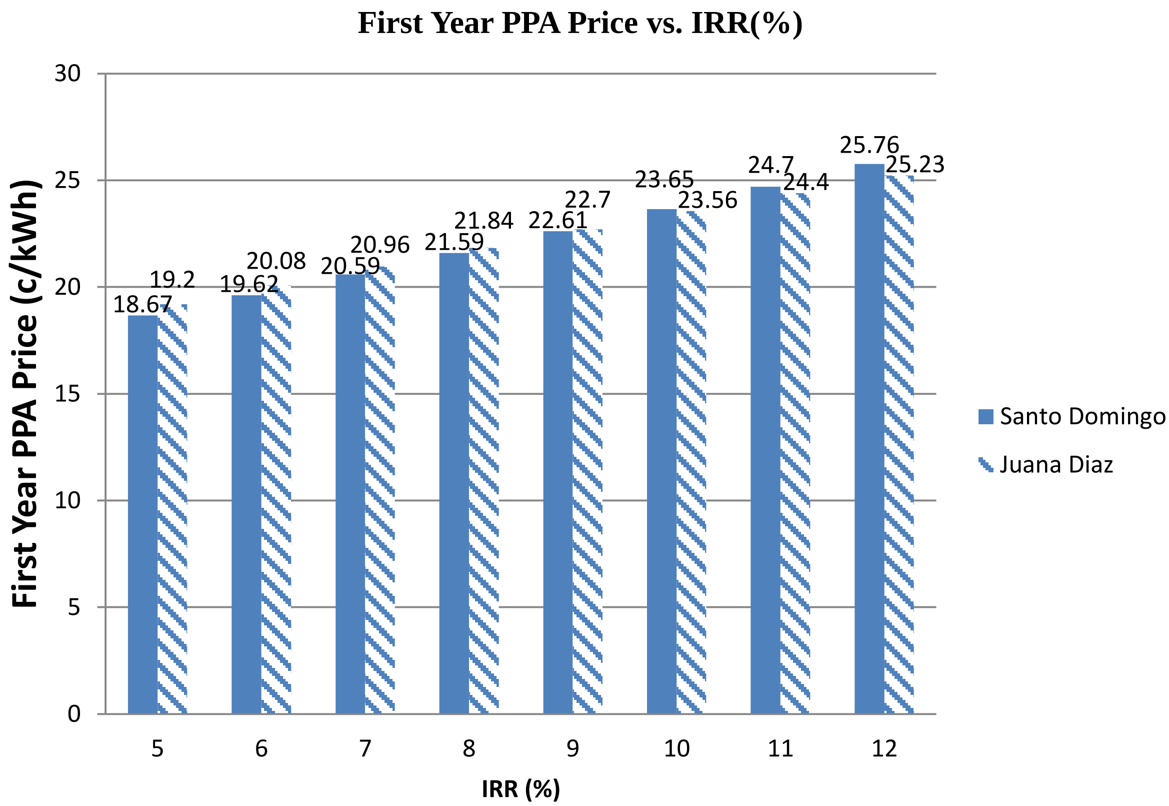

Figure 4-14 First Year PPA vs. IRR (%)

Figure 4-14 shows the first year PPA price for different IRRs. For an IRR of 5% the first year PPA price for Santo Domingo is lower than Juana Diaz's. However, as the IRR increases the price of energy in Santo Domingo increases more rapidly than in Juana Diaz. This phenomenon is due to the large difference in state tax between locations. The state tax for Santo

Domingo and Juana Diaz are 25% and 1% (with incentives), respectively. Penalizing more Santo Domingo's case as the project's owners becomes more ambitious.

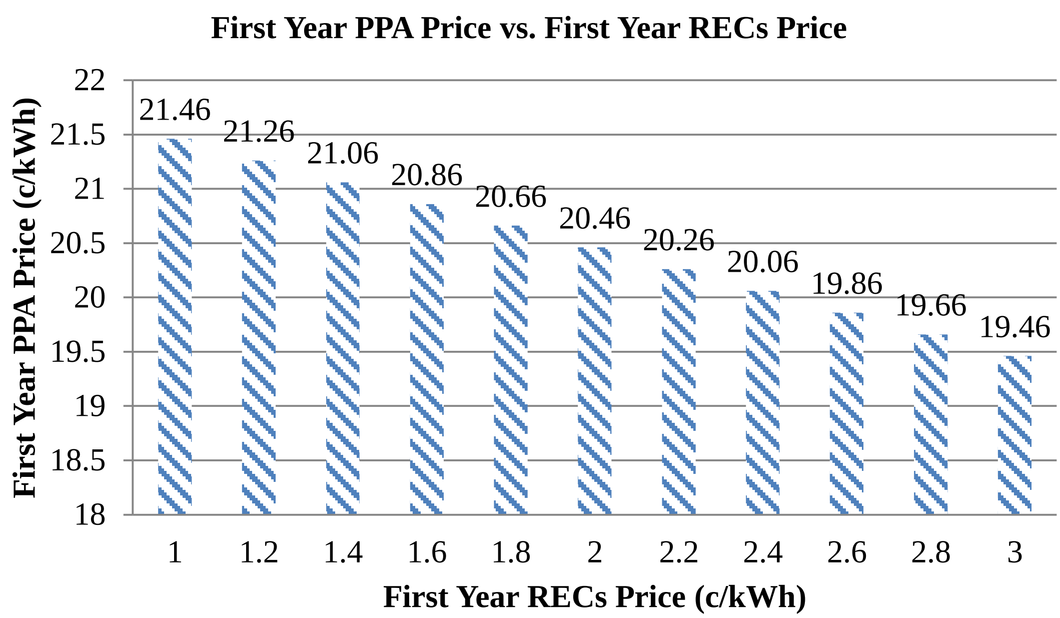

Figure 4-15 First Year PPA Price vs. First Year RECs Price (Juana Díaz)

Figure 4-15 shows the first year PPA price for different RECs prices. This relationship is inversely proportional and the first year PPA price is greatly sensitive to the variation of RECs prices.

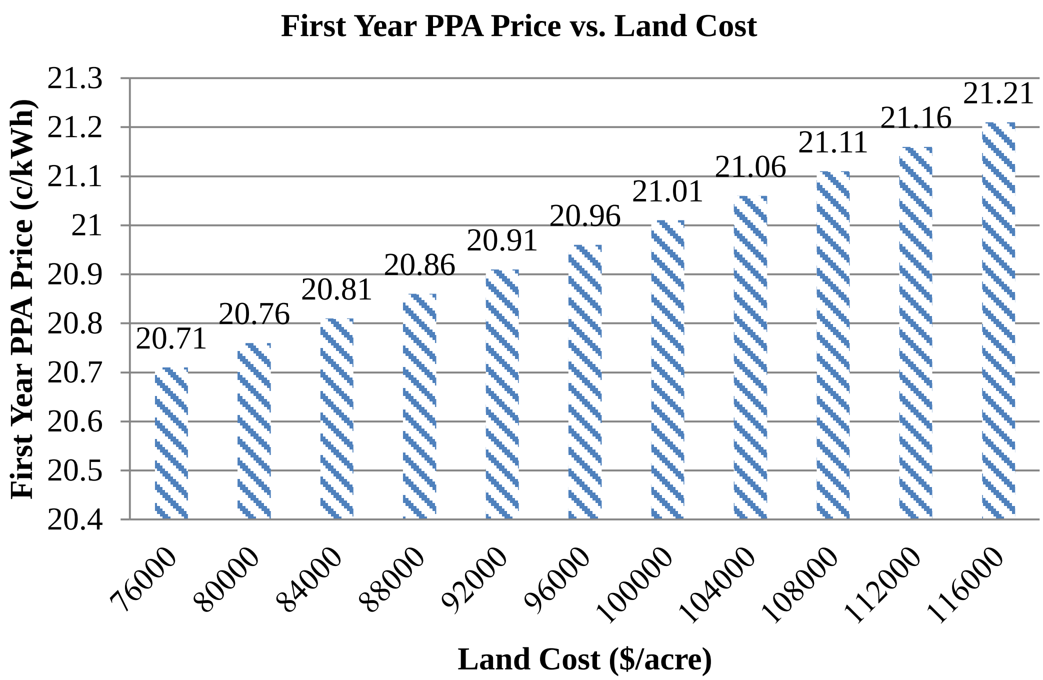

Figure 4-16 First Year PPA Price vs. Land Cost (Juana Diaz)

Figure 4-16 shows the first year PPA price for different land costs in Juana Diaz. This relationship is directly proportional as the first year PPA increases 0.05c/kWh per 4000$/acre increase in land cost. Land cost for Juana Diaz of 96,000 $/acre was chosen by averaging the land cost of 5 farms with similar area (22 acres) of the one needed for the 10 MW Dish/Stirling system.

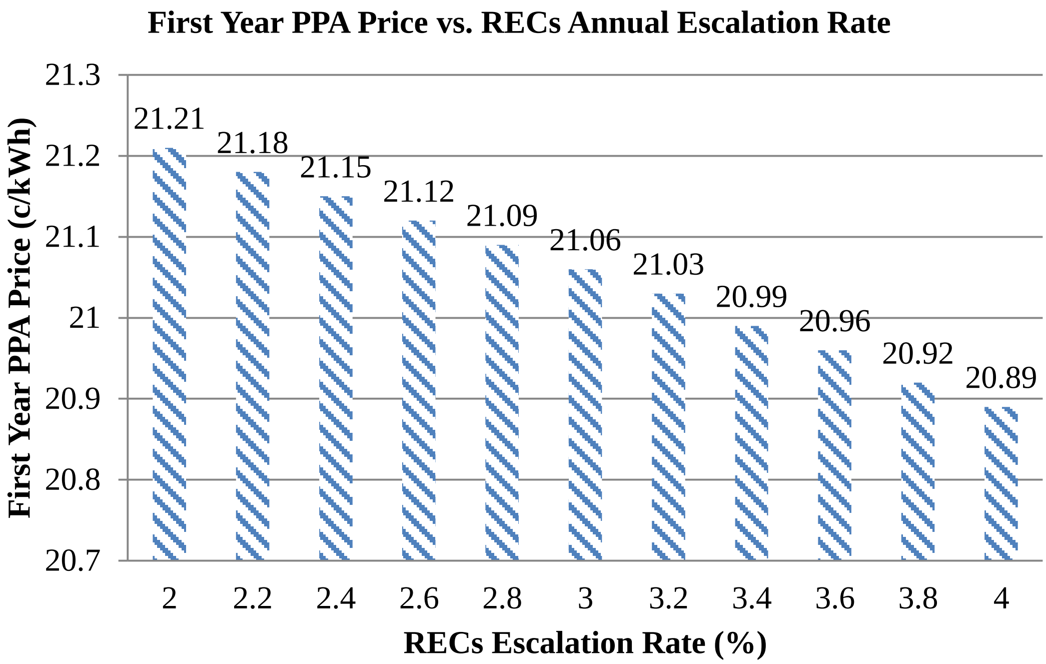

Figure 4-17 First Year PPA Price vs. RECs Annual Escalation Rate (%) (Juana Diaz)

Figure 4-17 shows the first year PPA price for different RECs escalation rate. This relationship is inversely proportional as the first year PPA decreases 0.03c/kWh per 0.2% increase in RECs escalation rate. This value is the same as the inflation rate for the base case scenario. Figure 4-4 shows the variation of RECs prices in the compliance market from January 2008 to January 2012. RECs prices are shown to be very unstable, making the forecast of the escalation rate a difficult task and a concern in the PPA due to their great influence over energy price.

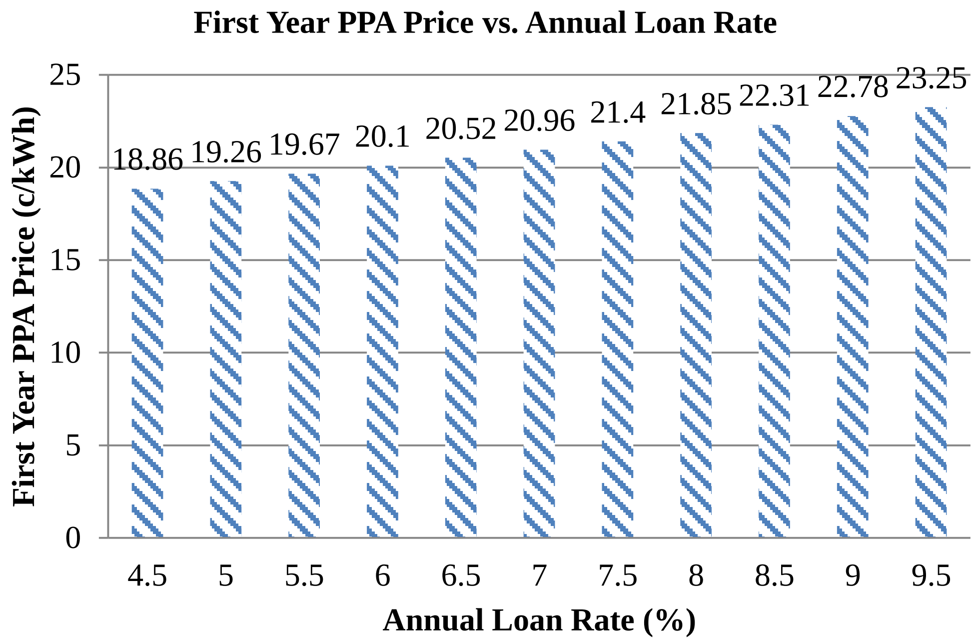

Figure 4-18 First Year PPA Price vs Annual Loan Rate (Juana Diaz)

Figure 4-18 shows the first year PPA price for different annual loan rate percentages in Juana Diaz. This relationship is directly proportional as the first year PPA increases 0.04c/kWh per 0.5% increase in annual loan rate. It should be noted that a parametric analysis was not realized for this parameter for the case of Santo Domingo because this value is fixed at 5% by law 57-17 of renewable incentives in the Dominican Republic [**48**].

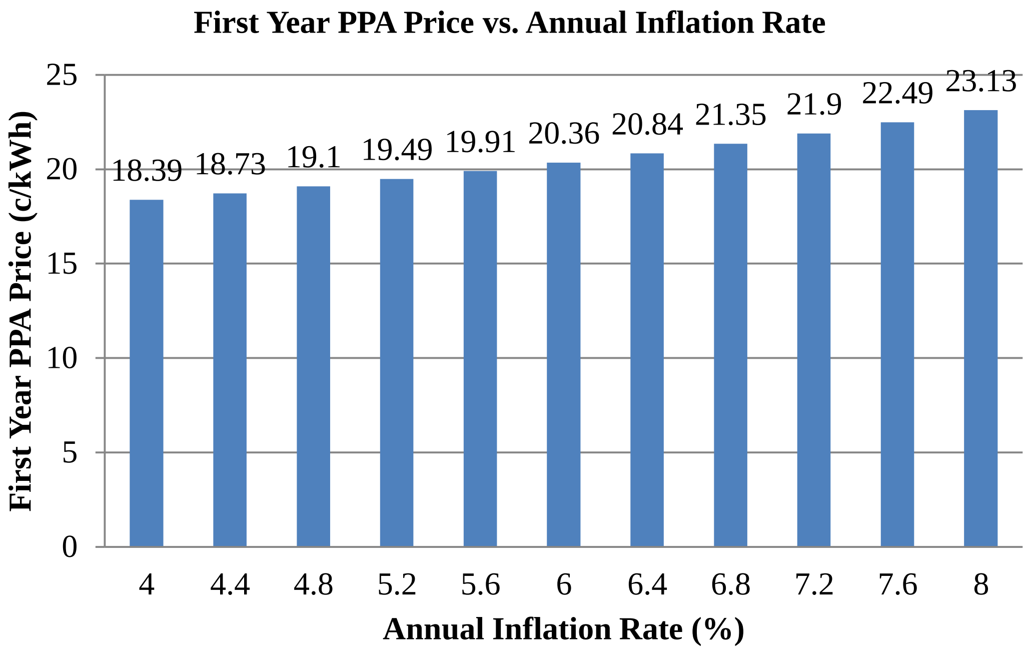

Figure 4-19 First Year PPA Price vs. Annual Inflation Rate (Santo Domingo)

Figure 4-19 shows the first year PPA price for different annual inflation rate percentages in Santo Domingo. This relationship is directly proportional as the first year PPA increases 0.38-0.45c/kWh per 0.4% increase in annual inflation rate. A value of 6.2% inflation rate for the base case scenario was chosen for Santo Domingo by averaging the annual inflation rate from 2000 to 2011.

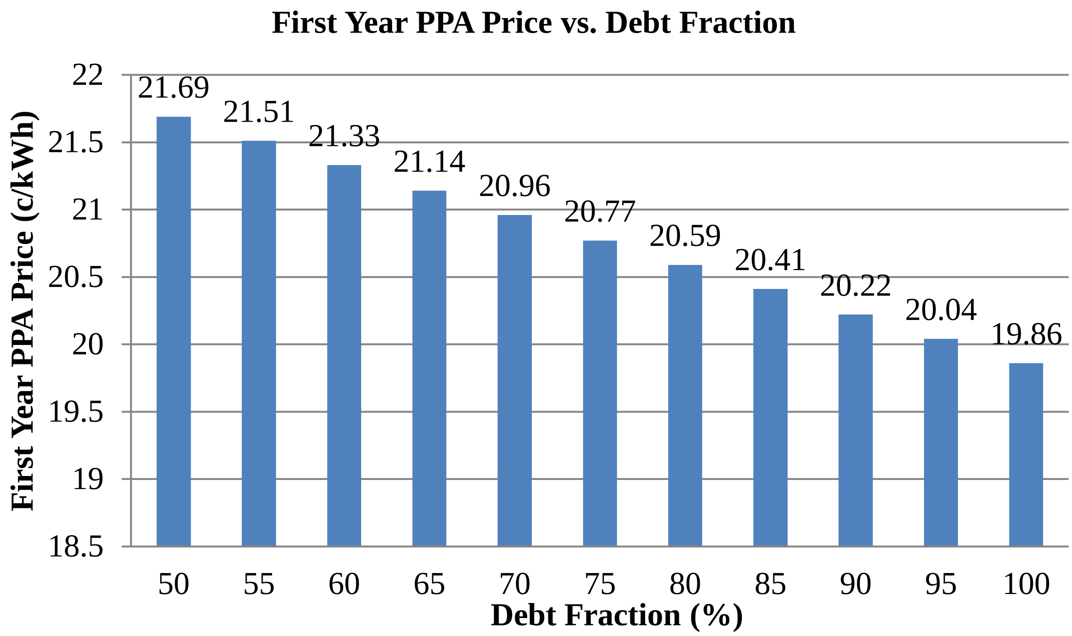

Figure 4-20 First Year PPA Price vs. Debt Fraction (Santo Domingo)

Figure 4-20 shows the first year PPA price for different debt fractions. This relationship is inversely proportional as the first year PPA decreases 0.18-0.19c/kWh per 5% increase in RECs escalation rate. The debt fraction was chosen to be 80% for the base case scenario.

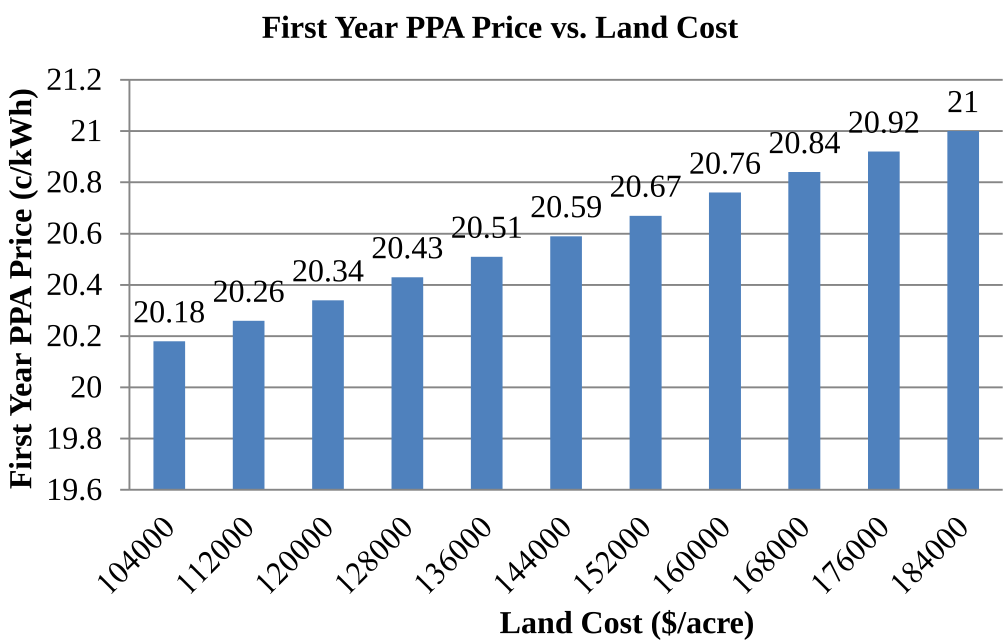

Figure 4-21 First Year PPA Price vs. Land Cost (Santo Domingo)

Figure 4-21 shows the first year PPA price for different land costs in Santo Domingo. This relationship is directly proportional as the first year PPA increases 0.08c/kWh per 8000$/acre increase in land cost. Land cost for Santo Domingo of 144,000 $/acre was chosen by averaging the land cost of 5 farms with similar area (22 acres) of the one needed for the 10 MW Dish/Stirling system.

