Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Bachelorthesis

Name	born the	in	Matriculationnr.
Jannik Thomsen	[redacted]	Hamburg	[redacted]

Title:
Feasibility Study of Converting an isolated 5 MW Fuel-Oil Power Plant in the Dominican Republic into a PV-Fuel-Oil Hybrid System.

Submission deadline
27.10.2017

supervising Professor
Prof. Dr. Timon Kampschulte

Second auditor
Eng. Ricardo Estévez Mejilla

Faculty: Life Science

Department: Umwelttechnik, Regenerative Energien / Environmental Engineering, Renewable Energies

Erklärung

Ich versichere, dass ich die vorliegende Arbeit ohne fremde Hilfe selbständig verfasst und nur die angegebenen Quellen und Hilfsmittel benutzt habe. Wörtlich oder dem Sin n nach aus anderen Werken entnommene Stellen sind unter Angabe der Quelle kenntlich gemacht.

Ich erkläre mich damit einverstanden, dass ein Exemplar meiner Bachelor Thesis in die Bibliothek des Fachbereichs aufgenommen wird; Rechte Dritter werden dadurch nicht verletzt.

I assure that I have written the present work independently without the help of others and have only used the sources and aids indicated. Parts taken literally or in the sense of the meaning from other works are indicated by the source.

I agree that a copy of my Bachelor Thesis will be included in the library of the faculty; the rights of third parties are not infringed.

Berlin, 20.10.2017 ……………………………………………….

Jannik Thomsen

Acknowledgement

At this point, I would like to thank all those who supported and motivated me during the preparation of this bachelor thesis.

First of all, my thanks go to Ricardo Estévez, who has supervised and assessed my bachelor thesis. I am very grateful for the helpful suggestions and the constructive criticism in the preparation of this work.
I would also like to thank Pascual Santana and Elvin Jimenez for their patience, interest and willingness to help.

I would like to thank all of them for the many interesting debates and ideas that have contributed significantly to the fact that this bachelor thesis is in this form.

Special thanks as well to Prof. Dr. Timon Kampschulte for the purposeful objections and important advice particularly in the initial and final phase of the process of developing this elaboration.

I also would like to thank my girlfriend Nathaly Zamalloa Farfan for her strong emotional support and encouragement during the whole time.

Last but not least I would like to express my gratitude to my parents Renate and Günter Thomsen, who through their help and care made these studies possible.

Abstract

This research studies the feasibility of designing a hybrid system by combining existing generators with a photovoltaic power plant and a battery bank. The investigation of a possible conversion of a 5 MW fuel oil driven stand-alone power plant in the Dominican Republic to a photovoltaic fuel-oil hybrid system is based on simulations with different programs.
To get a detailed and realistic image of the feasibility the regional conditions and the components of the hybrid system are discussed.
The most significant results are given by the software HOMER Pro containing the dimension of the components for the most economical application.

Hybrid systems in the remote areas in the Dominican Republic are expected to promise a high degree of success since the cost of energy can be decreased significantly by including renewable sources into conventional systems. Due to very well suiting conditions in this region especially PV-arrays can generate a lot of energy.
The intention of the study is, that it serves as an example for the electrification of rural areas in the Caribbean and around the world

Content

Tables

Figures

Abbreviations

AM	Air Mass is the distance the sunlight has to go through the atmosphere when it does not irradiate in an angle of 90° on the earth surface. In the photovoltaic-business an Air Mass of 1.5 is commonly estimated.
Capex:	The Capital Exposure is used to describe investment expenditures for longer-term assets.
DoD:	Depth of Discharge describes the ratio of the amount of electric charge taken from a battery to the total capacity.
EDE:	Empresa Distribudora de Electricidad are called the companies that are in charge of the distribution of the energy in the Dominican Republic
EGE:	Empresa Generadora de Electicidad are the companies in charge of the energy generation
HES:	Hybrid Energy System are systems used for the generation of energy that consist of more than one process to generate energy
IRES:	Integrated Renewable Energy Systems are systems for the generation of Energy that consist of one or more renewable energy sources. IRES can also include conventional energy generation systems like gen-sets.
LCOE:	The Levelized Cost Of Energy describes the total cost of the production of on kWh.
NOCT:	Nominal Operating Cell Temperature is the temperature of the PV-cell during the operation.
NPC:	Net Present Cost describes a dynamic value in the calculation of the investment which refers to the increase in assets related to the start date of the project.
O&M:	Operation and Maintenance plans are plans that describe the treatment of the power plant after the construction and during the whole life time. The plan includes for example rules for repairs, cleaning and further more.
Opex:	The Operational Exposure describes the cost that occur during the operation of the plant. Costs can be caused by maintenance or repairs. Costs of fuel is not included in this value.
SENI:	Sistema Electrico National Internconectado is the national transmission grid of the Dominican Republic
SOC:	State Of Charge describes present status of charge by relating the power available on the battery with the total capacity of the battery.

STC: Standard Testing Conditions are the standardized conditions under which PV-Modules are tested. STC are an irradiance of 1000 W/m^2, a module temperature of 25 °C and AM of 1.5.

1. Introduction

The World Energy Outlook 2016 shows, there are 1.2 billion people living without access to electrical energy world wide (World Energy Outlook, 2017).
According to this study 80 % of the people who do not have electrical energy obtainable live in remote areas that are not connected to the national grid. Often the isolated location of this area or geographical circumstances cause, that an electrical connection is difficult to realize and expensive.
Usually the electric energy supply for these rural areas is solved with stand-alone electric systems running with diesel generators, which can assure a steady and stable energy supply. The problem of this system is the provision with fuel for the gen-sets. Because of missing infrastructure in the regions, it is difficult and costly to carry the fuel to the power plants. That causes a very high Levelized Cost of Energy (LCOE) for these areas. Another aspect is that the cost of fuel is a highly varying factor, so that it is difficult to assure a stable cost of energy.

One option to minimize the costs of energy and to increase the level of independence from fuel prices is to combine diesel-generators with renewable energy sources and a battery bank. These systems are called hybrid systems. They make especially sense in areas with high availability of renewable energies (sun, wind).
The most common combination is a PV-Diesel-Hybrid which combines a conventional diesel engine-driven generator with a photovoltaic-power plant and a lead acid battery bank.

In the Dominican Republic, there are also still remote areas that are not connected to the national grid "Sistema Electrico Nacional Interconectado" (SENI). Because there is only a marginal part of the population living in these areas and because of geographical circumstances that complicate an extension of the transmission lines to connect the regions to the grid, the motivation to enable an access to electric energy in this region is low.
One of these rural areas is Pedernales, a region located in the south west of the country. Since 1998 the company EGE Haina (Empresa Generadora de Electricidad Haina) is the only energy supplier in the main municipality of Pedernales, that is the most populated of the province Pedernales. The company runs three fuel oil gen-sets with a total capacity of 5.1 MW to meet a peak load of 2.8 MW.

The electricity in Pedernales and the Dominican Republic in general is compared to the cost of living very high. That leads to the fact, that many people can only afford a limited access to electrical energy or no access at all. The idea of this thesis is it to design a system that lowers the cost of energy to enable electricity to a larger part of the population without influencing the high reliability that the current system has.

With Pedernales being one of the sunniest regions in the Dominican Republic the requirements for designing a PV-Diesel-Hybrid-System seem to be fulfilled and the auspicious conditions make a success of such a project on the first glance seem likely.

So far, many projects have been evaluated in remote areas primarily in swelling and developing countries with a tropical climate. Due to a low electrification rate in heavily populated countries there are many studies from India, Malaysia, Thailand and Nigeria. And because the size of the country the electrification with hybrid systems has been investigated in Australia for many years as well.

A study taken out by (Cader, Bertheau, Blechinger, Huyskens, & Breyer, 2015) show that hybrid system can achieve large success for the electrification of rural areas in countries with high solar irradiation. Particularly newer studies get to the result that the cost of energy from a hybrid system can be significantly lower compared to only diesel or other fuel power plants.

Although there are many studies about implementing hybrid systems for rural electrification, most of them deal with power plants in the kW rage between 10-200 kW. Evaluations of large MW hybrid systems are very rare.

The following thesis deals with feasibility to realize a PV-Fuel-Oil-Hybrid System in the range of MW in the urban part of Pedernales in the Dominican Republic.