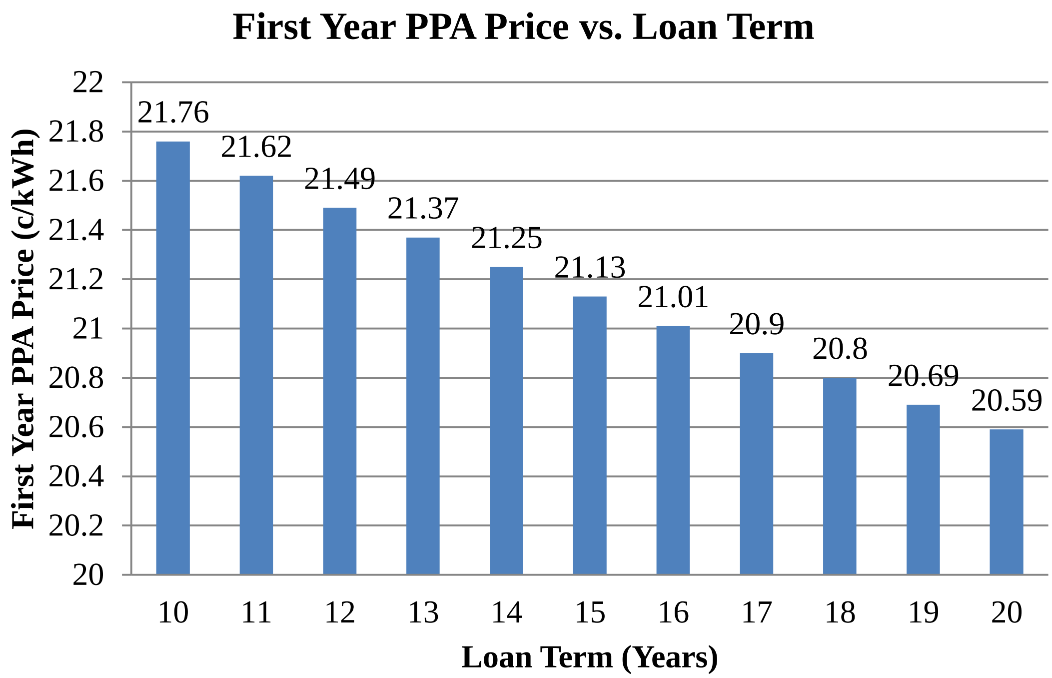

Figure 4-22 First Year PPA Price vs. Loan Term (Santo Domingo)

Figure 4-22 shows the first year PPA price for different loan terms in Santo Domingo. This relationship is inversely proportional as the first year PPA decreases 0.14-0.10c/kWh per 1 year increase in loan term. A 20 year loan term was selected for the base case scenario.

4.5 Monthly Energy Output Comparison

Figure 4-16 shows the monthly energy output comparison between Santo Domingo and Juana Diaz.

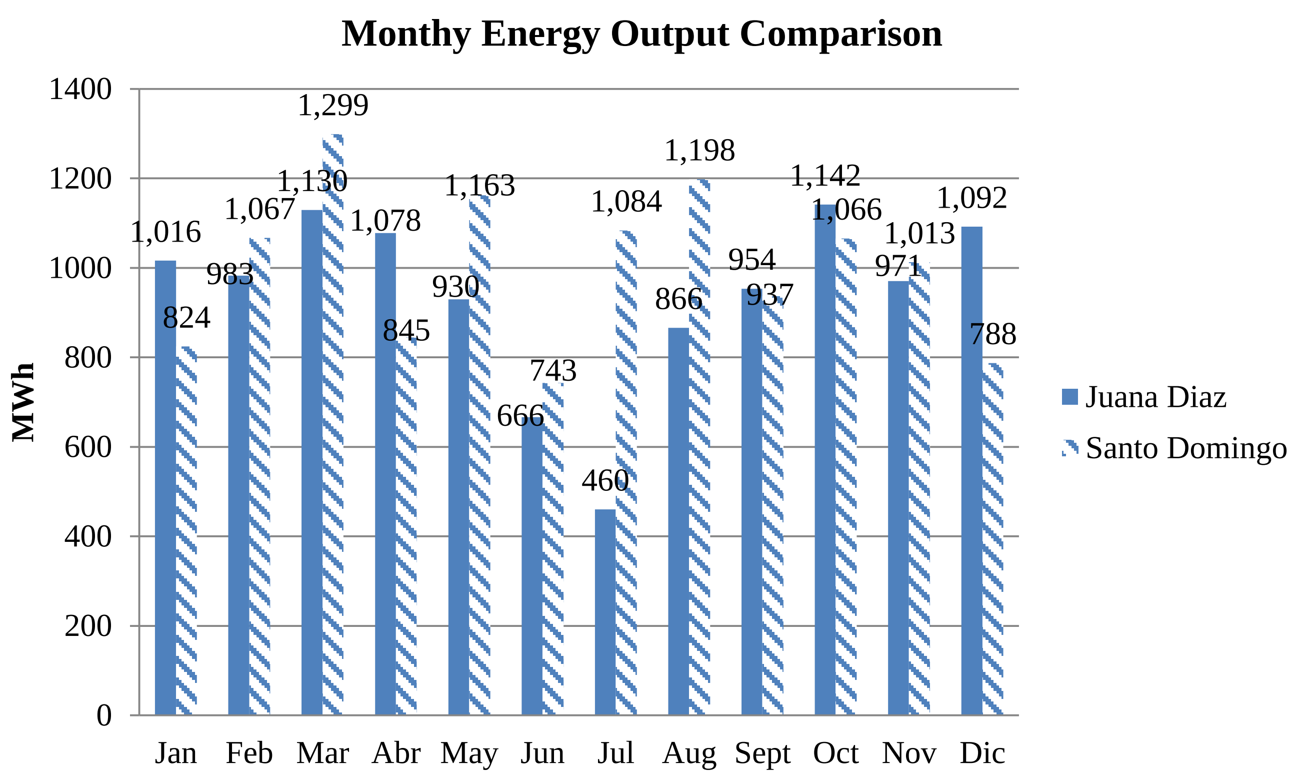

Figure 4-23 Monthly Energy Output Comparison

Figure 4-23 Utilizar figura

4.6 Site Comparison

The proposed system explained above was modeled for San Juan, Roosevelt Roads, Mercedita, Aguadilla and Eugenio Maria de Hostos using solar radiation data in NREL data base [**55**]. The same specifications of the base case scenario were used. Table 4-20 Summarizes the values of net annual energy and the first year PPA price for every location in Puerto Rico. Site comparison could not be done in the Dominican Republic; unfortunately NREL only have solar radiation data for the United States and Puerto Rico.

Table 4-18 Energy Output and First Year PPA Price Comparison from different sites in Puerto Rico

	Juana Diaz	**Aguadilla**	**San Juan**	**Mercedita**	**Roosevelt Roads**	**Eugenio Maria de Hostos**
Net Annual Energy (kWh)	11,544,102	11,732,967	9,323,070	12,115,929	9,082,195	11,668,883
First Year PPA price (¢/kWh)	20.96	20.60	26.24	19.91	26.97	20.72

Table 4-10 show Mercedita and Aguadilla as the sites with better solar resource. Land cost for every site was assumed to be the same as Juana Diaz. The land cost should be adjusted for every location for more accurate first year PPA price.

4.7 *Measured and Modeled Solar Radiation Data Comparison for Santo Domingo*

Solar radiation modeled data set was obtained from a study from 3Tier called ¨Site Climate Variability Analysis 13-Year Record Date from Santo Domingo, Dominican Republic¨ [**40**].This study is based on the past 13+ years (January 1997 through June 2010) of half hourly high-resolution (roughly 1 km) visible satellite imagery from GOES satellite data. The satellite imagery has been processed to create 13+ years of hourly values of Global Horizontal Irradiance, Direct Normal Irradiance and Diffuse Horizontal Irradiance from Santo Doming, Dominican Republic [**40**].

The base case scenario was modeled using 3Tier data sets. Table 4-19 shows the net annual energy production and first year PPA price at 7% IRR target for the modeled and processed solar radiation data sets in Santo Domingo.

Table 4-19 Net Annual Energy Production and First Year PPA Price at 7% IRR Target Using Modeled and Processed Solar Radiation Data in Santo Domingo

	Santo Domingo (PAES)	Santo Domingo (3Tier)
Net Annual Energy (kWh)	10,834,817	11,166,755
First Year PPA price (¢/kWh)	20.59	19.99

Despite the poor quality of the data measured in Santo Domingo, the performance and financial models produced similar results using the modeled data sets. With 3 % and 0.060¢/kWh difference in net annual energy production and first year PPA price, respectively.

4.8 *Comparison between Dish/Stirling and Photovoltaic (PV) systems*

A Photovoltaic system with the same specifications as the proposed for the dish/stirling was modeled.

For Santo Domingo the incentives for PV are the same as for the Dish/Stirling system. However, the incentive of 1% state tax for Juana Diaz was changed to 4% because the use of photovoltaic panels is not a pioneering activity in Puerto Rico. The 4% state tax incentive for PV is stated by law 73 [**47**]. Table 4-20 shows a comparison of the first year PPA price between Dish/Stirling and PV for both locations.

Table 4-20 Dish/Stirling and PV First Year PPA Price Comparison

	First Year PPA price (c/kWh)			
	Santo Domingo		Juana Diaz	
IRR%	Dish/Stirling	PV	Dish/Stirling	PV
5	18.67	10.33	19.20	12.50
6	19.62	10.91	20.08	13.10
7	20.59	11.51	20.96	13.71
8	21.59	12.13	21.84	14.31
9	22.61	12.75	22.70	14.90
10	23.65	13.39	23.56	15.49
11	24.7	14.03	24.40	16.06
12	25.76	14.67	25.23	16.63

PV systems require 50% more land area to produce the same amount of energy than Dish/Stilring systems. However, the values of table 4-20 reflect that the cost of producing energy with a dish/Stirling system is considerably higher compared with PV systems.

5 *CONCLUSIONS & FUTURE WORK*

5.1 Conclusions

Solar radiation from Juana Diaz and Santo Domingo was processed in this study. Erbs correlation and the equations of Collares-Pereira and Rabl are the techniques used to estimate the hourly direct solar radiation from Juana Diaz and Santo Domingo respectively.

Feasibility study of a 10 MW Dish/Stirling system is done. Realistic scenarios are developed by taking into account the renewable energy policies, financial parameters, incentives and cost for each location. These scenarios are simulated in SAM obtaining the first PPA price with an IRR target.

Sensitivity simulations with variables of uncertain future value are run to determine their influence on the PPA price. Finally, parametric simulations are run to determine the impact that some parameters have on the first year PPA price.

The conclusions are:

- First year PPA price for 5-12% IRRs was determined for a 10 MW Dish/Stirling system in Santo Domingo and Juana Diaz. The same analysis was also made for a 10 MW PV system in both locations. Table 5-1 summarizes the these results.

Table 5-1 Dish/Stirling and PV First Year PPA Price Comparison

	First Year PPA price (c/kWh)			
	Santo Domingo		Juana Diaz	
IRR%	Dish/Stirling	PV	Dish/Stirling	PV
5	18.67	10.33	19.20	12.50
6	19.62	10.91	20.08	13.10
7	20.59	11.51	20.96	13.71
8	21.59	12.13	21.84	14.31
9	22.61	12.75	22.70	14.90
10	23.65	13.39	23.56	15.49
11	24.7	14.03	24.40	16.06
12	25.76	14.67	25.23	16.63

- The annual energy output for a 10 MW Dish/Stirling system in Santo Domingo and Juana Diaz are 12,025 (MWh) and 11,990.93 (MWh) are, respectively.
- The overall efficiency for a 10 MW Dish/Stirling system in Santo Domingo and Juana Diaz are 24.3% and 22.87%, respectively.
- The sensibility analysis yields that the inflation rate, loan rate, RECs price, and land cost are variables that have great impact in the first year PPA price.

5.2 *Recommendations for Future Work*

The following are recommendations for future work:

- It is recommended to gather more frequent solar radiation measurements to create more accurate estimates of the annual energy production for Santo Domingo.

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APPENDIX A

HOURLY ESTIMATIONS OF DIRECT SOLAR RADIATION FROM JUANA DÍAZ

JUANA DIAZ DIRECT RADIATION

HOUR	JAN 1	JAN 2	JAN 3	JAN 4	JAN 5	JAN 6	JAN 7	JAN 8	JAN 9	JAN 10
6:00:00 AM	0	0	0	0	0	0	0	0	0	0
7:00:00 AM	4.2	392.5	144.6	266.4	277.9	382	328.2	170.3	401.4	412
8:00:00 AM	29.2	579.1	511.8	335.9	59.6	290.3	431	283.3	566.4	487.2
9:00:00 AM	348.3	677.1	29.3	197.7	15.8	243.2	600.5	188.9	698.4	308.1
10:00:00 AM	597.1	776.5	17.5	854.4	21.5	40.9	830.4	769.2	779.3	243.6
11:00:00 AM	769.1	795.2	166.3	875.7	7.2	63.9	812.2	815.1	580.3	649.8
12:00:00 PM	710.5	640.5	754.7	633	5.1	28.7	693.4	556.8	495	373.3
1:00:00 PM	587.9	709.3	705.8	271.3	322.5	9.6	246.5	475.3	762.2	451.7
2:00:00 PM	636.6	641.1	663.6	859.4	89.3	17.8	4.4	844.3	704.9	668.9
3:00:00 PM	292.4	299.3	447.5	347.6	9	55.5	1.1	626.1	306.5	132.9
4:00:00 PM	7.2	9.6	19.5	19.4	4.9	210.3	1.6	33.6	13.1	2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	JAN 11	JAN 12	JAN 13	JAN 14	JAN 15	JAN 16	JAN 17	JAN 18	JAN 19	JAN 20
6:00:00 AM	0	0	0	0	0	0	0	0	0	0
7:00:00 AM	315	344.6	135.2	93.8	382.4	456.4	416.4	345.5	442.7	384.2
8:00:00 AM	295.2	473.3	414.5	431.1	601.9	598.8	611.2	564.6	462.5	599.1
9:00:00 AM	705.3	710.4	435.8	765.2	644.2	732.6	564.6	580.8	20.2	566.4
10:00:00 AM	171.8	377.3	17.7	620.2	484.4	566	768	33.5	368.9	361.7
11:00:00 AM	310.8	106.2	512.5	25.2	220.4	111.8	158.8	14.8	719.7	78.1
12:00:00 PM	658.9	710.9	903.5	553.9	499	166	381.7	837.2	823.9	241.8
1:00:00 PM	452.3	527.3	510.6	788.4	550.3	844.1	701.7	769.2	583.1	445.6
2:00:00 PM	240.5	259.3	13.2	844.6	578.4	317	736	674.8	857.1	578
3:00:00 PM	499.2	540.4	29.1	705.2	552.5	533	175.8	132.4	704.3	257.6
4:00:00 PM	36.1	34.7	1.2	83.1	38.6	42.9	43.8	185.5	138.2	14.1
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION	HOUR	JAN 21	JAN 22	JAN 23	JAN 24	JAN 25	JAN 26	JAN 27	JAN 28	JAN 29	JAN 30	JAN 31
	6:00:00 AM	0	0	0	0	0	0	0	0	0	0	0
	7:00:00 AM	404.8	476.5	408.1	14.3	47.9	432.4	414.6	16.8	401.4	430.9	379.9
	8:00:00 AM	604.8	616.5	625.1	420.9	621.4	627.7	629.5	42.9	572.2	615.2	489.4
	9:00:00 AM	300	363.2	700.6	274.7	561.5	594.2	723	54.4	596.5	696.9	462.8
	10:00:00 AM	9.2	31.3	769.5	198.6	680.8	84.2	770.5	86.4	129.9	764.4	46.2
	11:00:00 AM	235.9	238.5	733.1	224.5	692.4	27.4	810	115.7	139.9	617.2	951.6
	12:00:00 PM	298.8	10	733.5	76.7	483.4	249.8	814.5	36.9	177.2	308.3	890.8
	1:00:00 PM	136.2	74.7	696.1	29.4	597.9	632.5	776.6	9.2	24	498.7	833.1
	2:00:00 PM	809.7	47.5	460.8	4.8	444.5	341.8	867.1	18.5	61	891.2	421.1
	3:00:00 PM	270.2	9.7	520.8	4.3	587	838.5	122.3	23.6	4.3	705.5	538.7
	4:00:00 PM	11.1	3.3	16.4	7.6	72	184.8	6.5	7.5	4.6	179.9	203.9
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION	HOUR	FEB 1	FEB 2	FEB 3	FEB 4	FEB 5	FEB 6	FEB 7	FEB 8	FEB 9	FEB 10
	6:00:00 AM	0	0	0	0	0	0	0	0	0	0
	7:00:00 AM	216.2	491.3	423.9	409.4	474.1	501.1	32.3	451	495.1	495
	8:00:00 AM	444.4	683.1	601.7	600.1	630.1	644	382.1	347.7	657.6	656.6
	9:00:00 AM	258.6	629	461.4	786.4	33.7	730.1	38.4	209	742.9	742
	10:00:00 AM	380	813.8	461.8	631.8	130.7	769.9	728.1	749.8	747.7	745.1
	11:00:00 AM	829.3	836.3	157.3	33.6	652.8	814.1	33	815.6	119.6	118.1
	12:00:00 PM	606.3	816.8	197.7	9.3	395.3	549.7	534.8	836.7	22.4	22.1
	1:00:00 PM	717.5	772.2	36.1	129.4	410.6	415.1	659.5	810.5	241	238.2
	2:00:00 PM	693.5	702.9	11.3	50	582.8	487	610.6	780.6	617.3	611.9
	3:00:00 PM	410.5	549.4	85	82.2	87	39.9	580.3	291.2	657	650.3
	4:00:00 PM	87.9	78.8	7	10.4	0.3	11.1	105.2	63.7	285.6	279.2
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	FEB 11	FEB 12	FEB 13	FEB 14	FEB 15	FEB 16	FEB 17	FEB 18	FEB 19	FEB 20
6:00:00 AM	0	0	0	0	0	0	0	0	0	0
7:00:00 AM	493.2	518.5	445.8	364.7	555.6	502.3	508.7	165.8	0.5	501.1
8:00:00 AM	657.4	662.6	649.5	100.9	381.7	243.4	53.9	74.5	13.2	741.8
9:00:00 AM	272.5	346.9	568.3	2.5	293.3	280.8	565.6	184.5	17.6	742.7
10:00:00 AM	392.8	480.5	423.1	758.3	710.4	827.4	814.1	780.2	1	818.1
11:00:00 AM	867	859.2	494.7	866.2	830.3	822.9	832.9	845.6	1.3	890.1
12:00:00 PM	852.3	840.1	120	327.9	837.1	825.6	687	894.6	5.6	875.3
1:00:00 PM	822.8	811.9	323	165.4	815.9	822.1	820.8	779.2	135	855.9
2:00:00 PM	758.8	756.9	494.2	538	224.5	748.5	765.9	731.5	213.7	806.6
3:00:00 PM	624.6	575.2	599.5	420.4	506.7	388.8	664.6	33	481.9	682
4:00:00 PM	246.1	248.4	270.2	214	112.8	309.2	336.8	3.4	125.7	416.5
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	FEB 21	FEB 22	FEB 23	FEB 24	FEB 25	FEB 26	FEB 27	FEB 28
6:00:00 AM	0	0	0	0	0	93	0	0
7:00:00 AM	550.2	540.1	549.6	543.3	540.3	8.8	564	488.3
8:00:00 AM	699.4	693.3	639.1	691	689	2.7	707	216.8
9:00:00 AM	778.5	717.3	496.9	755.5	753.5	211.5	777.9	675.4
10:00:00 AM	824.2	595.3	902.2	833	831.9	80.3	824.3	851.8
11:00:00 AM	855.6	788.9	858.4	851.7	850.6	22.8	852	901.8
12:00:00 PM	868.9	833.1	896.9	864.8	863.1	6.8	592.3	873
1:00:00 PM	860.3	836.9	557.2	856.6	854.2	50.6	859.8	879.8
2:00:00 PM	790.7	762.5	626.8	794.2	790.7	1	819.3	796.9
3:00:00 PM	670.7	680.8	337.1	675.7	671.1	170.3	798.1	403.6
4:00:00 PM	311.8	410	4.7	285.3	281.4	5.8	9.8	9.5
5:00:00 PM	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	MAR 1	MAR 2	MAR 3	MAR 4	MAR 5	MAR 6	MAR 7	MAR 8	MAR 9	MAR 10
6:00:00 AM	147.7	106.3	0	0	0	0	0	27.2	148.9	0
7:00:00 AM	29.3	383.1	556.9	546.2	594.3	497	0	354.8	620	546.1
8:00:00 AM	245.1	70.7	426.5	720.5	721.4	8.9	24.8	61	792.5	731.1
9:00:00 AM	150.4	120.2	793.2	736.5	792.3	690.7	394.4	109	746.3	398.5
10:00:00 AM	15.2	68.2	73.4	786.6	810.8	88.4	924.8	62.8	845	873.5
11:00:00 AM	14.5	452.1	123.6	593.5	839.7	484.7	897.5	432.1	637.6	910.9
12:00:00 PM	81.6	878.2	314.9	942.3	850.4	274.3	569.4	870.3	867.3	952
1:00:00 PM	5.8	879.5	844	865.4	74.7	840.8	795.1	835.7	623.1	759.7
2:00:00 PM	5.3	154.6	610.3	823.7	409.7	775.7	646.3	793.2	204.3	3
3:00:00 PM	6.8	10.5	130	683.8	353	532.6	406.7	521.2	20.5	4.3
4:00:00 PM	8.2	21.1	44	8.6	296.1	384.6	57.8	201.9	5.5	320.2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	MAR 11	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18	MAR 19	MAR 20
6:00:00 AM	0	277.6	237.8	366.6	0	387.1	413.3	419.8	446.4	0
7:00:00 AM	567	615.6	169.2	637.4	654.9	633.8	650.1	650.6	673.9	683.3
8:00:00 AM	695.8	716.4	390.5	779.2	760.9	748	760.7	757.2	779.9	783.6
9:00:00 AM	202.4	778.4	489.4	548.7	833	772.2	776.1	820.2	834.1	834.5
10:00:00 AM	31.7	708.9	523.2	898.8	794.9	831.7	422	753.7	864.6	868.7
11:00:00 AM	892.1	874.4	899	877.5	844.4	902.6	259	459.5	895.4	877.2
12:00:00 PM	920.4	882	887.7	889.9	886.9	881.5	255.9	527.9	836.6	905
1:00:00 PM	7.8	886	884	893.3	901	888.1	822.7	917.5	927.3	910.1
2:00:00 PM	1.4	812.7	843.9	871.7	68.8	163.4	735	711.3	745.9	875.7
3:00:00 PM	0.2	744	736.2	752.4	1.4	2	62.1	8.9	613.3	907.1
4:00:00 PM	0.3	416.7	427.8	524.8	0.7	0	13.9	200.7	31.5	534.1
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W$/m^2$