The objective is to design a model for an extension of the existing energy system to a PV-Fuel-Oil-Hybrid-System, with the existing engine-driven generator as primary generator, the PV plant as secondary generator and a Li-Ion battery bank for storage. Most of the studies mentioned include lead acid batteries as a backup. Since the technology of Lithium-Ion batteries is experiencing a great development in the last years, the idea is it to evaluate the feasibility of a project that includes this more expensive but technically more advanced and promising technology. The research applies a further evaluation of available structures and of new technologies that need to be integrated into the system.

The document is subdivided in different chapters that deal with the general information of the project region, the theory of hybrid power plants, analysis of the current situation and a feasibility study on the planed project.

2. Conditions for the Project

2.1 Electrical System of the Dominican Republic

Since the late 1990s the generation, transmission and distribution of electrical energy in the Dominican Republic is in the hand of private companies. There are ten major companies that generate electricity in different way, using fuel, wind, sun or water as the energy source (**Fehler! Verweisquelle konnte nicht gefunden werden.**). One company is in charge for the transmission lines of 12.5 kV, 34 kV, 69 kV and 138 kV. The frequency of the grid is 60 Hz. The distribution is mainly taken over by three companies, each being responsible for distributing energy in the north, south or east of the country. (OC SENI)
The electric sector of the Dominican Republic is divided into three main commercial groups. The Generation is covered private companies and governmental hydro electrical power stations. The transmission is controlled by the public company ETED (Empresa de Transmisión Eléctrica Dominicana). Three companies of which two are in the hands of the government accomplish the distribution of energy in the Dominican Republic.
The total load demand in 2016 was 15800 GWh that has been supplied with the energy-mix seen in Figure 1.

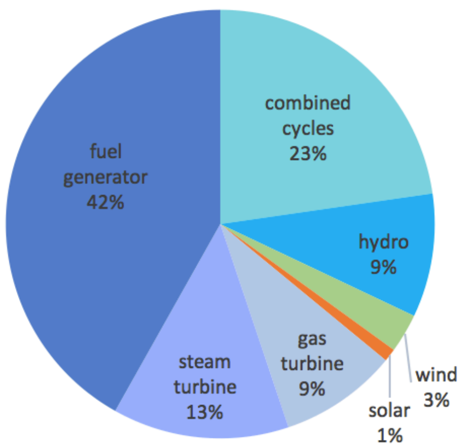


Figure 1: Energy share of the Dominican Republic (Data from OC SENI)

The electric situation of the Dominican Republic in general is marked by many blackouts.
There are large losses in the transmission lines among other things because of electricity theft.
The companies generate energy with high operating costs what results in high electricity tariffs for the people. Since the Dominican Republic does not have any fossil sources, all the fuel needed for the electric energy generation has to be imported, primarily from the United States of America. This is one reason for high electricity prices.

The electrical grid is not yet fully developed. In particular in the urban regions of the country the development of the grid is as far as possible complete, whereas some remote areas are still not linked to the national grid at all. In these regions mainly rely on expensive self-generated energy. Especially the touristic areas, if not connected to the SENI, are connected to private distribution grids and count with a high reliability of Energy. The electrical system in Pedernales has a quiet reliable system on its disposal itself. One important goal of the study is to design a system that does not take away this comfort by losing reliability.

2.2 Pedernales

2.2.1 Geography

Pedernales is a region located in the south west of the Dominican Republic. It is surrounded by the Caribbean ocean in the south and by the provinces Independencia in the north and Barahona in the east. In the west Pedernales is adjoined to the boarder with Haiti (Figure 2).
A large part of the area is covered by the Jaragua National Park in the southeast that is characterized by the dry, red-sanded ground and wide landscapes with cactus-growth. The mountain “Sierra de Bahoruco”, which ranges from the east coast far behind the boarder of Haiti and reaches a height of more than 2200 meters, confines the region in the north. Pedernales is a quite secluded region. The mountain chain is what primarily isolates Pedernales from the rest of the country. Being located like this, an expansion of the infrastructure is very costly and difficult to realize. Due to this fact the only direct access to the region is the road 44 to Barahona. Further connections to the country are only poorly developed and limited.