JUANA DIAZ DIRECT RADIATION

HOUR	MAR 21	MAR 22	MAR 23	MAR 24	MAR 25	MAR 26	MAR 27	MAR 28	MAR 29	MAR 30	MAR 31
6:00:00 AM	266.8	378.6	426.5	236.9	308.7	446.1	340.2	3.1	375.4	478.5	491.3
7:00:00 AM	225.7	136.1	635.8	499.7	531.8	619.5	527.9	332.4	597.3	639.7	671
8:00:00 AM	635.8	670.7	778	605.5	701	767.7	104.8	839.7	755.9	754.2	768.8
9:00:00 AM	132.5	631.8	611.6	605.5	730.1	741.6	233.8	796.6	814.4	170.3	834.3
10:00:00 AM	13.9	584.8	802.2	789.4	799.7	73.9	802.3	860.6	848	894	880
11:00:00 AM	168.6	562.3	880.7	799.8	815.9	581.4	873.3	877.8	875.9	921	883.7
12:00:00 PM	448.3	1001.9	957.4	823.5	832.7	688.4	895.6	873	717.3	755.6	902
1:00:00 PM	825.1	612.8	849.1	826	812.9	679	889	37.6	11.3	3.1	902.7
2:00:00 PM	932.1	904.7	822.7	765.4	760.2	656.3	1062.3	7	1.3	44.2	939.5
3:00:00 PM	619.9	434.1	644.7	620.3	666.5	451.5	661.6	378	0	1.2	583.9
4:00:00 PM	17.3	576	35.7	337.3	330.7	273.6	169.2	421.3	1.5	1.1	5.7
5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	APR 1	APR 2	APR 3	APR 4	APR 5	APR 6	APR 7	APR 8	APR 9	APR 10
6:00:00 AM	528.5	492.7	523.6	52.1	47.6	622.2	645.7	284.4	173.4	486.6
7:00:00 AM	699.7	88.9	599.9	109.5	106.5	315.5	261.2	240.8	233.7	738.8
8:00:00 AM	783.4	438.5	174.6	28.2	27.7	31.2	129.1	54.7	817.4	838
9:00:00 AM	833.8	410.3	500.2	176.6	175.1	19.9	644.9	243.8	849	814.9
10:00:00 AM	872.8	361.1	767.2	289.5	288.2	232.1	111.6	253.2	876.9	53.4
11:00:00 AM	901.7	936	936.8	902.5	902.7	37.7	133.1	631.1	892.5	655.7
12:00:00 PM	600.4	901	593.2	849.1	849.2	2.5	7.8	945.3	922.9	967.2
1:00:00 PM	934.7	910.3	755.5	922.8	923.5	4.8	1.5	888.7	943.8	804.5
2:00:00 PM	903	408.1	845.4	203.8	203.7	2.5	0.4	859.2	941	265.3
3:00:00 PM	205.8	304.4	795.1	7.6	7.4	3.7	1.2	709.9	868.2	984.2
4:00:00 PM	218	1.1	438.6	0.4	0.4	9	1.2	463.7	606.2	738.3
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION	HOUR	APR 11	APR 12	APR 13	APR 14	APR 15	APR 16	APR 17	APR 18	APR 19	APR 20
	6:00:00 AM	598.6	615.4	651.3	651.9	22.6	5.3	618.7	366.5	221.2	0.4
	7:00:00 AM	755.2	752.5	769.1	766.8	18.8	17.5	342.2	632.3	135.5	8.1
	8:00:00 AM	377.5	832.1	679.5	837.9	11.3	80	0.3	756.8	86.8	2.6
	9:00:00 AM	627.7	672.3	877.8	854.3	169	39	0	768.8	29.6	0.2
	10:00:00 AM	169.4	335.9	784.7	996.5	317.6	41.6	0	925.9	56.6	0.1
	11:00:00 AM	622.4	410.5	902.6	507.1	542.6	27.1	0	902	262.7	0
	12:00:00 PM	964.7	4.3	932.8	124.6	5.8	30.5	0.2	841.5	102.4	0
	1:00:00 PM	961.4	4.9	974.6	570.5	17.9	6.2	0	904	549.4	0.4
	2:00:00 PM	912.9	9.3	820	197.3	3.3	5.6	0.3	775.7	309.9	2.1
	3:00:00 PM	834	2.7	797.5	36.5	5.3	2.1	65.2	980.2	6.5	2.8
	4:00:00 PM	625.1	3.2	373.6	21.6	4.1	6.2	2.5	330	1.3	0.8
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION	HOUR	APR 21	APR 22	APR 23	APR 24	APR 25	APR 26	APR 27	APR 28	APR 29	APR 30
	6:00:00 AM	2.8	550.7	561.6	641.8	645.9	625.7	804.9	817.1	817.1	757.3
	7:00:00 AM	3.6	330.7	732.8	765.3	746.8	769.3	706.6	859.1	745.4	824.2
	8:00:00 AM	38.3	543.8	708.5	816.3	795.7	866.7	701.5	932.2	905.7	897.6
	9:00:00 AM	66	78.2	596.4	901.1	570.5	814	42.2	632	709.1	650.2
	10:00:00 AM	88.9	118.9	689.2	890.3	886.6	901.3	457.6	198.4	213.6	899.5
	11:00:00 AM	68.3	289.8	898.7	888.7	872.1	276.1	231.8	303.1	708.1	894.5
	12:00:00 PM	259.1	767.9	1008	917.2	253.7	0.7	174.9	379	898.7	896.8
	1:00:00 PM	171.4	536.4	25.6	294.9	7.3	0.9	5.5	350.3	859.6	930.4
	2:00:00 PM	54.7	430.9	0.8	414.5	0.5	0	2.2	224	827.9	822.6
	3:00:00 PM	7.4	226	0.9	3.1	2.2	1.5	6.2	45	3.3	8.6
	4:00:00 PM	6.7	231.7	0.9	6.4	9	91.4	1.7	10.9	2.2	89.8
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	MAY 1	MAY 2	MAY 3	MAY 4	MAY 5	MAY 6	MAY 7	MAY 8	MAY 9	MAY 10
6:00:00 AM	581.7	751.6	789.1	831.5	850.2	873.4	863.2	861.6	886.4	203.9
7:00:00 AM	829.8	815.2	841.1	868.2	883.3	874.1	876.3	872.3	892	190
8:00:00 AM	861.8	884.1	881.4	635.4	810.6	914.7	986	645.1	916.8	79.2
9:00:00 AM	889.8	312.5	881.6	161.7	319.3	553.6	249.1	489.3	400.3	29.8
10:00:00 AM	883.9	676.5	65.8	194.3	11.9	413.5	861.7	245.6	960.5	928.5
11:00:00 AM	872.1	911.8	897.3	878.2	400.4	642.9	715.3	825.1	910.1	668.7
12:00:00 PM	893.5	328.5	379.2	45.7	258.6	911.1	542.6	722.8	904.6	923.5
1:00:00 PM	669.1	0.1	42.4	76.2	59.6	915.7	459.2	843.8	897.4	873.7
2:00:00 PM	1.1	1.1	55.5	9.7	384.5	833.9	609.7	130.5	825.6	951.6
3:00:00 PM	25.8	12.5	83	258.4	602.9	676.6	339.4	45.3	77.2	221.2
4:00:00 PM	48.3	9.7	61.9	135.3	143.7	369.5	5.8	7.6	3.6	9.9
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	MAY 11	MAY 12	MAY 13	MAY 14	MAY 15	MAY 16	MAY 17	MAY 18	MAY 19	MAY 20
6:00:00 AM	631.8	870.3	824.8	694.4	883.2	995.1	879.6	703.4	840.9	360.8
7:00:00 AM	849.5	889.3	898.6	197.7	857.9	953.7	370.3	165.6	822.7	536.1
8:00:00 AM	900.9	904.4	658.6	288	927.8	849.3	839.4	327.9	217.7	531.4
9:00:00 AM	241.3	927.1	712.3	574.8	149.1	894.7	260.7	140.6	536.4	470.9
10:00:00 AM	81.1	759.1	399.6	404.1	791.8	978.2	501.3	366.5	543.1	561
11:00:00 AM	808.7	879.7	852.2	857.9	896.1	679.5	340.5	668.4	227.7	172.1
12:00:00 PM	945	777.2	858.6	863.5	940.1	884.6	953.6	891.1	159.4	24.7
1:00:00 PM	914.5	910.2	871.8	906.2	939	671.1	888.3	864.8	741.5	101.3
2:00:00 PM	789.4	836.7	712.2	846.1	657.3	355.3	834	832.7	538.1	60.1
3:00:00 PM	24.2	705.5	406.6	689.9	160.7	31.9	653.9	639.3	126.8	622.4
4:00:00 PM	589.5	347.3	50.3	407.7	280.6	2.3	389.5	353.8	47.8	44.2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	MAY 21	MAY 22	MAY 23	MAY 24	MAY 25	MAY 26	MAY 27	MAY 28	MAY 29	MAY 30
6:00:00 AM	434.2	627.1	163.9	64.2	497.9	717	20.6	188.8	8.3	202.4
7:00:00 AM	563.3	679.9	20.7	780.9	109.4	777	335.5	65.8	187.7	391.4
8:00:00 AM	401.4	824.4	450	894.1	205.5	827.8	92.2	855	169	533
9:00:00 AM	700	837.9	169.3	766.4	793.2	943.6	170.4	304.1	61.8	41.7
10:00:00 AM	674.8	837.5	670	663.8	599.2	864	84.7	334.1	491.2	138.4
11:00:00 AM	732.3	645.6	455.2	528.2	327.6	115	55	450.9	576.9	555
12:00:00 PM	822.7	828.9	125.8	850.6	959.4	325.4	26.3	662.3	345.1	839
1:00:00 PM	801.8	798.4	511.5	895.2	886.6	9.3	465.4	824.5	707.3	308.9
2:00:00 PM	668.9	674.5	750.8	791.7	788	11	448.5	507.8	256	170.1
3:00:00 PM	495.1	477.8	91.9	627.7	545.5	152.7	5.3	127	12.9	64.4
4:00:00 PM	227	176	86.6	272	259.6	127.9	41.4	58.2	10.9	23.6
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	JUN 1	JUN 2	JUN 3	JUN 4	JUN 5	JUN 6	JUN 7	JUN 8	JUN 9	JUN 10
6:00:00 AM	40.6	175	46.7	21.1	0.4	190.2	132.8	247.6	125.6	193.3
7:00:00 AM	21.1	207.7	32.5	28.6	1.1	19.1	658.6	142.5	145.7	365.9
8:00:00 AM	604.1	73.9	39.1	191.2	1.4	77.2	206.4	153.4	312.9	172.2
9:00:00 AM	938.1	10	7.2	105.5	0.3	138.3	305.8	731.4	191.9	735.5
10:00:00 AM	484.4	6.4	1.2	8.6	1.4	562.6	167.4	86.9	146.1	58.6
11:00:00 AM	618.8	5.4	10.5	1.5	2.8	100.2	626.1	28.7	215.9	460.1
12:00:00 PM	612.2	3.1	12.8	0.5	0.5	427.6	623.8	9	184.1	871.4
1:00:00 PM	1043	295.8	5	0.1	3.6	429.5	696.6	52.6	700	722.4
2:00:00 PM	851.8	15.7	4	1	7.1	12	287.7	33	475.9	807
3:00:00 PM	127	61.9	19.3	2.1	6.9	5.5	23.2	129.1	298	566.2
4:00:00 PM	22.6	100.2	12.2	0.4	2.7	4.9	125.9	11.1	127.1	296.5
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	JUN 11	JUN 12	JUN 13	JUN 14	JUN 15	JUN 16	JUN 17	JUN 18	JUN 19	JUN 20
6:00:00 AM	44.6	10	32.7	5.3	10.5	58.7	10.2	88.4	10.3	5.4
7:00:00 AM	757.7	886.3	807.7	886.5	838.2	861	823.6	566.3	779.2	817.4
8:00:00 AM	348	804	310	902.1	729.7	882.1	870.8	654.9	592.2	384.8
9:00:00 AM	254.1	693.1	415.6	568.9	389.4	745.2	848.7	439.4	823.1	354.4
10:00:00 AM	62.5	30.9	57.4	54.6	52	29.8	42	181.2	66.2	14.5
11:00:00 AM	274.3	567.3	511.3	489.3	475.4	446.2	34.7	499.9	357.4	78.2
12:00:00 PM	815.6	806.2	899.9	881.6	892.6	883.9	96.4	184.3	241.2	86.2
1:00:00 PM	596.4	945.4	865.5	847.8	904.3	877.1	404.8	552.6	673.2	524.9
2:00:00 PM	675.4	890.7	732.6	747.9	749.9	778.9	290.6	64.1	323.3	541.2
3:00:00 PM	677	21	365.5	579.1	496.4	621.7	71.5	716.8	453.4	729.5
4:00:00 PM	212.2	205.9	11	142.9	59.9	382.1	6.9	77.5	347.4	66.2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	JUN 21	JUN 22	JUN 23	JUN 24	JUN 25	JUN 26	JUN 27	JUN 28	JUN 29	JUN 30
6:00:00 AM	21.6	46	22.2	116.1	152	56.2	8.2	79.5	184.8	134
7:00:00 AM	437.7	586.9	750	545.2	496.3	552.3	759.6	183.3	442.1	708.3
8:00:00 AM	484.3	911.9	620.2	669.9	749	113.4	563.6	445.2	319.7	302.5
9:00:00 AM	596.4	801.8	719	501.6	763.9	152.3	259.2	323.9	39.8	499.9
10:00:00 AM	70	50.3	25.6	69.9	76.3	63.2	17.8	85.1	92.3	57.6
11:00:00 AM	385.4	470.3	420.1	475.3	501.7	507.2	586.9	480	310.9	592.5
12:00:00 PM	915.8	918.2	949.3	818.6	815.3	589.5	124	888.6	237.3	897.1
1:00:00 PM	580.9	899.1	1001.6	402.4	794.6	962.7	131.7	705.7	231.6	887.2
2:00:00 PM	700.2	819.2	54.6	39.1	701.3	249.7	24.6	725	660.6	841.1
3:00:00 PM	560.4	671.5	25.2	99.7	97.3	135.2	31.1	415.1	529.5	710.8
4:00:00 PM	13.3	407.2	14.1	104.8	52.5	423.3	121	543.1	131.1	495
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	JUL 1	JUL 2	JUL 3	JUL 4	JUL 5	JUL 6	JUL 7	JUL 8	JUL 9	JUL 10
6:00:00 AM	26.4	47.9	36.3	166.3	127.4	80.3	111.5	131	147.3	199.1
7:00:00 AM	838.5	376.8	864.8	631	852.7	677.3	831.6	883.7	763.7	903
8:00:00 AM	881.5	269.8	412.3	742.7	641.1	255.4	914	922.9	420.4	74.5
9:00:00 AM	370.2	561.4	592.8	570.5	790.6	81.8	755.7	822.4	902.9	436.5
10:00:00 AM	15.1	27.5	69.9	156.1	97.6	30.8	243	273.9	437.8	315.8
11:00:00 AM	341.6	372.1	524.5	452.8	411.1	333.5	281.7	335	315.5	371.1
12:00:00 PM	922.5	789	921.9	799	409.9	2	870.3	866	841.9	896.5
1:00:00 PM	932.2	834.4	877.8	742.6	4.2	1.8	598.1	856.1	848.3	660.1
2:00:00 PM	779.7	784.8	4.4	78.1	33.8	0.8	544.6	797.7	732.2	461.2
3:00:00 PM	427.5	600.1	1.3	7.3	1065.3	0.7	236.2	105.5	347	370.8
4:00:00 PM	112.8	427.2	14.8	24.6	68.7	2	264.3	235.9	126.9	21.8
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	JUL 11	JUL 12	JUL 13	JUL 14	JUL 15	JUL 16	JUL 17	JUL 18	JUL 19	JUL 20
6:00:00 AM	237.3	264.2	367.5	409.7	29.5	603.6	895.9	744.2	765.3	952.5
7:00:00 AM	936.8	866.6	348.1	641.1	88.3	891.1	486.7	472.9	606.2	945.6
8:00:00 AM	719.5	828.5	903.5	485.9	73.7	924.5	549.6	207.3	799.7	989.5
9:00:00 AM	930.9	856.3	763.7	558.5	263	888.7	954.5	139.6	629.5	912
10:00:00 AM	660	719.9	766.2	585.2	724.1	316.9	768.4	234.6	831.6	171.3
11:00:00 AM	211.5	183.3	228.2	332.6	356.5	73.5	380.4	544.8	548.1	303.8
12:00:00 PM	338.2	953.6	869.6	872.8	696.8	50.1	862.9	793.1	816.4	189.9
1:00:00 PM	508.3	15.6	864.6	634.5	322.7	14.1	807.6	625.7	765.3	742.5
2:00:00 PM	116.3	12.5	783.9	2.8	704	201.3	363.6	57.3	702.3	470.3
3:00:00 PM	39.8	152.5	623.8	0.6	297.4	294.7	252.6	3.7	584	109.5
4:00:00 PM	28.5	8.4	359.6	1.2	36.6	174.9	21	4.7	228	1.6
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	JUL 21	JUL 22	JUL 23	JUL 24	JUL 25	JUL 26	JUL 27	JUL 28	JUL 29	JUL 30	JUL 31
6:00:00 AM	696.5	157.1	484	167.4	554.8	624.4	170.1	891.7	731.9	870	680.5
7:00:00 AM	796.2	889	198.2	807.3	719.2	744.8	7.7	229.9	311.6	763.8	720.2
8:00:00 AM	760.2	836.9	244.3	204.4	418.2	877.2	27.4	79.6	420.7	798.1	607.9
9:00:00 AM	135.6	818.2	41.8	595.6	334.8	803.3	155.3	57.8	720.1	234.3	621.4
10:00:00 AM	63.1	927.7	235.6	544.6	164	377.3	381.3	11.8	777.6	367.4	631.6
11:00:00 AM	6.3	600.4	236.7	179.2	110.8	573.7	69.9	172.4	875.2	801.2	757
12:00:00 PM	529.5	992.6	618.6	365.7	535.5	671.6	508	870.5	877.2	786.8	835.6
1:00:00 PM	829.7	653.5	628.6	568.9	636.1	827.8	158.7	749	859	842.9	556.4
2:00:00 PM	929.5	632.1	347.4	421.2	707.4	680.2	57.4	391.1	763	73.9	70
3:00:00 PM	720.1	527.6	89.8	426.4	356.6	594.6	104.6	27.5	550.9	1.3	46
4:00:00 PM	404	396.6	12.9	92.9	185.8	49.4	82.4	2.7	140.8	0.8	11.2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	AUG 1	AUG 2	AUG 3	AUG 4	AUG 5	AUG 6	AUG 7	AUG 8	AUG 9	AUG 10
6:00:00 AM	780.2	747.3	602.4	821.6	940.1	899.1	467.6	23.4	800.6	749.1
7:00:00 AM	739.8	383.5	28.5	837.3	885.3	834.4	710.4	574.1	845.8	386.8
8:00:00 AM	552.2	39.2	75.5	612.6	702.2	882.9	889.1	868.3	393.7	813.1
9:00:00 AM	620.9	240.3	602.8	164.5	585.6	890.4	508.8	593.2	741.8	896.5
10:00:00 AM	820.4	900.7	640.3	859.7	396.2	937.8	2.1	281.5	889.3	924.6
11:00:00 AM	781.1	849.5	840.1	662.9	275.4	913	3.1	570.5	885	905.5
12:00:00 PM	729.4	853.7	908.3	373.9	1.8	930	263.9	563	815	572.1
1:00:00 PM	10.2	847.6	58.3	72.5	0.2	890.8	226.7	753.3	943.5	22.7
2:00:00 PM	3.3	773.7	1.2	4.8	2.7	841.4	191	845.8	333.5	23.8
3:00:00 PM	1.9	13.3	4.2	4.4	8.4	688	164.2	335.1	822.1	218.9
4:00:00 PM	10.8	1.9	5	25.1	5	377.6	15.1	410.9	87.6	122.2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	AUG 11	AUG 12	AUG 13	AUG 14	AUG 15	AUG 16	AUG 17	AUG 18	AUG 19	AUG 20
6:00:00 AM	890.6	898.9	0	830.4	868.7	84.2	662.6	752.6	0	0
7:00:00 AM	882.3	887.6	832.6	864.9	891.8	330.5	608.3	566.5	570.9	429.8
8:00:00 AM	732.7	804.7	671.5	181.5	899.5	59.9	893.1	350.3	845.9	483.1
9:00:00 AM	807.9	855	663.9	392.3	848.7	40.4	715.8	733.1	617.8	872
10:00:00 AM	924.7	812.8	925.7	684	904.6	41.2	691.8	368.8	843.3	541.4
11:00:00 AM	926.9	596.2	891.4	759.9	884.2	14.6	2.9	235.2	864.2	447.4
12:00:00 PM	15.9	348.2	815.7	857.3	863.4	56.6	294.8	35.1	872.5	200
1:00:00 PM	73.7	793.8	675.4	527.3	844.8	68.7	55.8	684.9	873.9	109.8
2:00:00 PM	67.5	833.7	849.9	564.7	751.5	25.7	181.2	680.7	522.2	158.7
3:00:00 PM	2.1	698.7	621.1	195.6	567.5	8.4	796.2	662.5	635.1	257.5
4:00:00 PM	1.6	297.1	10.5	365.5	301.6	3.1	535.5	328.3	221.9	18.6
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	AUG 21	AUG 22	AUG 23	AUG 24	AUG 25	AUG 26	AUG 27	AUG 28	AUG 29	AUG 30	AUG 31
6:00:00 AM	599.9	770.3	0	785.3	725.5	791.2	0	657.1	714.5	508	571.6
7:00:00 AM	773.7	719.6	861.7	848.3	104.9	804.4	80.2	691.7	761.4	733.2	261.9
8:00:00 AM	395.6	689.9	729.6	688.6	656.5	755	698.6	788.1	854.6	314.2	215.3
9:00:00 AM	122.3	219.7	912.7	708.2	274.9	896.3	815.5	354.2	643.9	843.5	890.8
10:00:00 AM	267.2	786.2	903	421.6	943.3	663.6	869.4	212.7	526.6	874.4	895.6
11:00:00 AM	484.9	838	946.1	909.5	944.1	916.4	922.3	188	894	943.3	842.6
12:00:00 PM	620.1	911.6	909.7	845	939.1	918	835.5	292	890.9	864.3	816
1:00:00 PM	271.9	931.4	861.6	585.2	382.3	679.8	932.4	1.3	39.6	17.3	42.3
2:00:00 PM	168	335.8	759.5	145.8	81	714.2	48.6	0.9	3.9	5.7	2.6
3:00:00 PM	5	4.6	627	47.8	7.6	4	4.2	1.7	4.9	17.4	3.4
4:00:00 PM	4.8	5.6	241.7	32	16.5	2.8	2.8	5.7	9.4	6.1	6.6
5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION	HOUR	SEPT 1	SEPT 2	SEPT 3	SEPT 4	SEPT 5	SEPT 6	SEPT 7	SEPT 8	SEPT 9	SEPT 10
	6:00:00 AM	702.3	704	615.4	0	0	639.1	681.6	0	0	0
	7:00:00 AM	743.9	361.7	65.8	832.9	500.8	466.8	542.9	817	452.9	789.8
	8:00:00 AM	511.7	33.6	337.3	377.9	918.4	259.4	751.8	611.3	672.5	742.9
	9:00:00 AM	660.9	335.1	411.4	388.4	879.6	612.9	348.1	793.5	590.4	789
	10:00:00 AM	776.1	863.2	810.4	798.7	857.1	865.8	798.5	890.8	926.8	888.5
	11:00:00 AM	766.3	821.4	814.4	735.8	885.2	875.3	526.2	876.4	891.3	835.1
	12:00:00 PM	627.8	821.1	897.3	198.8	879.2	890.4	510	872.1	861.8	332.7
	1:00:00 PM	7.5	805.8	4.2	62	877.5	880.5	953.1	835.9	860.8	5.3
	2:00:00 PM	3.6	746.6	1.5	3.6	336.1	777.9	516.1	741.4	732.4	737.3
	3:00:00 PM	1.9	3.8	4.7	4.9	6	161.6	746.5	564.3	391.9	8.9
	4:00:00 PM	18.2	2.1	5.4	26	9.3	141.7	253.5	115.5	85.5	3.5
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION	HOUR	SEPT 11	SEPT 12	SEPT 13	SEPT 14	SEPT 15	SEPT 16	SEPT 17	SEPT 18	SEPT 19	SEPT 20
	6:00:00 AM	615.1	628.9	659.5	0	258.3	22.9	624.2	239.1	0	0
	7:00:00 AM	750.2	729.2	756.4	781.5	134.8	14.1	744.2	549	769.4	527.2
	8:00:00 AM	514.1	832.3	821.4	837.8	292.6	153.5	732.9	429	319.5	836
	9:00:00 AM	724.9	798.5	873.7	732.4	139.9	443.8	867.6	770.6	713.2	891.1
	10:00:00 AM	855.1	840.9	420.9	910.7	60.5	719.2	864.1	879.6	866.5	871.4
	11:00:00 AM	859.1	846.6	829	837.5	1.5	519.9	833.8	878.6	867.6	896.7
	12:00:00 PM	20	845.8	860.4	423.6	0.1	351.7	817.3	914.4	855	899.7
	1:00:00 PM	166.4	242.1	806.5	6.7	0.1	875.8	730.3	4.5	736	827.9
	2:00:00 PM	3	245.8	688.6	27.3	0.2	184.3	5.1	0.2	1.1	487
	3:00:00 PM	6.1	289	24.5	6.4	0.9	19.2	1.3	2.2	8.9	84.6
	4:00:00 PM	6.6	10.1	2.7	2.7	0.4	33.4	3.6	19.2	6.9	45
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION	HOUR	SEPT 21	SEPT 22	SEPT 23	SEPT 24	SEPT 25	SEPT 26	SEPT 27	SEPT 28	SEPT 29	SEPT 30
	6:00:00 AM	0	496.8	0	0	185	100.9	328.3	249.2	275.6	366.2
	7:00:00 AM	445.1	295.5	619.5	689.9	362.4	11.4	752.8	258	83.6	524.2
	8:00:00 AM	743.6	472	792.1	718.1	21.6	6.1	213.5	60.3	51.5	133
	9:00:00 AM	695.7	239.3	740.1	413.5	4.6	8.2	776.7	205.8	64.8	428.4
	10:00:00 AM	559.6	862	846.2	799.9	21.2	13.8	659.7	281.4	72.1	212.8
	11:00:00 AM	163.3	909.5	627.4	164	2.3	6	534	38.8	128.7	641.9
	12:00:00 PM	438.9	889.6	871.6	0.8	4.1	5.7	72.1	46.4	15.6	562.8
	1:00:00 PM	149.6	862.9	780.5	0.2	1.2	5.6	124.7	18.4	11.4	682
	2:00:00 PM	111	692.8	557.6	1.1	1.7	4.7	64.7	6.9	48.1	609.2
	3:00:00 PM	285.1	381.9	48.9	2.5	1.4	11.4	26	2.3	23.7	49.8
	4:00:00 PM	9.3	160	4.7	2.4	1.4	5.8	5.9	1.5	14.4	4
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION	HOUR	OCT 1	OCT 2	OCT 3	OCT 4	OCT 5	OCT 6	OCT 7	OCT 8	OCT 9	OCT 10
	6:00:00 AM	0	0	461.2	0	0	0	0	0	0	0
	7:00:00 AM	736.4	735.1	542	675	737.1	730.8	724.7	709.6	628.8	713
	8:00:00 AM	839.2	89.9	522.8	570	659.4	822.7	716.2	505.5	779.2	701.8
	9:00:00 AM	328.7	732.6	669.5	817.1	778.4	440.3	780.5	832.2	923.3	796.8
	10:00:00 AM	877.3	856.5	621.6	841.5	454.8	805.2	843.5	812.2	227.4	721.5
	11:00:00 AM	480.2	879.6	549.1	864.8	523.8	862.1	846.6	897.6	6	243.8
	12:00:00 PM	926.8	859.7	733.3	877.7	866	714.3	825.8	621.7	33.7	281.1
	1:00:00 PM	799.3	821.6	732.7	879.7	598.6	309.4	938.4	88.5	1.1	5.1
	2:00:00 PM	58.7	856.5	613.2	12.3	730	0.5	1	495.3	2.6	277.7
	3:00:00 PM	437.4	528.7	68	1.4	212.4	1.4	1.2	60.1	2.1	255.3
	4:00:00 PM	33.6	5.1	9.2	1.5	26.9	1.6	1	1.1	7.4	13.3
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