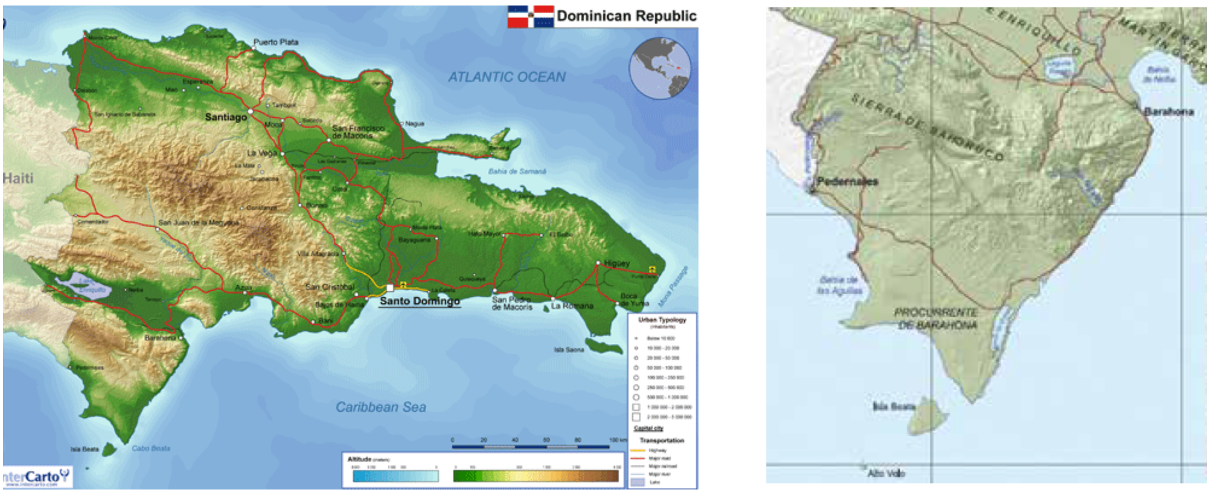


Figure 2: a) Map of Dominican Republic ; b) Mountain Pedernales (Zhengyunpeng.info, mapsofworld.com)

The territory of the province Pedernales covers an area of 2080 km^2, which corresponds to 4% of the national area. With about 31,600 people living there which equal to 0.3% of the population Pedernales is the region with the lowest population density in the Dominican Republic. Mainly the people are settled in urban zones. About 64% of the people live in cities and surrounded urban zones while 34% live in secluded areas with even less access to important infrastructure.

2.2.2 Climate

The region Pedernales is considered as one of the sunniest in the country. Especial the coastal zone, where the city of Pedernales and thus the project area is located, is extremely dry having many sun hours on its disposal..

Due to the fact, that the Dominican Republic is located close to the equator, day/night shift during the year is fairly low. In the summer (July) the sun rises at 6:30 am and sets at 7:30 pm. In the winter the sun rises at 7:30 am and sets at 6:30 pm. This leads to a fairly constant climate over the year. The National Aeronautics and Space Association (NASA) measured the annual average temperature at 24 °C whereas the difference between the monthly minimum and the monthly maximum temperature does not exceed 7 °C (Figure 3). The over the year the maximal temperature recorded is 28.2 °C.

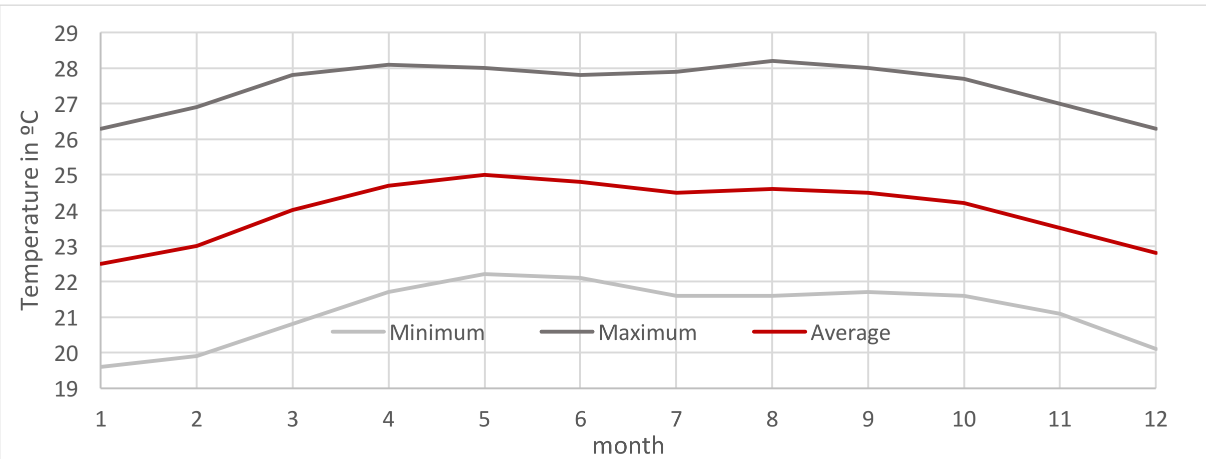


Figure 3: Annual Temperature (min, max, average) (Data from NASA)