	HOUR	OCT 11	OCT 12	OCT 13	OCT 14	OCT 15	OCT 16	OCT 17	OCT 18	OCT 19	OCT 20
JUANA DIAZ DIRECT RADIATION	6:00:00 AM	486.2	0	0	0	0	22.6	363.2	0	0	0
	7:00:00 AM	0	720.3	111.8	712	694.2	733.2	489.4	704.9	730.9	697.5
	8:00:00 AM	560.9	719.1	561.3	722.6	748	677	576.4	736.4	290.8	559.9
	9:00:00 AM	712.1	819.9	488.8	317.9	729.2	416.6	572.8	877.1	43.5	11.4
	10:00:00 AM	806.5	518.4	793.4	551.4	841.8	876.2	306.6	820.1	725.1	368.1
	11:00:00 AM	638.6	75.2	789.4	5	856.8	734.3	551.2	756.5	854.4	907
	12:00:00 PM	788	600.7	882.7	4.8	59.7	739	682.2	849.1	871.1	891.8
	1:00:00 PM	743.4	859.7	811.3	0.1	0.8	683	731.3	154.2	689.8	57.6
	2:00:00 PM	622	20.3	2.6	0	3.6	589.3	590.5	14	11.6	0.8
	3:00:00 PM	37.7	18.7	2.2	1.7	89.2	69.6	156.6	116.3	3.4	2.9
	4:00:00 PM	1.1	1.6	5.4	8.2	6.6	0.6	0.6	3.4	1.7	1.7
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

	HOUR	OCT 21	OCT 22	OCT 23	OCT 24	OCT 25	OCT 26	OCT 27	OCT 28	OCT 29	OCT 30	OCT 31
JUANA DIAZ DIRECT RADIATION	6:00:00 AM	0	0	0	443.8	0	0	0	0	0	0	0
	7:00:00 AM	698.8	640.1	566.7	643	706	638.1	391.2	662.5	665.7	666.5	643
	8:00:00 AM	734	694.6	596.6	542	743	818	727.6	663.3	707.9	753.6	183.6
	9:00:00 AM	76.6	448.3	557.4	840.2	691.9	617.4	283.3	23.1	572.9	861.3	846.6
	10:00:00 AM	8.7	10.8	824.3	654.7	192.6	859.8	78.9	6	375.2	694.9	268.3
	11:00:00 AM	647.1	73.2	877.9	137.8	826	810.2	3.8	541.4	823.4	870.8	2.5
	12:00:00 PM	2.4	45.3	774.6	909.7	766.9	780.4	386.4	743.7	836.6	600.9	525.8
	1:00:00 PM	0.3	3.6	6	837.4	658	236.5	129.1	634.8	791.3	62.7	316.9
	2:00:00 PM	0.5	1.8	2.6	647.6	488.1	2.3	4.5	465.5	37.9	6.5	76.4
	3:00:00 PM	3.9	5.4	25.4	84.6	303.7	1.5	10.5	176.8	1	11.3	242.2
	4:00:00 PM	3.4	1.7	17.7	4.6	6.3	2.9	1.7	2.9	0	6.4	3.5
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

	HOUR	NOV 1	NOV 2	NOV 3	NOV 4	NOV 5	NOV 6	NOV 7	NOV 8	NOV 9	NOV 10
JUANA DIAZ DIRECT RADIATION	6:00:00 AM	0	0	0	127.3	0	0	0	0	0	0
	7:00:00 AM	666.6	687.5	667.5	243.5	653.4	643.2	648.5	657.5	643.6	434
	8:00:00 AM	677.7	756.2	740.7	609.6	650.9	733.2	723.1	732.5	367.6	673.5
	9:00:00 AM	453.1	814.2	271.3	827.7	429.5	22.5	827.9	764.6	180.5	841.5
	10:00:00 AM	54.5	835.5	734.3	813.4	171.9	743.1	815.5	795.1	57.8	761.9
	11:00:00 AM	4.7	839	807.1	784.3	823.4	781.7	784.7	799	575	755.7
	12:00:00 PM	4.2	844.6	754.2	753.2	689.8	686.1	741.6	12.3	678.1	670.5
	1:00:00 PM	807.6	808.7	443.7	638.3	654.8	605.6	629	489.3	300.9	451
	2:00:00 PM	81.2	690.3	203.7	425.3	164.2	198.9	504.1	161.5	228.3	364.6
	3:00:00 PM	42.9	2.5	0.5	107	1.3	40.8	107.2	125.9	6.8	91.7
	4:00:00 PM	1.2	1.8	0	0	0.6	0.6	1.8	1.2	1.2	1.2
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

	HOUR	NOV 11	NOV 12	NOV 13	NOV 14	NOV 15	NOV 16	NOV 17	NOV 18	NOV 19	NOV 20
JUANA DIAZ DIRECT RADIATION	6:00:00 AM	0	0	0	0	0	0	190.4	0	0	0
	7:00:00 AM	621.3	637.7	402.3	187.4	610.8	553.2	608.3	628.2	633.6	576.8
	8:00:00 AM	772	466.3	775.2	647	555.6	438	574.1	707.3	647.3	701.8
	9:00:00 AM	638.8	795.3	837.2	700.1	788.8	774.1	616.6	733.8	742.8	741.7
	10:00:00 AM	789.2	843.6	810.8	407.9	787.6	529.7	785.2	450.9	934.3	767.7
	11:00:00 AM	777.4	897.9	802.1	791.7	769.5	770	223.5	293.4	87.7	768.6
	12:00:00 PM	731.2	120.1	642.2	707.6	836.8	709	202.1	859.8	749.8	701.2
	1:00:00 PM	639.4	291.8	628.5	617.9	423.7	593.3	675.7	7.7	598.2	614.1
	2:00:00 PM	423.6	575.3	581.9	473.9	0.5	459.7	384	0.5	401.2	437
	3:00:00 PM	98.3	3	532	177.8	1	47.4	43.1	2	81.1	87.3
	4:00:00 PM	2.9	1.7	39.3	5.2	1.1	0.6	2.3	2.3	0.6	1.1
	5:00:00 PM	0	0	0	0	0	0	0	0	0	0
	6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	NOV 21	NOV 22	NOV 23	NOV 24	NOV 25	NOV 26	NOV 27	NOV 28	NOV 29	NOV 30
6:00:00 AM	0	0	0	0	199.8	157.4	173.9	97.6	82.4	140.4
7:00:00 AM	610	492.4	528.1	605.9	251.7	486.8	524.7	513.3	1.7	498.6
8:00:00 AM	772.7	211.5	517.6	156.4	52.8	553	686	660.5	11.5	641.6
9:00:00 AM	747.2	676.5	774.6	668.1	610.7	731.3	684.4	731	8.2	713.7
10:00:00 AM	784.7	788.5	760.8	796.9	720	483.9	7.8	766.2	43.1	765.6
11:00:00 AM	750	788.5	700.2	765.5	315.7	139.7	452.3	720.6	280.2	505.6
12:00:00 PM	698.3	741.6	262.5	650.8	22.1	57.1	4.8	546.3	375.1	288.3
1:00:00 PM	556.7	623.7	5.7	612.2	28.7	87	344.5	162.4	244.4	757.8
2:00:00 PM	187.7	416.3	10.5	442.5	3.9	223.8	96	617.3	442.9	630.5
3:00:00 PM	30.9	80.1	6.8	31.3	17.2	547.8	4	306	36.2	381.7
4:00:00 PM	1.1	0.6	0.6	1.1	5.5	1.1	6	2.2	2.1	2.7
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	DIC 1	DIC 2	DIC 3	DIC 4	DIC 5	DIC 6	DIC 7	DIC 8	DIC 9	DIC 10
6:00:00 AM	135.6	123.8	120.8	78.1	64.1	0	0	0	0	0
7:00:00 AM	473.7	458.2	95.4	210.6	426.8	456.1	467.8	462.4	475	438.8
8:00:00 AM	620.8	572.2	581.3	600	585.1	608.6	612.5	614.5	643.6	592.8
9:00:00 AM	719	692.2	489.8	672.2	672.8	424.6	676.5	639.9	476.3	595.4
10:00:00 AM	786	186.8	719.5	786.5	22.7	379.8	533.6	635	197.7	147.2
11:00:00 AM	729.5	76	559.3	473	25.3	664.5	864.2	769.6	40.7	770.4
12:00:00 PM	245.6	38.6	7.5	312.7	714.3	528	524.7	57.4	883.5	853.5
1:00:00 PM	642.8	2.3	10	13.9	0.7	210.1	556.4	427.8	763.8	27.7
2:00:00 PM	542.8	201.9	33.5	3.9	1	236.6	683.2	196.9	658.6	36
3:00:00 PM	307.7	470.9	157.1	9.8	7.8	146.4	207.3	404.4	655.9	1.2
4:00:00 PM	5.3	2.6	4.7	1.6	1.5	3.1	3.6	2.5	3.5	2
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

JUANA DIAZ DIRECT RADIATION

HOUR	DIC 11	DIC 12	DIC 13	DIC 14	DIC 15	DIC 16	DIC 17	DIC 18	DIC 19	DIC 20
6:00:00 AM	0	0	0	0	0	0	0	0	0	0
7:00:00 AM	561.4	0	448.9	467	170	4.7	398.1	12.2	358.1	264
8:00:00 AM	542.8	715.8	630.9	604.5	23.3	11.2	497.8	22.4	554.3	247.7
9:00:00 AM	616.5	724.2	183.5	625.4	8.8	2.4	573.5	2.9	672.2	537.7
10:00:00 AM	802.7	766.3	67.9	43.4	3	13	715.5	1.1	744.6	337.1
11:00:00 AM	393.4	729.5	53.8	356.1	0.9	30.8	660.7	2	732.2	715
12:00:00 PM	612.7	711	417.1	412.7	1.2	3.7	267.1	9.2	720.3	422.6
1:00:00 PM	505.7	596.8	427.1	540.7	2.3	5.6	77.2	16.4	682.1	702.5
2:00:00 PM	269	365.1	490.9	293	4.3	3	828.2	3.8	552.9	285.2
3:00:00 PM	7.5	11.5	393.5	12.9	1.4	2.6	142.1	74.9	351.3	120.1
4:00:00 PM	0.5	0.5	3.4	4.8	2.9	0.5	1.9	1.4	3.7	6.4
5:00:00 PM	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0

JUANA DIAZ DIRECT RADIATION

HOUR	DIC 21	DIC 22	DIC 23	DIC 24	DIC 25	DIC 26	DIC 27	DIC 28	DIC 29	DIC 30	DIC 31
6:00:00 AM	0	0	0	0	0	0	0	0	0	0	0
7:00:00 AM	48	2.1	473.9	459.4	319.3	364.3	413.8	425.9	314.1	132.1	34
8:00:00 AM	425.9	4.4	659.3	614.4	550	565.7	579.1	598.5	569.6	134.3	534.1
9:00:00 AM	527.1	53.6	35.8	534.5	535.2	567	389.2	719.1	37.5	80.9	88.6
10:00:00 AM	717.9	13.8	10.3	374.5	658.6	784.1	451	642.5	685.1	266.7	24.4
11:00:00 AM	778.5	96.2	14.1	509.6	795.6	751.4	770.1	753.2	206.9	323.6	709.6
12:00:00 PM	845.8	36.9	72.1	194.1	747.1	746.2	804.6	576.7	766	173.3	790.5
1:00:00 PM	795.9	58.8	29.6	324.9	396	701	169.8	548.2	739.7	215.7	763.6
2:00:00 PM	660.1	46	17.3	81.5	438.8	625.7	102.6	534.6	625.5	437	653
3:00:00 PM	262.6	57.4	9.9	422.7	341.4	372.1	135	222.1	480.2	55.3	411.2
4:00:00 PM	4.6	1.8	4.9	5.8	4.4	11.4	6.1	21.1	8.1	2.5	5.1
5:00:00 PM	0	0	0	0	0	0	0	0	0	0	0
6:00:00 PM	0	0	0	0	0	0	0	0	0	0	0

- Irradiation values in W/m^2

APPENDIX B

HOURLY ESTIMATIONS OF DIRECT SOLAR RADIATION FROM SANTO DOMINGO

SANTO DOMINGO DIRECT RADIATION

HOUR	JAN 1	JAN 2	JAN 3	JAN 4	JAN 5	JAN 6	JAN 7	JAN 8	JAN 9	JAN 10
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	373.8	114.9	12.0	354.8	6.0	225.3	388.0	0.0	322.8	192.5
8:00:00 AM	476.9	196.9	96.9	435.7	81.6	316.4	489.6	0.0	403.7	275.6
9:00:00 AM	565.5	267.2	169.8	505.2	146.6	394.7	576.7	33.0	473.2	346.9
10:00:00 AM	633.5	321.2	225.8	558.5	196.5	454.7	643.6	71.2	526.5	401.7
11:00:00 AM	676.2	355.2	261.0	592.0	227.8	492.5	685.7	95.3	560.1	436.1
12:00:00 PM	690.9	366.8	273.0	603.5	238.5	505.4	700.0	103.5	571.5	447.9
1:00:00 PM	676.2	355.2	261.0	592.0	227.8	492.5	685.7	95.3	560.1	436.1
2:00:00 PM	633.5	321.2	225.8	558.5	196.5	454.7	643.6	71.2	526.5	401.7
3:00:00 PM	565.5	267.2	169.8	505.2	146.6	394.7	576.7	33.0	473.2	346.9
4:00:00 PM	476.9	196.9	96.9	435.7	81.6	316.4	489.6	0.0	403.7	275.6
5:00:00 PM	373.8	114.9	12.0	354.8	6.0	225.3	388.0	0.0	322.8	192.5
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION

HOUR	JAN 11	JAN 12	JAN 13	JAN 14	JAN 15	JAN 16	JAN 17	JAN 18	JAN 19	JAN 20
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	388.9	464.2	446.0	283.3	405.2	333.7	378.9	250.3	316.9	222.2
8:00:00 AM	487.8	570.1	547.8	376.1	500.0	424.4	481.3	349.7	413.5	301.7
9:00:00 AM	572.7	661.0	635.1	455.7	581.4	502.4	569.2	435.2	496.5	369.9
10:00:00 AM	637.8	730.7	702.2	516.8	643.9	562.2	636.6	500.7	560.1	422.3
11:00:00 AM	678.8	774.6	744.3	555.3	683.2	599.7	679.0	541.9	600.1	455.3
12:00:00 PM	692.8	789.5	758.7	568.4	696.6	612.6	693.5	556.0	613.8	466.5
1:00:00 PM	678.8	774.6	744.3	555.3	683.2	599.7	679.0	541.9	600.1	455.3
2:00:00 PM	637.8	730.7	702.2	516.8	643.9	562.2	636.6	500.7	560.1	422.3
3:00:00 PM	572.7	661.0	635.1	455.7	581.4	502.4	569.2	435.2	496.5	369.9
4:00:00 PM	487.8	570.1	547.8	376.1	500.0	424.4	481.3	349.7	413.5	301.7
5:00:00 PM	388.9	464.2	446.0	283.3	405.2	333.7	378.9	250.3	316.9	222.2
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	JAN 21	JAN 22	JAN 23	JAN 24	JAN 25	JAN 26	JAN 27	JAN 28	JAN 29	JAN 30	JAN 31
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	388.5	175.7	220.7	383.7	229.3	475.6	147.5	536.0	465.3	537.0	388.5
8:00:00 AM	486.5	247.3	310.0	483.6	322.9	580.1	224.0	643.9	572.6	639.2	486.5
9:00:00 AM	570.7	308.8	386.8	569.4	403.3	669.9	289.7	736.6	664.7	726.8	570.7
10:00:00 AM	635.2	356.1	445.7	635.2	464.9	738.8	340.2	807.7	735.4	794.1	635.2
11:00:00 AM	675.8	385.7	482.7	676.6	503.7	782.1	371.9	852.4	779.8	836.4	675.8
12:00:00 PM	689.7	395.8	495.3	690.8	516.9	796.9	382.7	867.6	795.0	850.9	689.7
1:00:00 PM	675.8	385.7	482.7	676.6	503.7	782.1	371.9	852.4	779.8	836.4	675.8
2:00:00 PM	635.2	356.1	445.7	635.2	464.9	738.8	340.2	807.7	735.4	794.1	635.2
3:00:00 PM	570.7	308.8	386.8	569.4	403.3	669.9	289.7	736.6	664.7	726.8	570.7
4:00:00 PM	486.5	247.3	310.0	483.6	322.9	580.1	224.0	643.9	572.6	639.2	486.5
5:00:00 PM	388.5	175.7	220.7	383.7	229.3	475.6	147.5	536.0	465.3	537.0	388.5
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION

HOUR	FEB 1	FEB 2	FEB 3	FEB 4	FEB 5	FEB 6	FEB 7	FEB 8	FEB 9	FEB 10
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	491.7	445.5	313.6	-38.3	106.4	338.4	169.8	328.9	92.2	0.0
8:00:00 AM	592.6	549.1	406.7	35.7	185.3	437.2	254.1	425.4	172.0	40.1
9:00:00 AM	679.2	638.0	486.6	99.3	253.1	522.1	326.5	508.2	240.5	103.0
10:00:00 AM	745.7	706.2	547.9	148.0	305.1	587.2	382.0	571.8	293.0	151.3
11:00:00 AM	787.5	749.1	586.4	178.7	337.8	628.1	416.9	611.8	326.1	181.6
12:00:00 PM	801.8	763.8	599.6	189.1	348.9	642.1	428.8	625.4	337.3	191.9
1:00:00 PM	787.5	749.1	586.4	178.7	337.8	628.1	416.9	611.8	326.1	181.6
2:00:00 PM	745.7	706.2	547.9	148.0	305.1	587.2	382.0	571.8	293.0	151.3
3:00:00 PM	679.2	638.0	486.6	99.3	253.1	522.1	326.5	508.2	240.5	103.0
4:00:00 PM	592.6	549.1	406.7	35.7	185.3	437.2	254.1	425.4	172.0	40.1
5:00:00 PM	491.7	445.5	313.6	-38.3	106.4	338.4	169.8	328.9	92.2	0.0
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in w/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	FEB 11	FEB 12	FEB 13	FEB 14	FEB 15	FEB 16	FEB 17	FEB 18	FEB 19	FEB 20
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	0.0	471.2	382.0	109.4	64.5	48.2	52.3	470.5	375.7	469.1
	8:00:00 AM	0.0	574.4	482.5	197.0	130.2	116.6	81.2	572.7	467.3	567.9
	9:00:00 AM	0.0	663.1	568.8	272.3	186.7	175.3	106.1	660.4	545.9	652.7
	10:00:00 AM	7.1	731.1	635.1	330.0	230.1	220.3	125.2	727.7	606.3	717.9
	11:00:00 AM	24.4	773.9	676.7	366.3	257.3	248.7	137.2	770.0	644.2	758.8
	12:00:00 PM	30.2	788.5	690.9	378.7	266.6	258.3	141.3	784.4	657.2	772.8
	1:00:00 PM	24.4	773.9	676.7	366.3	257.3	248.7	137.2	770.0	644.2	758.8
	2:00:00 PM	7.1	731.1	635.1	330.0	230.1	220.3	125.2	727.7	606.3	717.9
	3:00:00 PM	0.0	663.1	568.8	272.3	186.7	175.3	106.1	660.4	545.9	652.7
	4:00:00 PM	0.0	574.4	482.5	197.0	130.2	116.6	81.2	572.7	467.3	567.9
	5:00:00 PM	0.0	471.2	382.0	109.4	64.5	48.2	52.3	470.5	375.7	469.1
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION	HOUR	FEB 21	FEB 22	FEB 23	FEB 24	FEB 25	FEB 26	FEB 27	FEB 28
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	563.4	543.0	562.7	461.7	521.7	513.2	449.7	392.4
	8:00:00 AM	667.4	644.3	664.3	562.2	622.4	613.7	551.4	486.9
	9:00:00 AM	756.7	731.3	751.6	648.4	708.9	700.0	638.7	568.1
	10:00:00 AM	825.2	798.1	818.5	714.6	775.3	766.3	705.7	630.4
	11:00:00 AM	868.3	840.1	860.6	756.3	817.0	807.9	747.8	669.6
	12:00:00 PM	883.0	854.4	875.0	770.4	831.2	822.1	762.2	682.9
	1:00:00 PM	868.3	840.1	860.6	756.3	817.0	807.9	747.8	669.6
	2:00:00 PM	825.2	798.1	818.5	714.6	775.3	766.3	705.7	630.4
	3:00:00 PM	756.7	731.3	751.6	648.4	708.9	700.0	638.7	568.1
	4:00:00 PM	667.4	644.3	664.3	562.2	622.4	613.7	551.4	486.9
	5:00:00 PM	563.4	543.0	562.7	461.7	521.7	513.2	449.7	392.4
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	MAR 1	MAR 2	MAR 3	MAR 4	MAR 5	MAR 6	MAR 7	MAR 8	MAR 9	MAR 10
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	338.7	116.1	298.6	540.1	395.2	571.6	449.9	134.0	527.9	375.4
	8:00:00 AM	424.7	190.6	386.1	642.3	486.1	676.0	547.5	208.3	619.9	463.4
	9:00:00 AM	498.5	254.6	461.3	730.1	564.1	765.7	631.4	272.0	699.0	538.9
	10:00:00 AM	555.2	303.7	519.0	797.4	624.0	834.5	695.7	321.0	759.6	596.9
	11:00:00 AM	590.8	334.5	555.3	839.8	661.6	877.8	736.1	351.7	797.7	633.3
	12:00:00 PM	602.9	345.1	567.6	854.2	674.5	892.5	749.9	362.2	810.7	645.8
	1:00:00 PM	590.8	334.5	555.3	839.8	661.6	877.8	736.1	351.7	797.7	633.3
	2:00:00 PM	555.2	303.7	519.0	797.4	624.0	834.5	695.7	321.0	759.6	596.9
	3:00:00 PM	498.5	254.6	461.3	730.1	564.1	765.7	631.4	272.0	699.0	538.9
	4:00:00 PM	424.7	190.6	386.1	642.3	486.1	676.0	547.5	208.3	619.9	463.4
	5:00:00 PM	338.7	116.1	298.6	540.1	395.2	571.6	449.9	134.0	527.9	375.4
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION	HOUR	MAR 11	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18	MAR 19	MAR 20
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	479.0	147.1	141.5	56.0	110.8	527.7	177.4	542.6	513.8	482.5
	8:00:00 AM	578.9	205.0	210.9	130.9	182.7	630.7	252.5	642.0	610.1	579.0
	9:00:00 AM	664.6	254.8	270.5	195.2	244.4	719.2	317.1	727.3	692.8	661.9
	10:00:00 AM	730.4	292.9	316.3	244.5	291.8	787.1	366.6	792.7	756.2	725.6
	11:00:00 AM	771.8	316.9	345.0	275.5	321.6	829.8	397.7	833.9	796.1	765.6
	12:00:00 PM	785.9	325.1	354.8	286.1	331.7	844.3	408.3	847.9	809.7	779.2
	1:00:00 PM	771.8	316.9	345.0	275.5	321.6	829.8	397.7	833.9	796.1	765.6
	2:00:00 PM	730.4	292.9	316.3	244.5	291.8	787.1	366.6	792.7	756.2	725.6
	3:00:00 PM	664.6	254.8	270.5	195.2	244.4	719.2	317.1	727.3	692.8	661.9
	4:00:00 PM	578.9	205.0	210.9	130.9	182.7	630.7	252.5	642.0	610.1	579.0
	5:00:00 PM	479.0	147.1	141.5	56.0	110.8	527.7	177.4	542.6	513.8	482.5
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	MAR 21	MAR 22	MAR 23	MAR 24	MAR 25	MAR 26	MAR 27	MAR 28	MAR 29	MAR 30	MAR 31
	6:00:00 AM	0.0	404.6	0.0	0.0	390.7	444.2	419.1	398.1	420.8	196.2	0.0
	7:00:00 AM	520.2	507.0	0.0	0.0	488.0	546.8	518.6	496.7	522.5	278.5	520.2
	8:00:00 AM	615.3	602.4	38.7	28.4	578.6	642.4	611.4	588.6	617.4	355.1	615.3
	9:00:00 AM	697.0	684.4	87.3	71.3	656.4	724.5	691.1	667.4	698.8	421.0	697.0
	10:00:00 AM	759.8	747.2	124.6	104.2	716.2	787.6	752.2	728.0	761.3	471.5	759.8
	11:00:00 AM	799.2	786.8	148.1	124.9	753.7	827.2	790.6	766.0	800.6	503.3	799.2
	12:00:00 PM	812.6	800.2	156.1	131.9	766.5	840.7	803.7	779.0	814.0	514.1	812.6
	1:00:00 PM	799.2	786.8	148.1	124.9	753.7	827.2	790.6	766.0	800.6	503.3	799.2
	2:00:00 PM	759.8	747.2	124.6	104.2	716.2	787.6	752.2	728.0	761.3	471.5	759.8
	3:00:00 PM	697.0	684.4	87.3	71.3	656.4	724.5	691.1	667.4	698.8	421.0	697.0
	4:00:00 PM	615.3	602.4	38.7	28.4	578.6	642.4	611.4	588.6	617.4	355.1	615.3
	5:00:00 PM	520.2	507.0	0.0	0.0	488.0	546.8	518.6	496.7	522.5	278.5	520.2
	6:00:00 PM	0.0	404.6	0.0	0.0	390.7	444.2	419.1	398.1	420.8	196.2	0.0

SANTO DOMINGO DIRECT RADIATION	HOUR	APR 1	APR 2	APR 3	APR 4	APR 5	APR 6	APR 7	APR 8	APR 9	APR 10
	6:00:00 AM	353.8	1.9	250.8	373.4	322.1	279.6	222.1	306.4	350.1	507.3
	7:00:00 AM	448.2	61.9	340.3	469.6	417.9	374.9	314.5	402.4	447.1	609.3
	8:00:00 AM	536.3	117.8	423.7	559.3	507.1	463.7	400.6	491.8	537.5	704.4
	9:00:00 AM	611.9	165.7	495.3	636.3	583.7	539.9	474.6	568.5	615.2	786.0
	10:00:00 AM	669.9	202.6	550.2	695.4	642.5	598.4	531.4	627.5	674.8	848.7
	11:00:00 AM	706.3	225.7	584.7	732.5	679.5	635.2	567.1	664.5	712.2	888.1
	12:00:00 PM	718.8	233.6	596.5	745.2	692.1	647.7	579.2	677.1	725.0	901.5
	1:00:00 PM	706.3	225.7	584.7	732.5	679.5	635.2	567.1	664.5	712.2	888.1
	2:00:00 PM	669.9	202.6	550.2	695.4	642.5	598.4	531.4	627.5	674.8	848.7
	3:00:00 PM	611.9	165.7	495.3	636.3	583.7	539.9	474.6	568.5	615.2	786.0
	4:00:00 PM	536.3	117.8	423.7	559.3	507.1	463.7	400.6	491.8	537.5	704.4
	5:00:00 PM	448.2	61.9	340.3	469.6	417.9	374.9	314.5	402.4	447.1	609.3
	6:00:00 PM	353.8	1.9	250.8	373.4	322.1	279.6	222.1	306.4	350.1	507.3