The province can be divided in three principle climate zones regarding humidity. The driest is the coastal zone. Than there is a semi dry strip reaching from the peninsula to the mountain. The region close to the boarder is characterized by a fairly wet climate.

Although there it is raining during the hole year, there are eight months of dry-season between November and April and from June to July. Whereas in the dry season the precipitation is low, in the rain season, which usually lasts from August till October, it has to be reckoned with intensive rainfalls and a high frequency of extreme climate events.
In the past years hurricanes as well as earthquakes affected Pedernales. (Instituto de Investigaciones Socioeconómicas de la Universidad Autónoma, 2012)

Although Pedernales is considered as a radiation rich region, the precipitation is relatively high with 1085 mm per year at 253 rain-days (Figure 4). This is significantly higher than the precipitation in Hamburg for example. Still the region is very sunny with only little cloud coverage over the year, since the rain periods are heavy but short and in many sun hours per day the earth parches quickly. (World Weather Online, 2017)

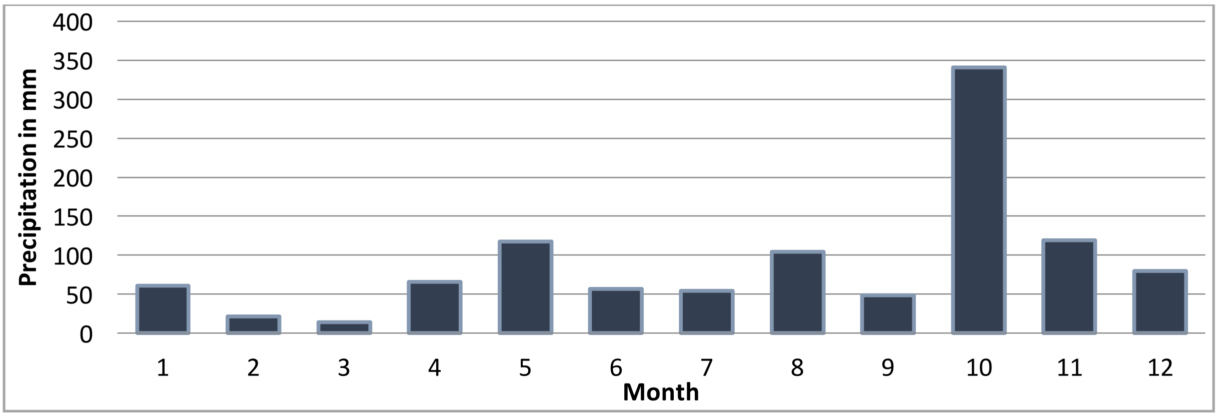


Figure 4: Annual precipitation in mm in 2016 (Data from NASA)

2.2.3 Solar irradiation

The solar energy industry assumes a global horizontal irradiance (GHI) on earth with a peak of 1 kW/m^2. The irradiance describes the power of the sun on earth. The theoretical value represents the ideal power of the sun on a clear day around solar noon at sea level. In the solar energy industry, the value set as the rating condition for solar modules and arrays.

The values for the irradiance, annual irradiation and solar noon in Pedernales are based on the database of the National Aeronautics and Space Administration (NASA).

The average solar noon in Pedernales is at 12:43 pm. The NASA provides values for the irradiance in 3 hour periods, starting at 00:00 GMT (Greenwich Mean Time), which is equal to 8:00 pm AST (Atlantic Standard Time). The following times are given in AST. There are no specific values for the time 12:43 pm. The value of the insolation incident has to be determined from the values at 11:00 am and 02:00 pm (Table 1). For 12:43 pm the estimated mean value of the irradiance in Pedernales is 0.73 kW/m^2. During the year the determined irradiance fluctuates between about 0.78 kW/m^2 in July and 0.61 kW/m^2 in December.