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	APR 11	APR 12	APR 13	APR 14	APR 15	APR 16	APR 17	APR 18	APR 19	APR 20
6:00:00 AM	354.9	345.2	252.1	355.9	157.9	429.2	333.8	433.8	220.4	216.9
7:00:00 AM	451.9	435.1	335.0	445.4	243.6	527.8	425.2	532.3	302.8	295.9
8:00:00 AM	542.2	518.9	412.4	528.8	323.5	619.6	510.3	624.1	379.6	369.6
9:00:00 AM	619.7	590.8	478.8	600.4	392.0	698.5	583.4	703.0	445.5	432.8
10:00:00 AM	679.2	646.0	529.7	655.3	444.6	759.0	639.5	763.4	496.1	481.4
11:00:00 AM	716.6	680.7	561.7	689.9	477.7	797.1	674.8	801.5	527.9	511.9
12:00:00 PM	729.4	692.6	572.7	701.7	489.0	810.1	686.8	814.4	538.7	522.3
1:00:00 PM	716.6	680.7	561.7	689.9	477.7	797.1	674.8	801.5	527.9	511.9
2:00:00 PM	679.2	646.0	529.7	655.3	444.6	759.0	639.5	763.4	496.1	481.4
3:00:00 PM	619.7	590.8	478.8	600.4	392.0	698.5	583.4	703.0	445.5	432.8
4:00:00 PM	542.2	518.9	412.4	528.8	323.5	619.6	510.3	624.1	379.6	369.6
5:00:00 PM	451.9	435.1	335.0	445.4	243.6	527.8	425.2	532.3	302.8	295.9
6:00:00 PM	354.9	345.2	252.1	355.9	157.9	429.2	333.8	433.8	220.4	216.9

SANTO DOMINGO DIRECT RADIATION

HOUR	APR 21	APR 22	APR 23	APR 24	APR 25	APR 26	APR 27	APR 28	APR 29	APR 30
6:00:00 AM	72.1	185.1	310.3	324.7	428.2	394.8	0.0	310.4	367.3	384.1
7:00:00 AM	136.7	257.6	390.7	409.9	518.5	481.1	1.1	382.7	452.4	472.4
8:00:00 AM	196.9	325.2	465.5	489.3	602.7	561.6	36.3	450.2	531.6	554.8
9:00:00 AM	248.6	383.2	529.8	557.4	675.0	630.7	66.5	508.1	599.7	625.5
10:00:00 AM	288.3	427.7	579.1	609.7	730.5	683.8	89.7	552.5	652.0	679.8
11:00:00 AM	313.2	455.7	610.1	642.6	765.4	717.1	104.2	580.4	684.8	713.9
12:00:00 PM	321.7	465.3	620.7	653.8	777.2	728.5	109.2	590.0	696.0	725.6
1:00:00 PM	313.2	455.7	610.1	642.6	765.4	717.1	104.2	580.4	684.8	713.9
2:00:00 PM	288.3	427.7	579.1	609.7	730.5	683.8	89.7	552.5	652.0	679.8
3:00:00 PM	248.6	383.2	529.8	557.4	675.0	630.7	66.5	508.1	599.7	625.5
4:00:00 PM	196.9	325.2	465.5	489.3	602.7	561.6	36.3	450.2	531.6	554.8
5:00:00 PM	136.7	257.6	390.7	409.9	518.5	481.1	1.1	382.7	452.4	472.4
6:00:00 PM	72.1	185.1	310.3	324.7	428.2	394.8	0.0	310.4	367.3	384.1

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	MAY 1	MAY 2	MAY 3	MAY 4	MAY 5	MAY 6	MAY 7	MAY 8	MAY 9	MAY 10
6:00:00 AM	353.1	365.0	276.3	237.3	181.7	93.8	146.9	430.7	491.7	389.8
7:00:00 AM	438.3	455.6	354.6	313.2	246.0	155.1	211.6	520.4	579.1	481.1
8:00:00 AM	517.7	540.1	427.5	383.9	306.0	212.3	271.8	604.0	660.5	566.2
9:00:00 AM	585.9	612.6	490.1	444.7	357.5	261.4	323.6	675.8	730.4	639.3
10:00:00 AM	638.2	668.3	538.2	491.3	397.0	299.0	363.3	730.9	784.0	695.3
11:00:00 AM	671.1	703.3	568.4	520.6	421.8	322.7	388.2	765.5	817.8	730.6
12:00:00 PM	682.4	715.2	578.7	530.6	430.3	330.8	396.7	777.3	829.3	742.6
1:00:00 PM	671.1	703.3	568.4	520.6	421.8	322.7	388.2	765.5	817.8	730.6
2:00:00 PM	638.2	668.3	538.2	491.3	397.0	299.0	363.3	730.9	784.0	695.3
3:00:00 PM	585.9	612.6	490.1	444.7	357.5	261.4	323.6	675.8	730.4	639.3
4:00:00 PM	517.7	540.1	427.5	383.9	306.0	212.3	271.8	604.0	660.5	566.2
5:00:00 PM	438.3	455.6	354.6	313.2	246.0	155.1	211.6	520.4	579.1	481.1
6:00:00 PM	353.1	365.0	276.3	237.3	181.7	93.8	146.9	430.7	491.7	389.8

SANTO DOMINGO DIRECT RADIATION

HOUR	MAY 11	MAY 12	MAY 13	MAY 14	MAY 15	MAY 16	MAY 17	MAY 18	MAY 19	MAY 20
6:00:00 AM	344.0	305.2	198.6	354.3	489.6	526.2	484.8	479.4	280.7	240.3
7:00:00 AM	430.9	389.7	267.0	444.6	580.8	616.1	572.1	566.9	355.0	307.3
8:00:00 AM	511.9	468.6	330.8	528.8	665.7	699.9	653.5	648.4	424.3	369.7
9:00:00 AM	581.4	536.2	385.6	601.1	738.7	771.8	723.3	718.4	483.7	423.3
10:00:00 AM	634.7	588.2	427.6	656.6	794.6	827.1	776.9	772.0	529.3	464.5
11:00:00 AM	668.3	620.8	454.0	691.5	829.8	861.8	810.6	805.8	558.0	490.4
12:00:00 PM	679.7	631.9	463.0	703.4	841.8	873.6	822.1	817.3	567.8	499.2
1:00:00 PM	668.3	620.8	454.0	691.5	829.8	861.8	810.6	805.8	558.0	490.4
2:00:00 PM	634.7	588.2	427.6	656.6	794.6	827.1	776.9	772.0	529.3	464.5
3:00:00 PM	581.4	536.2	385.6	601.1	738.7	771.8	723.3	718.4	483.7	423.3
4:00:00 PM	511.9	468.6	330.8	528.8	665.7	699.9	653.5	648.4	424.3	369.7
5:00:00 PM	430.9	389.7	267.0	444.6	580.8	616.1	572.1	566.9	355.0	307.3
6:00:00 PM	344.0	305.2	198.6	354.3	489.6	526.2	484.8	479.4	280.7	240.3

- Irradiation values in w/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	MAY 21	MAY 22	MAY 23	MAY 24	MAY 25	MAY 26	MAY 27	MAY 28	MAY 29	MAY 30	MAY 31
	6:00:00 AM	206.8	3.1	56.5	70.4	190.9	182.8	107.2	0.0	371.7	252.0	206.8
	7:00:00 AM	276.7	43.1	98.7	116.6	254.9	249.3	159.2	8.3	457.4	328.5	276.7
	8:00:00 AM	341.9	80.3	138.1	159.7	314.6	311.4	207.7	39.2	537.3	399.9	341.9
	9:00:00 AM	397.8	112.3	171.9	196.7	365.8	364.7	249.4	65.7	605.8	461.1	397.8
	10:00:00 AM	440.8	136.9	197.9	225.1	405.1	405.6	281.3	86.1	658.4	508.1	440.8
	11:00:00 AM	467.7	152.3	214.2	242.9	429.8	431.3	301.4	98.9	691.5	537.6	467.7
	12:00:00 PM	476.9	157.6	219.8	249.0	438.2	440.0	308.3	103.3	702.8	547.7	476.9
	1:00:00 PM	467.7	152.3	214.2	242.9	429.8	431.3	301.4	98.9	691.5	537.6	467.7
	2:00:00 PM	440.8	136.9	197.9	225.1	405.1	405.6	281.3	86.1	658.4	508.1	440.8
	3:00:00 PM	397.8	112.3	171.9	196.7	365.8	364.7	249.4	65.7	605.8	461.1	397.8
	4:00:00 PM	341.9	80.3	138.1	159.7	314.6	311.4	207.7	39.2	537.3	399.9	341.9
	5:00:00 PM	276.7	43.1	98.7	116.6	254.9	249.3	159.2	8.3	457.4	328.5	276.7
	6:00:00 PM	206.8	3.1	56.5	70.4	190.9	182.8	107.2	0.0	371.7	252.0	206.8

SANTO DOMINGO DIRECT RADIATION	HOUR	JUN 1	JUN 2	JUN 3	JUN 4	JUN 5	JUN 6	JUN 7	JUN 8	JUN 9	JUN 10
	6:00:00 AM	0.0	154.6	368.3	357.1	189.4	57.5	0.0	260.9	277.6	209.2
	7:00:00 AM	27.7	223.2	447.4	426.9	240.5	92.6	0.0	332.7	353.6	278.2
	8:00:00 AM	61.3	287.0	521.2	491.9	288.1	125.4	0.0	399.6	424.5	342.5
	9:00:00 AM	90.1	341.9	584.5	547.7	329.0	153.5	12.9	457.0	485.3	397.7
	10:00:00 AM	112.2	384.0	633.1	590.5	360.4	175.0	26.3	501.1	532.0	440.1
	11:00:00 AM	126.1	410.5	663.6	617.4	380.1	188.6	34.8	528.8	561.3	466.8
	12:00:00 PM	130.8	419.5	674.0	626.6	386.8	193.2	37.6	538.2	571.3	475.9
	1:00:00 PM	126.1	410.5	663.6	617.4	380.1	188.6	34.8	528.8	561.3	466.8
	2:00:00 PM	112.2	384.0	633.1	590.5	360.4	175.0	26.3	501.1	532.0	440.1
	3:00:00 PM	90.1	341.9	584.5	547.7	329.0	153.5	12.9	457.0	485.3	397.7
	4:00:00 PM	61.3	287.0	521.2	491.9	288.1	125.4	0.0	399.6	424.5	342.5
	5:00:00 PM	27.7	223.2	447.4	426.9	240.5	92.6	0.0	332.7	353.6	278.2
	6:00:00 PM	0.0	154.6	368.3	357.1	189.4	57.5	0.0	260.9	277.6	209.2

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	JUN 11	JUN 12	JUN 13	JUN 14	JUN 15	JUN 16	JUN 17	JUN 18	JUN 19	JUN 20
	6:00:00 AM	95.9	118.5	0.0	276.4	266.6	199.7	0.0	50.7	221.4	325.0
	7:00:00 AM	147.4	169.3	39.6	354.2	345.7	277.8	0.0	100.4	288.9	410.3
	8:00:00 AM	195.4	216.6	85.6	426.6	419.3	350.5	0.0	146.8	351.8	489.7
	9:00:00 AM	236.6	257.3	125.2	488.9	482.6	413.0	0.0	186.5	405.8	557.9
	10:00:00 AM	268.2	288.5	155.6	536.6	531.1	460.9	8.6	217.1	447.2	610.3
	11:00:00 AM	288.1	308.1	174.7	566.6	561.7	491.0	17.3	236.2	473.2	643.2
	12:00:00 PM	294.8	314.8	181.2	576.9	572.1	501.3	20.2	242.8	482.1	654.4
	1:00:00 PM	288.1	308.1	174.7	566.6	561.7	491.0	17.3	236.2	473.2	643.2
	2:00:00 PM	268.2	288.5	155.6	536.6	531.1	460.9	8.6	217.1	447.2	610.3
	3:00:00 PM	236.6	257.3	125.2	488.9	482.6	413.0	0.0	186.5	405.8	557.9
	4:00:00 PM	195.4	216.6	85.6	426.6	419.3	350.5	0.0	146.8	351.8	489.7
	5:00:00 PM	147.4	169.3	39.6	354.2	345.7	277.8	0.0	100.4	288.9	410.3
	6:00:00 PM	95.9	118.5	0.0	276.4	266.6	199.7	0.0	50.7	221.4	325.0

SANTO DOMINGO DIRECT RADIATION	HOUR	JUN 21	JUN 22	JUN 23	JUN 24	JUN 25	JUN 26	JUN 27	JUN 28	JUN 29	JUN 30
	6:00:00 AM	335.9	240.0	198.6	252.2	253.8	301.5	214.4	182.1	399.4	264.5
	7:00:00 AM	419.5	318.4	273.7	331.2	325.3	378.2	289.2	248.1	478.3	335.1
	8:00:00 AM	497.4	391.4	343.6	404.9	391.9	449.8	359.0	309.5	551.7	401.0
	9:00:00 AM	564.2	454.1	403.7	468.1	449.1	511.2	418.8	362.3	614.8	457.5
	10:00:00 AM	615.6	502.2	449.8	516.7	493.0	558.3	464.8	402.8	663.3	500.9
	11:00:00 AM	647.8	532.4	478.7	547.2	520.6	588.0	493.6	428.3	693.7	528.2
	12:00:00 PM	658.9	542.7	488.6	557.6	530.0	598.1	503.5	436.9	704.1	537.5
	1:00:00 PM	647.8	532.4	478.7	547.2	520.6	588.0	493.6	428.3	693.7	528.2
	2:00:00 PM	615.6	502.2	449.8	516.7	493.0	558.3	464.8	402.8	663.3	500.9
	3:00:00 PM	564.2	454.1	403.7	468.1	449.1	511.2	418.8	362.3	614.8	457.5
	4:00:00 PM	497.4	391.4	343.6	404.9	391.9	449.8	359.0	309.5	551.7	401.0
	5:00:00 PM	419.5	318.4	273.7	331.2	325.3	378.2	289.2	248.1	478.3	335.1
	6:00:00 PM	335.9	240.0	198.6	252.2	253.8	301.5	214.4	182.1	399.4	264.5

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	JUL 1	JUL 2	JUL 3	JUL 4	JUL 5	JUL 6	JUL 7	JUL 8	JUL 9	JUL 10
	6:00:00 AM	91.6	164.1	261.1	316.6	104.7	36.6	186.9	218.9	267.7	373.5
	7:00:00 AM	132.6	222.9	334.0	394.8	166.4	97.7	251.4	296.0	346.3	449.5
	8:00:00 AM	170.7	277.8	401.8	467.6	223.8	154.6	311.5	368.0	419.5	520.4
	9:00:00 AM	203.5	324.9	460.1	530.2	273.2	203.5	363.0	429.7	482.4	581.2
	10:00:00 AM	228.7	361.0	504.8	578.2	311.1	241.0	402.6	477.1	530.7	627.9
	11:00:00 AM	244.5	383.7	532.9	608.3	334.9	264.6	427.5	506.9	561.0	657.3
	12:00:00 PM	249.9	391.5	542.5	618.6	343.0	272.6	436.0	517.1	571.4	667.3
	1:00:00 PM	244.5	383.7	532.9	608.3	334.9	264.6	427.5	506.9	561.0	657.3
	2:00:00 PM	228.7	361.0	504.8	578.2	311.1	241.0	402.6	477.1	530.7	627.9
	3:00:00 PM	203.5	324.9	460.1	530.2	273.2	203.5	363.0	429.7	482.4	581.2
	4:00:00 PM	170.7	277.8	401.8	467.6	223.8	154.6	311.5	368.0	419.5	520.4
	5:00:00 PM	132.6	222.9	334.0	394.8	166.4	97.7	251.4	296.0	346.3	449.5
	6:00:00 PM	91.6	164.1	261.1	316.6	104.7	36.6	186.9	218.9	267.7	373.5

SANTO DOMINGO DIRECT RADIATION	HOUR	JUL 11	JUL 12	JUL 13	JUL 14	JUL 15	JUL 16	JUL 17	JUL 18	JUL 19	JUL 20
	6:00:00 AM	362.9	111.6	177.3	232.2	0.0	102.7	113.6	194.2	216.8	187.2
	7:00:00 AM	445.0	182.5	247.6	302.6	0.0	164.7	185.8	257.0	287.2	251.7
	8:00:00 AM	521.6	248.6	313.1	368.3	0.0	222.4	253.0	315.6	352.8	311.7
	9:00:00 AM	587.3	305.3	369.4	424.6	0.0	271.9	310.8	365.9	409.1	363.3
	10:00:00 AM	637.8	348.8	412.6	467.9	7.5	310.0	355.1	404.4	452.3	402.8
	11:00:00 AM	669.5	376.2	439.8	495.1	13.8	333.9	382.9	428.7	479.5	427.7
	12:00:00 PM	680.3	385.5	449.0	504.4	15.9	342.0	392.4	437.0	488.8	436.2
	1:00:00 PM	669.5	376.2	439.8	495.1	13.8	333.9	382.9	428.7	479.5	427.7
	2:00:00 PM	637.8	348.8	412.6	467.9	7.5	310.0	355.1	404.4	452.3	402.8
	3:00:00 PM	587.3	305.3	369.4	424.6	0.0	271.9	310.8	365.9	409.1	363.3
	4:00:00 PM	521.6	248.6	313.1	368.3	0.0	222.4	253.0	315.6	352.8	311.7
	5:00:00 PM	445.0	182.5	247.6	302.6	0.0	164.7	185.8	257.0	287.2	251.7
	6:00:00 PM	362.9	111.6	177.3	232.2	0.0	102.7	113.6	194.2	216.8	187.2

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	JUL 21	JUL 22	JUL 23	JUL 24	JUL 25	JUL 26	JUL 27	JUL 28	JUL 29	JUL 30	JUL 31
	6:00:00 AM	210.7	4.5	145.0	133.4	37.0	88.5	0.0	141.1	139.4	87.7	210.7
	7:00:00 AM	286.2	43.3	195.5	190.2	97.4	137.3	26.6	199.8	209.3	125.9	286.2
	8:00:00 AM	356.5	79.5	242.6	243.1	153.6	182.7	77.9	254.5	274.5	161.5	356.5
	9:00:00 AM	416.8	110.6	283.0	288.5	201.8	221.8	122.0	301.5	330.4	192.0	416.8
	10:00:00 AM	463.1	134.4	314.0	323.4	238.9	251.7	155.9	337.5	373.4	215.5	463.1
	11:00:00 AM	492.3	149.4	333.5	345.3	262.2	270.6	177.1	360.2	400.4	230.2	492.3
	12:00:00 PM	502.2	154.5	340.2	352.7	270.1	277.0	184.4	367.9	409.6	235.2	502.2
	1:00:00 PM	492.3	149.4	333.5	345.3	262.2	270.6	177.1	360.2	400.4	230.2	492.3
	2:00:00 PM	463.1	134.4	314.0	323.4	238.9	251.7	155.9	337.5	373.4	215.5	463.1
	3:00:00 PM	416.8	110.6	283.0	288.5	201.8	221.8	122.0	301.5	330.4	192.0	416.8
	4:00:00 PM	356.5	79.5	242.6	243.1	153.6	182.7	77.9	254.5	274.5	161.5	356.5
	5:00:00 PM	286.2	43.3	195.5	190.2	97.4	137.3	26.6	199.8	209.3	125.9	286.2
	6:00:00 PM	210.7	4.5	145.0	133.4	37.0	88.5	0.0	141.1	139.4	87.7	210.7

SANTO DOMINGO DIRECT RADIATION	HOUR	AUG 1	AUG 2	AUG 3	AUG 4	AUG 5	AUG 6	AUG 7	AUG 8	AUG 9	AUG 10
	6:00:00 AM	154.3	0.0	168.7	234.0	227.6	408.1	436.9	335.6	271.1	356.8
	7:00:00 AM	211.6	0.0	239.6	306.5	301.8	500.2	529.9	416.8	346.9	442.9
	8:00:00 AM	264.9	0.0	305.6	374.1	370.8	586.0	616.6	492.5	417.5	523.1
	9:00:00 AM	310.7	0.0	362.3	432.1	430.2	659.6	691.1	557.6	478.1	592.0
	10:00:00 AM	345.8	4.4	405.9	476.6	475.7	716.2	748.3	607.4	524.7	644.8
	11:00:00 AM	367.9	9.3	433.2	504.6	504.3	751.7	784.2	638.8	553.9	678.1
	12:00:00 PM	375.4	10.9	442.6	514.2	514.1	763.8	796.4	649.5	563.9	689.4
	1:00:00 PM	367.9	9.3	433.2	504.6	504.3	751.7	784.2	638.8	553.9	678.1
	2:00:00 PM	345.8	4.4	405.9	476.6	475.7	716.2	748.3	607.4	524.7	644.8
	3:00:00 PM	310.7	0.0	362.3	432.1	430.2	659.6	691.1	557.6	478.1	592.0
	4:00:00 PM	264.9	0.0	305.6	374.1	370.8	586.0	616.6	492.5	417.5	523.1
	5:00:00 PM	211.6	0.0	239.6	306.5	301.8	500.2	529.9	416.8	346.9	442.9
	6:00:00 PM	154.3	0.0	168.7	234.0	227.6	408.1	436.9	335.6	271.1	356.8

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	AUG 11	AUG 12	AUG 13	AUG 14	AUG 15	AUG 16	AUG 17	AUG 18	AUG 19	AUG 20
6:00:00 AM	221.7	242.5	323.9	447.0	241.5	82.7	169.0	46.8	247.6	346.4
7:00:00 AM	298.0	319.8	405.1	535.8	323.3	129.6	243.3	105.8	330.6	429.7
8:00:00 AM	369.1	391.8	480.7	618.5	399.5	173.3	312.5	160.9	408.0	507.4
9:00:00 AM	430.2	453.7	545.7	689.5	464.9	210.8	372.0	208.2	474.4	574.1
10:00:00 AM	477.0	501.1	595.5	744.0	515.1	239.6	417.6	244.4	525.4	625.3
11:00:00 AM	506.5	531.0	626.9	778.3	546.7	257.7	446.3	267.2	557.4	657.5
12:00:00 PM	516.5	541.1	637.5	790.0	557.4	263.9	456.1	275.0	568.4	668.4
1:00:00 PM	506.5	531.0	626.9	778.3	546.7	257.7	446.3	267.2	557.4	657.5
2:00:00 PM	477.0	501.1	595.5	744.0	515.1	239.6	417.6	244.4	525.4	625.3
3:00:00 PM	430.2	453.7	545.7	689.5	464.9	210.8	372.0	208.2	474.4	574.1
4:00:00 PM	369.1	391.8	480.7	618.5	399.5	173.3	312.5	160.9	408.0	507.4
5:00:00 PM	298.0	319.8	405.1	535.8	323.3	129.6	243.3	105.8	330.6	429.7
6:00:00 PM	221.7	242.5	323.9	447.0	241.5	82.7	169.0	46.8	247.6	346.4

SANTO DOMINGO DIRECT RADIATION

HOUR	AUG 21	AUG 22	AUG 23	AUG 24	AUG 25	AUG 26	AUG 27	AUG 28	AUG 29	AUG 30	AUG 31
6:00:00 AM	246.5	98.9	215.4	166.3	246.2	188.8	7.0	0.0	154.1	265.6	246.5
7:00:00 AM	326.5	163.4	299.1	244.2	325.3	254.5	45.4	11.5	237.6	355.0	326.5
8:00:00 AM	401.0	223.6	377.0	316.9	398.9	315.6	81.1	49.6	315.5	438.3	401.0
9:00:00 AM	465.0	275.2	443.9	379.2	462.2	368.2	111.8	82.2	382.3	509.8	465.0
10:00:00 AM	514.1	314.8	495.3	427.1	510.7	408.5	135.3	107.3	433.6	564.7	514.1
11:00:00 AM	544.9	339.7	527.6	457.2	541.2	433.8	150.1	123.1	465.9	599.1	544.9
12:00:00 PM	555.4	348.2	538.6	467.4	551.6	442.5	155.2	128.4	476.9	610.9	555.4
1:00:00 PM	544.9	339.7	527.6	457.2	541.2	433.8	150.1	123.1	465.9	599.1	544.9
2:00:00 PM	514.1	314.8	495.3	427.1	510.7	408.5	135.3	107.3	433.6	564.7	514.1
3:00:00 PM	465.0	275.2	443.9	379.2	462.2	368.2	111.8	82.2	382.3	509.8	465.0
4:00:00 PM	401.0	223.6	377.0	316.9	398.9	315.6	81.1	49.6	315.5	438.3	401.0
5:00:00 PM	326.5	163.4	299.1	244.2	325.3	254.5	45.4	11.5	237.6	355.0	326.5
6:00:00 PM	246.5	98.9	215.4	166.3	246.2	188.8	7.0	0.0	154.1	265.6	246.5

- Irradiation values in w/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	SEPT 1	SEPT 2	SEPT 3	SEPT 4	SEPT 5	SEPT 6	SEPT 7	SEPT 8	SEPT 9	SEPT 10
	6:00:00 AM	69.5	288.5	413.5	418.8	290.0	0.0	233.2	168.3	287.7	249.6
	7:00:00 AM	132.3	371.3	507.0	509.6	375.6	0.0	318.8	241.4	377.5	336.6
	8:00:00 AM	190.8	448.4	594.1	594.1	455.3	0.0	398.6	309.5	461.2	417.7
	9:00:00 AM	241.0	514.6	668.8	666.7	523.8	16.6	467.2	368.0	533.1	487.3
	10:00:00 AM	279.5	565.4	726.2	722.4	576.4	30.4	519.8	412.9	588.2	540.7
	11:00:00 AM	303.8	597.4	762.3	757.5	609.4	39.1	552.8	441.1	622.9	574.3
	12:00:00 PM	312.0	608.3	774.6	769.4	620.7	42.1	564.1	450.7	634.7	585.8
	1:00:00 PM	303.8	597.4	762.3	757.5	609.4	39.1	552.8	441.1	622.9	574.3
	2:00:00 PM	279.5	565.4	726.2	722.4	576.4	30.4	519.8	412.9	588.2	540.7
	3:00:00 PM	241.0	514.6	668.8	666.7	523.8	16.6	467.2	368.0	533.1	487.3
	4:00:00 PM	190.8	448.4	594.1	594.1	455.3	0.0	398.6	309.5	461.2	417.7
	5:00:00 PM	132.3	371.3	507.0	509.6	375.6	0.0	318.8	241.4	377.5	336.6
	6:00:00 PM	69.5	288.5	413.5	418.8	290.0	0.0	233.2	168.3	287.7	249.6

SANTO DOMINGO DIRECT RADIATION	HOUR	SEPT 11	SEPT 12	SEPT 13	SEPT 14	SEPT 15	SEPT 16	SEPT 17	SEPT 18	SEPT 19	SEPT 20
	6:00:00 AM	377.8	410.9	120.5	89.4	26.7	122.5	222.2	209.4	398.7	0.0
	7:00:00 AM	467.8	503.8	183.9	133.8	78.5	190.4	287.9	286.6	498.8	100.3
	8:00:00 AM	551.6	590.4	243.0	175.2	126.7	253.6	349.1	358.6	592.1	167.5
	9:00:00 AM	623.6	664.7	293.7	210.8	168.1	307.9	401.7	420.4	672.2	225.1
	10:00:00 AM	678.8	721.8	332.7	238.1	199.9	349.6	442.0	467.8	733.7	269.4
	11:00:00 AM	713.5	757.6	357.1	255.3	219.9	375.8	467.4	497.6	772.3	297.2
	12:00:00 PM	725.3	769.9	365.5	261.1	226.8	384.7	476.0	507.8	785.5	306.7
	1:00:00 PM	713.5	757.6	357.1	255.3	219.9	375.8	467.4	497.6	772.3	297.2
	2:00:00 PM	678.8	721.8	332.7	238.1	199.9	349.6	442.0	467.8	733.7	269.4
	3:00:00 PM	623.6	664.7	293.7	210.8	168.1	307.9	401.7	420.4	672.2	225.1
	4:00:00 PM	551.6	590.4	243.0	175.2	126.7	253.6	349.1	358.6	592.1	167.5
	5:00:00 PM	467.8	503.8	183.9	133.8	78.5	190.4	287.9	286.6	498.8	100.3
	6:00:00 PM	377.8	410.9	120.5	89.4	26.7	122.5	222.2	209.4	398.7	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	SEPT 21	SEPT 22	SEPT 23	SEPT 24	SEPT 25	SEPT 26	SEPT 27	SEPT 28	SEPT 29	SEPT 30
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	0.0	172.0	334.2	371.7	615.5	529.0	345.4	395.7	404.2	452.1
8:00:00 AM	0.0	237.5	415.7	458.7	712.2	628.8	428.9	484.1	497.3	545.9
9:00:00 AM	3.8	293.7	485.7	533.4	795.2	714.5	500.6	559.9	577.2	626.3
10:00:00 AM	19.3	336.8	539.4	590.7	858.9	780.3	555.7	618.1	638.6	688.1
11:00:00 AM	29.1	364.0	573.2	626.7	899.0	821.6	590.3	654.7	677.2	726.9
12:00:00 PM	32.5	373.2	584.7	639.0	912.6	835.7	602.1	667.1	690.3	740.2
1:00:00 PM	29.1	364.0	573.2	626.7	899.0	821.6	590.3	654.7	677.2	726.9
2:00:00 PM	19.3	336.8	539.4	590.7	858.9	780.3	555.7	618.1	638.6	688.1
3:00:00 PM	3.8	293.7	485.7	533.4	795.2	714.5	500.6	559.9	577.2	626.3
4:00:00 PM	0.0	237.5	415.7	458.7	712.2	628.8	428.9	484.1	497.3	545.9
5:00:00 PM	0.0	172.0	334.2	371.7	615.5	529.0	345.4	395.7	404.2	452.1
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION

HOUR	OCT 1	OCT 2	OCT 3	OCT 4	OCT 5	OCT 6	OCT 7	OCT 8	OCT 9	OCT 10
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	490.5	447.0	342.6	61.7	0.0	238.6	422.2	444.1	553.4	198.6
8:00:00 AM	582.2	540.1	430.3	125.2	0.0	303.9	514.9	536.9	649.1	272.0
9:00:00 AM	661.0	620.2	505.5	179.8	9.1	359.9	594.5	616.7	731.3	335.0
10:00:00 AM	721.4	681.6	563.3	221.6	28.4	402.9	655.5	677.8	794.3	383.4
11:00:00 AM	759.4	720.2	599.6	247.9	40.6	429.9	693.9	716.3	834.0	413.8
12:00:00 PM	772.3	733.3	612.0	256.9	44.7	439.1	707.0	729.4	847.5	424.2
1:00:00 PM	759.4	720.2	599.6	247.9	40.6	429.9	693.9	716.3	834.0	413.8
2:00:00 PM	721.4	681.6	563.3	221.6	28.4	402.9	655.5	677.8	794.3	383.4
3:00:00 PM	661.0	620.2	505.5	179.8	9.1	359.9	594.5	616.7	731.3	335.0
4:00:00 PM	582.2	540.1	430.3	125.2	0.0	303.9	514.9	536.9	649.1	272.0
5:00:00 PM	490.5	447.0	342.6	61.7	0.0	238.6	422.2	444.1	553.4	198.6
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	OCT 11	OCT 12	OCT 13	OCT 14	OCT 15	OCT 16	OCT 17	OCT 18	OCT 19	OCT 20
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	309.3	525.9	386.2	413.7	359.0	469.5	312.5	345.2	410.0	306.2
8:00:00 AM	385.1	623.1	476.6	504.2	437.8	563.2	387.5	423.2	497.7	383.8
9:00:00 AM	450.1	706.6	554.2	581.9	505.4	643.6	451.9	490.1	573.1	450.4
10:00:00 AM	500.1	770.6	613.7	641.6	557.3	705.3	501.4	541.5	630.9	501.5
11:00:00 AM	531.4	810.9	651.2	679.1	590.0	744.1	532.5	573.8	667.2	533.6
12:00:00 PM	542.1	824.6	663.9	691.8	601.1	757.3	543.1	584.8	679.6	544.6
1:00:00 PM	531.4	810.9	651.2	679.1	590.0	744.1	532.5	573.8	667.2	533.6
2:00:00 PM	500.1	770.6	613.7	641.6	557.3	705.3	501.4	541.5	630.9	501.5
3:00:00 PM	450.1	706.6	554.2	581.9	505.4	643.6	451.9	490.1	573.1	450.4
4:00:00 PM	385.1	623.1	476.6	504.2	437.8	563.2	387.5	423.2	497.7	383.8
5:00:00 PM	309.3	525.9	386.2	413.7	359.0	469.5	312.5	345.2	410.0	306.2
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION

HOUR	OCT 21	OCT 22	OCT 23	OCT 24	OCT 25	OCT 26	OCT 27	OCT 28	OCT 29	OCT 30	OCT 31
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	156.3	299.9	392.6	399.8	0.0	114.8	221.2	381.2	425.3	451.8	156.3
8:00:00 AM	216.1	386.5	491.7	493.6	27.2	164.9	292.2	476.5	521.3	548.9	216.1
9:00:00 AM	267.5	460.8	576.9	574.1	73.4	207.9	353.1	558.4	603.7	632.3	267.5
10:00:00 AM	306.9	517.8	642.2	635.9	108.8	240.9	399.9	621.2	666.9	696.3	306.9
11:00:00 AM	331.6	553.7	683.3	674.8	131.1	261.6	429.4	660.7	706.6	736.5	331.6
12:00:00 PM	340.1	565.9	697.3	688.0	138.7	268.7	439.4	674.1	720.2	750.2	340.1
1:00:00 PM	331.6	553.7	683.3	674.8	131.1	261.6	429.4	660.7	706.6	736.5	331.6
2:00:00 PM	306.9	517.8	642.2	635.9	108.8	240.9	399.9	621.2	666.9	696.3	306.9
3:00:00 PM	267.5	460.8	576.9	574.1	73.4	207.9	353.1	558.4	603.7	632.3	267.5
4:00:00 PM	216.1	386.5	491.7	493.6	27.2	164.9	292.2	476.5	521.3	548.9	216.1
5:00:00 PM	156.3	299.9	392.6	399.8	0.0	114.8	221.2	381.2	425.3	451.8	156.3
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION	HOUR	NOV 1	NOV 2	NOV 3	NOV 4	NOV 5	NOV 6	NOV 7	NOV 8	NOV 9	NOV 10
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	455.3	264.7	418.6	267.4	140.5	288.4	123.5	278.5	93.4	505.8
	8:00:00 AM	556.4	347.1	519.9	339.5	210.4	379.5	186.5	370.8	159.4	611.6
	9:00:00 AM	643.2	417.9	606.9	401.4	270.4	457.8	240.6	450.0	216.1	702.5
	10:00:00 AM	709.8	472.3	673.6	449.0	316.4	517.9	282.1	510.9	259.6	772.2
	11:00:00 AM	751.6	506.4	715.6	478.8	345.3	555.6	308.2	549.1	286.9	816.0
	12:00:00 PM	765.9	518.0	729.9	489.0	355.2	568.5	317.1	562.1	296.3	831.0
	1:00:00 PM	751.6	506.4	715.6	478.8	345.3	555.6	308.2	549.1	286.9	816.0
	2:00:00 PM	709.8	472.3	673.6	449.0	316.4	517.9	282.1	510.9	259.6	772.2
	3:00:00 PM	643.2	417.9	606.9	401.4	270.4	457.8	240.6	450.0	216.1	702.5
	4:00:00 PM	556.4	347.1	519.9	339.5	210.4	379.5	186.5	370.8	159.4	611.6
	5:00:00 PM	455.3	264.7	418.6	267.4	140.5	288.4	123.5	278.5	93.4	505.8
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION	HOUR	NOV 11	NOV 12	NOV 13	NOV 14	NOV 15	NOV 16	NOV 17	NOV 18	NOV 19	NOV 20
	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	574.5	246.6	379.8	543.2	20.8	137.8	0.0	397.0	363.6	467.6
	8:00:00 AM	684.3	341.1	476.0	649.2	83.4	210.0	44.8	492.4	456.0	571.1
	9:00:00 AM	778.6	422.3	558.7	740.2	137.1	272.0	104.2	574.3	535.3	660.0
	10:00:00 AM	851.0	484.6	622.1	810.1	178.3	319.6	149.7	637.1	596.1	728.2
	11:00:00 AM	896.5	523.8	661.9	854.0	204.2	349.6	178.3	676.6	634.3	771.1
	12:00:00 PM	912.0	537.2	675.5	868.9	213.1	359.8	188.1	690.1	647.4	785.7
	1:00:00 PM	896.5	523.8	661.9	854.0	204.2	349.6	178.3	676.6	634.3	771.1
	2:00:00 PM	851.0	484.6	622.1	810.1	178.3	319.6	149.7	637.1	596.1	728.2
	3:00:00 PM	778.6	422.3	558.7	740.2	137.1	272.0	104.2	574.3	535.3	660.0
	4:00:00 PM	684.3	341.1	476.0	649.2	83.4	210.0	44.8	492.4	456.0	571.1
	5:00:00 PM	574.5	246.6	379.8	543.2	20.8	137.8	0.0	397.0	363.6	467.6
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

	HOUR	NOV 21	NOV 22	NOV 23	NOV 24	NOV 25	NOV 26	NOV 27	NOV 28	NOV 29	NOV 30
SANTO DOMINGO DIRECT RADIATION	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	252.5	363.8	162.7	229.8	522.4	0.0	0.0	518.5	378.0	315.0
	8:00:00 AM	339.1	464.7	245.3	315.9	624.7	28.6	40.9	625.8	475.8	401.9
	9:00:00 AM	413.6	551.4	316.3	389.9	712.6	90.6	98.9	718.0	559.8	476.6
	10:00:00 AM	470.7	617.9	370.8	446.6	780.0	138.1	143.4	788.7	624.2	533.9
	11:00:00 AM	506.6	659.7	405.1	482.3	822.4	168.0	171.4	833.1	664.7	570.0
	12:00:00 PM	518.9	673.9	416.8	494.4	836.8	178.2	181.0	848.3	678.5	582.3
	1:00:00 PM	506.6	659.7	405.1	482.3	822.4	168.0	171.4	833.1	664.7	570.0
	2:00:00 PM	470.7	617.9	370.8	446.6	780.0	138.1	143.4	788.7	624.2	533.9
	3:00:00 PM	413.6	551.4	316.3	389.9	712.6	90.6	98.9	718.0	559.8	476.6
	4:00:00 PM	339.1	464.7	245.3	315.9	624.7	28.6	40.9	625.8	475.8	401.9
	5:00:00 PM	252.5	363.8	162.7	229.8	522.4	0.0	0.0	518.5	378.0	315.0
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	HOUR	DIC 1	DIC 2	DIC 3	DIC 4	DIC 5	DIC 6	DIC 7	DIC 8	DIC 9	DIC 10
SANTO DOMINGO DIRECT RADIATION	6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7:00:00 AM	441.3	484.4	415.7	291.3	313.2	249.2	347.2	398.7	224.0	448.5
	8:00:00 AM	537.3	589.5	523.7	379.4	412.9	329.0	445.0	489.0	308.1	548.1
	9:00:00 AM	619.8	679.7	616.4	455.1	498.6	397.5	528.9	566.6	380.4	633.7
	10:00:00 AM	683.0	749.0	687.6	513.2	564.3	450.1	593.3	626.1	435.9	699.3
	11:00:00 AM	722.8	792.5	732.3	549.7	605.6	483.1	633.8	663.5	470.7	740.6
	12:00:00 PM	736.4	807.4	747.5	562.1	619.7	494.4	647.6	676.3	482.6	754.7
	1:00:00 PM	722.8	792.5	732.3	549.7	605.6	483.1	633.8	663.5	470.7	740.6
	2:00:00 PM	683.0	749.0	687.6	513.2	564.3	450.1	593.3	626.1	435.9	699.3
	3:00:00 PM	619.8	679.7	616.4	455.1	498.6	397.5	528.9	566.6	380.4	633.7
	4:00:00 PM	537.3	589.5	523.7	379.4	412.9	329.0	445.0	489.0	308.1	548.1
	5:00:00 PM	441.3	484.4	415.7	291.3	313.2	249.2	347.2	398.7	224.0	448.5
	6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

SANTO DOMINGO DIRECT RADIATION

HOUR	DIC 11	DIC 12	DIC 13	DIC 14	DIC 15	DIC 16	DIC 17	DIC 18	DIC 19	DIC 20
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	539.5	367.8	434.2	339.2	287.5	233.8	465.0	261.7	77.5	370.2
8:00:00 AM	647.0	462.7	536.9	440.7	394.9	326.5	577.1	357.1	161.3	477.3
9:00:00 AM	739.3	544.2	625.1	527.9	487.2	406.1	673.3	439.0	233.3	569.2
10:00:00 AM	810.2	606.7	692.7	594.8	557.9	467.2	747.2	501.9	288.5	639.7
11:00:00 AM	854.7	646.0	735.3	636.9	602.4	505.6	793.6	541.4	323.2	684.0
12:00:00 PM	869.9	659.4	749.8	651.2	617.6	518.7	809.5	554.9	335.1	699.1
1:00:00 PM	854.7	646.0	735.3	636.9	602.4	505.6	793.6	541.4	323.2	684.0
2:00:00 PM	810.2	606.7	692.7	594.8	557.9	467.2	747.2	501.9	288.5	639.7
3:00:00 PM	739.3	544.2	625.1	527.9	487.2	406.1	673.3	439.0	233.3	569.2
4:00:00 PM	647.0	462.7	536.9	440.7	394.9	326.5	577.1	357.1	161.3	477.3
5:00:00 PM	539.5	367.8	434.2	339.2	287.5	233.8	465.0	261.7	77.5	370.2
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SANTO DOMINGO DIRECT RADIATION

HOUR	DIC 21	DIC 22	DIC 23	DIC 24	DIC 25	DIC 26	DIC 27	DIC 28	DIC 29	DIC 30	DIC 31
6:00:00 AM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7:00:00 AM	432.7	0.0	391.0	0.0	252.9	162.6	83.5	223.1	387.6	176.4	432.7
8:00:00 AM	539.7	0.0	495.4	47.8	342.9	246.1	164.3	310.2	481.0	251.7	539.7
9:00:00 AM	631.6	21.9	584.9	94.2	420.2	317.8	233.7	385.0	561.1	316.4	631.6
10:00:00 AM	702.1	56.7	653.7	129.8	479.5	372.9	287.0	442.4	622.6	366.0	702.1
11:00:00 AM	746.4	78.6	696.9	152.2	516.7	407.4	320.4	478.5	661.3	397.2	746.4
12:00:00 PM	761.5	86.1	711.7	159.8	529.5	419.2	331.9	490.8	674.5	407.8	761.5
1:00:00 PM	746.4	78.6	696.9	152.2	516.7	407.4	320.4	478.5	661.3	397.2	746.4
2:00:00 PM	702.1	56.7	653.7	129.8	479.5	372.9	287.0	442.4	622.6	366.0	702.1
3:00:00 PM	631.6	21.9	584.9	94.2	420.2	317.8	233.7	385.0	561.1	316.4	631.6
4:00:00 PM	539.7	0.0	495.4	47.8	342.9	246.1	164.3	310.2	481.0	251.7	539.7
5:00:00 PM	432.7	0.0	391.0	0.0	252.9	162.6	83.5	223.1	387.6	176.4	432.7
6:00:00 PM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Irradiation values in W/m^2

APPENDIX C

SAM'S COMPONENT MODELS

This section presents the component models used in SAM to make the performance modeling. The content of this section comes from [**32**].

C.1 Parabolic Collector Model

The parabolic concentrator model predicts the thermal power intercepted by the receiver ($P_{in,rec}$) based on the direct normal insolation (I_{DNI}), projected area of the mirror ($A_{proj}j$), intercept factor ($\varphi_{int,fac}$), mirror reflectivity (. ρ_{ref}), and the shading factor (φ_{shade}) as given by Equation (C.1)

$$P_{in,rec} = I_{DNI} \; . \; A_{proj} . \; \rho_{ref} . \; \varphi_{int,\,fac} . \varphi_{shade} \tag{C.1}$$

Where,

$$\varphi_{shade} = \frac{A_{proj} - S_{AVG}}{A_{proj}} \tag{C.2}$$

S_{AVG}, is the average shaded area per dish in a field

The wind cut-out velocity is a user-specified value indicating the wind speed at which the parabolic concentrator will be sent into a stow position to prevent wind damage.

The intercept factor($\varphi_{int,fac}$) in (C.1) is the fraction of energy reflected from the parabolic concentrator that enters the receiver aperture. The SAM model uses theory from [**56**] and requires the intercept factor as input for a specific receiver aperture diameter, focal length, and collector diameter. The model then determines the total collector error (σ_{tot}) in mille-radians by iterating (C.3) with a guess value for the total collector error until the appropriate value for the input of the intercept factor is found. Once the total concentrator error is determined, it can be used to obtain a new intercept factor for a different receiver aperture diameter using the same theory [**32**].

The term $P_{intercept,tot}$ is the total power intercepted by the receiver, $P_{reflect,tot}$ is the total power reflected by the collector, г is the intercept factor for a specific differential ring evaluated at the ring-specific rim angle (Ψ). The total rim angle at the collector perimeter is given byΨ_{rim}, I_{DNI}. is the direct normal insolation, f is the focal length of the mirror, and A_{proj} is the projected area of the mirror. The ring specific intercept factor (г) is a function of the total error (σ_{tot}) as shown in (C.4) and (C.5). The terms $Q(n)$ is a function of the number of standard deviations (n) described in [**56**], d_{ap} is the receiver aperture diameter, and p is the length between the foci and the specific differential ring on the collector. The concentrator model, combined with the receiver model described below, allows an optimal receiver aperture diameter to provide the greatest solar net energy transfer to the Stirling engine to be found.

$$\varphi_{int,\,fac} = P_{intercept,tot} / P_{reflect,tot} \quad \text{(C.3)}$$

$$\varphi_{int,\,fac} = P_{intercept,tot} / P_{reflect,tot} = \left[\sum_{\Psi=0^0}^{\Psi rim} \frac{\Gamma.8\Pi.I_{DNI}.f^{2}.sin(\Psi).\Delta\Psi}{(1+cos?(\Psi))^{2}} \right] / \left(I_{DNI}.A_{proj} \right) \quad \text{(C.4)}$$

$$\Gamma = 1 - 2.Q(n) \quad \text{(C.5)}$$

$$n = 2 / \sigma_{tot}.tan^{-1}(d_{ap}.cos(\psi) / (2.p)) \quad \text{(C.6)}$$

C.2 Receiver Model

The SAM receiver model computes the thermal input power to the Stirling engine by subtracting the receiver thermal losses due to conduction, convection, and radiation from the total power intercepted by the receiver as shown in (C.7). The conduction losses (q_{con}) through the receiver housing are minimal. The natural convection coefficient used for the receiver cavity is location and time-of-day dependent and is determined from the Nusselt number correlation in (C.8) and (C.9) with the interior cavity diameter parallel to the aperture as the characteristic length. The forced convection heat transfer coefficient for receiver cavity is shown in Equation (3.10). The total convection heat transfer coefficient is given by Equation (3.11) with the natural convection coefficient derived from Equation (C.8). The total receiver heat loss rate due to convection is given by Equation (C.12) where A_{cav} , is the total surface area of the cavity interior.

$$P_{in,SE} = P_{in,rec} - q_{rad,reflect} - (q_{con} + q_{conv,tot} + q_{rad,emit})_{losses} \tag{C.7}$$

$$Nu_{nat,conv} = 0.088.Gr^{1/3}.\ (T_{cav} / T_{amb})^{0.18}.\ (\cos\theta)^{2.47}\ .\ (d_{ap} / d_{cav})^{s} \tag{C.8}$$

$$S = -0.982\ .\ (d_{ap} / d_{cav}) + 1.12 \tag{C.9}$$

$$h_{forced} = 0.1697.v^{1.849} \tag{C.10}$$

$$h_{total,\ convection} = h_{natural} + h_{forced} \tag{C.11}$$

$$q_{conv,tot} = h_{total,convection}\ .\ A_{cav}.\ (T_{cav} - T_{amb}) \tag{C.12}$$

The term $P_{in,SE}$ in Equation (3.6) represents the thermal input power to the Stirling engine while $q_{conv,tot}$, $q_{rad,emit}$, and $q_{rad,reflect}$ represent the rate of heat loss from the receiver by convection (natural and forced), emitted radiation out of the receiver aperture, and the reflected radiation out of the aperture, respectively. The quantity,$Nu_{nat,conv}$, in Equation (C.8) represents the free convection Nusselt number with the interior cavity diameter as the characteristic length. Gr is the Grashof number using the interior cavity diameter as the characteristic length, T_{cav} is the average temperature of the interior cavity walls, T_{amb} is the ambient temperature, θ is the sun elevation angle, d_{ap} is the aperture diameter, and d_{cav} is the cavity diameter parallel to the receiver aperture and v is the wind speed. The emitted radiation from the receiver cavity ($q_{rad,emit}$) is estimated as the thermal emission given by the Stefan-Boltzmann law in Equation (C.13) where, ε is the emissivity of the cavity, A_{ap} is the surface area of the receiver aperture opening, and σ is the Stefan-Boltzmann constant. The reflected radiation, ($q_{rad,reflect}$) from the receiver is shown in Equations (C.14) and (C.15) where, α_{eff} is the effective absorptance of the cavity, α_{cav} is the absorptance of the cavity interior surface, and A_{cav} is the interior cavity surface area.

$$q_{(rad,emit)} = \varepsilon . A_{ap} . \sigma . (T_{cav}{}^4 - T_{amb}{}^4) \tag{C.13}$$

$$\alpha_{eff} = \frac{\alpha_{cav}}{\alpha_{cav} + (1-\alpha_{cav}) \, . \, (A_{ap} / A_{cav})} \tag{C.14}$$

$$q_{rad,reflect} = \left(1-\alpha_{eff}\right) \, . \, q_{in,receiver} \tag{C.15}$$

An aperture cover can be used for hybrid systems to supplement solar energy with natural gas or for systems that replace the Stirling engine with a gas turbine. A receiver aperture cover can be simulated in the model providing a value for the cover transmittance for radiation at normal incidence (τ_c). An aperture cover will reduce the transmitted energy through the cover to the receiver cavity due to reflection as shown in Equations (C.16) and (C.17) but it will also reduce radiation and convection losses from the receiver cavity. The terms τ_c and τ_d are the transmittance of the cover for incident solar radiation and isotropic diffuse radiation respectively.

$$\tau_c \ . \ \alpha_{eff} = \tau_c \ . \left[\frac{\alpha_{cav}}{\alpha_{cav} + \left(1 - \alpha_{cav}\right) . \tau_d \ (A_{ap} / A_{cav})} \right] \tag{C.16}$$

$$q_{rad,reflect} = \left(1 - \tau_c \ . \ \alpha_{eff}\right) \ . \ q_{in,receiver} \tag{C.17}$$

Convection from the cavity to the aperture cover is determined using internal volume convection correlations given by Equations (C.18) and (C.19). Convection from the exterior plate surface to the environment is found by combining free convection with forced convection using (C.20) with the value for n in (C.23) chosen to be three. Free convection from a flat plate at the appropriate sun elevation angle is given by (C.21) and (C.22) with forced convection given by Equation (C.20). The characteristic length used for these equations is the receiver aperture diameter. The terms, Pr, Re, and Ra are the Prandtl, Reynolds, and Rayleigh numbers respectively.

$$Nu_{internal} = 1 + \left[Nu_{x=90^0} - 1 \right] . \sin\left(90^0 + \theta\right) \tag{C.18}$$

$$Nu_{\tau=90^0} = 0.18 . [\frac{Pr}{(0.2 + Pr)} . Ra]^{0.29} \tag{C.19}$$

$$Nu_{exterior,free} = 0.68 + \frac{0.67 . Ra^{1/4}}{\left[1 + (0.492 / Pr)^{9/16}\right]^{4/9}} \ (Ra \le 10^9 ; 0^0 \le \theta \le 60^0) \tag{C.20}$$

$$Nu_{exterior,\,free} = 0.27\ .\ Ra^{1/4} \qquad (10^5 \le Ra \le 10^9; 60^0 \le \theta \le 90^0) \tag{C.21}$$

$$Nu_{exterior,\,forced,\,lam} = 0.664\ .\ Re^{1/2}\ .Pr^{1/3} \tag{C.22}$$

$$h_{combined,\,convection} = \left[h_{free}^{n} + h_{forced}^{n} \right]^{1/n} \tag{C.23}$$

C.3 Stirling Engine Model & Generator Model

The Stirling engine model provides the best agreement with three years of Wilkinson, Goldberg, and Associates, Inc. (WGA) data for the gross output power (P_{Gross}) and was based on a Beale number (*Beale*) curve at part- to full-load using a temperature correction term ($T_{correct}$) from finite-time theory as given by Equation (C.25). The temperature correction term includes values for the expansion (T_E) and compression space (T_c) temperatures. The expansion space temperature is the heater head and operating temperature and the compression space temperature is determined by the cooling system model. One individual day of data is used to determine the temperature corrected Beale number (*Beale#corrected*) in (C.23) and generate a curve fit shown in Figure C-1 with the input power to the Stirling engine determined by the collector and receiver models using Equation (3.6). The terms P_{mean}, V_{sw}, and f refer to the mean engine pressure, swept volume, and engine frequency.

$$Beale\ \#_{corrected} = P_{Gross} / \left[P_{mean}\ .\ V_{sw}\ .\ f\ .\ T_{correct} \right] \tag{C.24}$$

$$T_{correct} = \left(1 - \left(T_E / T_C \right)^{0.5} \right) \tag{C.25}$$

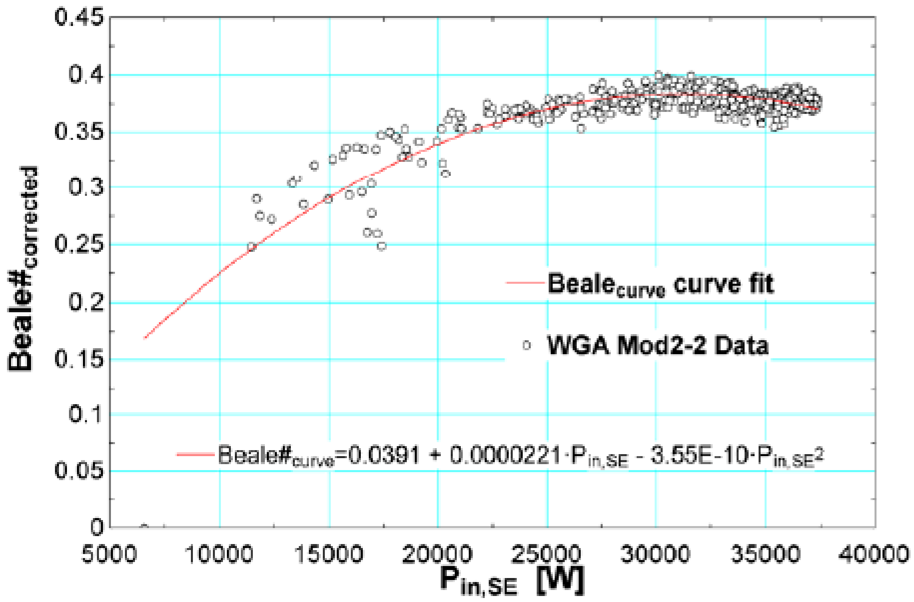

Figure C-0-1Temperature-Corrected Beale Number vs. Stirling Engine Input Power Using WGA Data [32]

Once a curve fit is generated using data for a specific engine, the gross output power of the engine is predicted using (C.26) where the Beale number (*Bealecurve*) is determined from the curve fit in Figure 3-1 and the input power to the engine. The other terms in Equation (C.24) are determined either using TMY-2 data, or another data set. The temperature corrected performance of the Stirling engine component allows for system optimization by altering the heater head (expansion space) temperature, fan or pump operating speeds, or replacing the fan and radiator with a central cooling tower.

$$P_{Gross} = Beale_{curve} \cdot \left[P_{mean} \cdot V_{sw} \cdot f \cdot T_{correct} \right] \qquad \text{(C.26)}$$

The expansion space temperature can also be modified to determine the effect on system performance. A term can be input for the lowest temperature of the heater head, which would occur in a 4-cylinder engine (SES & SAIC) with varying heater head temperatures. Similar to improving the receiver efficiency by reducing the temperature drop between the receiver and engine heater head, the engine performance will improve by reducing the temperature drop from the highest and lowest heater head in a multiple cylinder engine. This change in performance is simulated in the model by using the lowest heater head temperature in the engine. A Stirling engine from a specific manufacturer can be chosen (SES, WGA/SBP, SAIC), or a new/modified Stirling engine can be chosen.

C. 4 Parasitic Power Model

SAM cooling system model predicts the compression space temperature of the Stirling engine and the parasitic power consumption of the Stirling dish system. The compression space temperature affects the Stirling engine performance, and the predicted parasitic power is used to the net power from the system. The compression space temperature is determined with inputs of the ambient temperature, pump speed, fan speed, and the effectiveness of the radiator and cooler at test conditions. The appropriate effectiveness- NTU correlations are used in the model to predict how the radiator or cooler effectiveness will change at different operating speeds. The fan and pump parasitic powers are determined using the "fan laws" and the dimensionless pump performance equations [**33**]. The net system power (P_{Net}) is found by subtracting the parasitic power of the tracking and controls ($P_{controls}$), pump (P_{pump}), and fan (P_{fan}) from the gross output power ($P_{Gross,op}$) of the engine as shown in Equation (C.27). The pump and controls parasitic power are initiated in the model when the direct normal insolation is positive, whereas the parasitic power from the fan is not included until the DNI is higher than the insolation cut-in value, which corresponds to when the fan is connected to the grid.

$$P_{Net} = P_{Gross,op} - (P_{controls} + P_{fan} + P_{pump}) \tag{C.27}$$

APPENDIX D

PPA CALCULATIONS

This section presents the calculation performed by SAM to calculate the PPA results. The content of this section comes from SAM's manual [**45**].

The following equations show the calculations used in the iterative algorithm to determine the IRR and minimum DSCR, which are both reported as results with the 1st Year PPA Price. The internal rate of return is the discount rate, *IRR* in the equation below, that corresponds to a project net present value, *NPV*, of zero:

$$NPV = \sum_{n=0}^{N} \frac{R_n - C_{AfterTax,n}}{(1+IRR)^n} = 0$$

Where,

$\boldsymbol{NPV}$ **($)** = the net present value of the project over its life.

$\boldsymbol{N}$ **=** the number of years in the project life.

$\boldsymbol{R_n}$ **($) =** the required revenue in year *n*. The revenue in year 1 (*Rn=1*) is equal to the first year PPA price. The revenue is subsequent years (*R1<n<=N*) is equal to the first year PPA price adjusted by the PPA escalation rate.

$\boldsymbol{C_{AfterTax,n}}$ **($) =** the after tax cash flow in year *n*, equal to State Tax Savings + Federal Tax Savings + PBI Incentives - Operating Costs - Debt Total Payment + Revenues in the project cash flow.

IRR = Internal rate of return, calculated by systematically trying different values until the NPV is equal to zero.

The debt service coverage ratio in each analysis year ($\mathrm{DSCR_n}$) is the ratio of operating income to expenses in that year:

$$\mathrm{DSCR_n} = \frac{\mathrm{R_n} - \mathrm{C_{Operating,\,n}}}{\mathrm{C_{Interest,n}} + \mathrm{C_{principal,n}}}$$

Where,

$\mathbf{DSCR_n}$ **=** debt service coverage ratio in year n shown in the PreTax Debt Service Coverage Ratio row of the cash flow.

$\mathbf{R_n}$ **($) =** the required revenue in year n. Note that the electricity sales price in year 1 is equal to the first year PPA price, and in subsequent years (R1<n<=N) is equal to the first year PPA price adjusted by the PPA escalation rate.

$\mathbf{C_{Operating,n}}$ **($) =** the total operating costs in year n.

$\mathbf{C_{Interest,n}}$ **($) =** the loan interest payment in year n, shown in the Debt Interest Payment row of the cash flow.

$\mathbf{C_{principal,n}}$ **($) =** the loan principal payment in year n, shown in the Debt Repayment row of the cash flow.

The minimum DSCR is the lowest value of the project's debt-service coverage ratio that occurs in the life of the project:

$$\text{minimum DSCR} = \min_{n\in[1,N]} \mathrm{DSCR_n}$$

Where,

Minimum DSCR = minimum debt service coverage ratio.

$\mathbf{DSCR_n}$ **=** debt service coverage ratio in year n shown in the PreTax Debt Service Coverage Ratio row of the cash flow. (The symbol min represents the function that searches for the minimum value of the DSCR in the cash flow.)