Table 1: Average irradiance in 3 hour intervals during the year in kW/m^2 (Data from NASA)

GMT	**AST**	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	*Av.*
6:00	**2:00**	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	*0,000*
9:00	**5:00**	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	*0,000*
12:00	**8:00**	0,100	0,110	0,160	0,230	0,270	0,270	0,250	0,230	0,230	0,210	0,160	0,120	*0,195*
15:00	**11:00**	0,560	0,620	0,660	0,690	0,690	0,730	0,740	0,740	0,710	0,670	0,600	0,560	*0,664*
19:00	**14:00**	0,570	0,630	0,640	0,650	0,630	0,680	0,710	0,690	0,640	0,570	0,540	0,550	*0,625*
21:00	**17:00**	0,200	0,250	0,270	0,270	0,250	0,270	0,280	0,240	0,180	0,150	0,140	0,150	*0,221*
0:00	**20:00**	0,000	0,000	0,000	0,000	0,000	0,010	0,010	0,000	0,000	0,000	0,000	0,000	*0,002*
3:00	**23:00**	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	*0,000*
Solar Noon (AST)		12:57	13:02	12:56	12:48	12:44	12:47	12:54	12:52	12:43	12:33	12:32	12:40	12:47

The value of the irradiation describes the energy of the sun on earth. That means that simplified the following link between irradiance and irradiation can be inferred:

$$H = E \cdot t \quad \Rightarrow \quad irradiation = irradiance \cdot t$$

The analysis of the irradiation data from the NASA-database shows that during the year the global horizontal solar irradiation varies between 4.30 kWh/m^2/day in December and 6.17 kWh/m^2/day in July (Figure 6). The diffuse horizontal irradiation is about 35 % of the global radiation. The average annual global horizontal irradiation in Pedernales is 1935 kWh/m^2, which is equal to a solar availability of more than 1900 full-load-hours. Thus the requirements for applying photovoltaic system are definitely fulfilled.

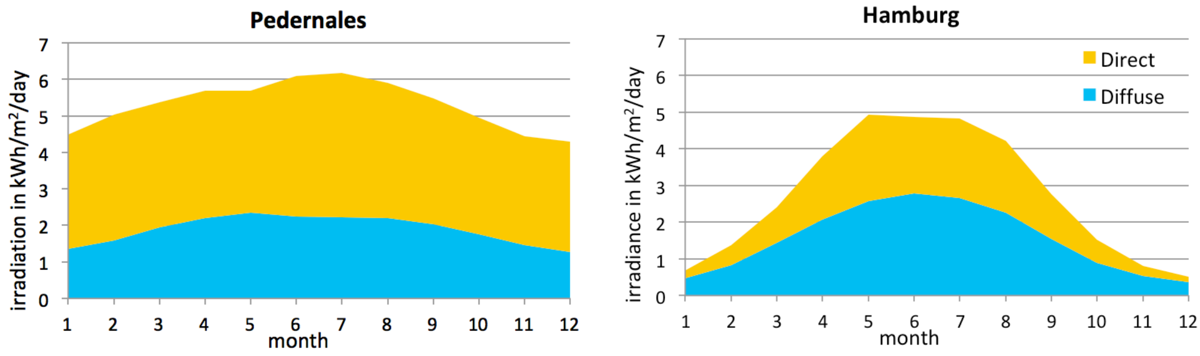


Figure 5: Global horrizontal irradiation, splitted in diffuse and direct for Pedernales and Hamburg (Data from NASA)

To highlight the high irradiation in Pedernales, Figure 5 shows the curses of the irradiation over the year in Pedernales and in Hamburg. Compared with a location like Hamburg the annual irradiation in Pedernales is as twice as high, while the diffuse irradiation in Hamburg is with almost 60% almost double. A high share of direct irradiation, and vice versa a low share of diffuse irradiation, is favorable for solar projects, since the energy yield is higher than from diffuse irradiation. The clearness index is an indicator for the direct part of the irradiation. It is described as the proportion of the radiation that reaches the earth surface in relation to the radiation at the top of the atmosphere. With a clearness index constantly over 0.5 a good condition is indicated for Pedernales.

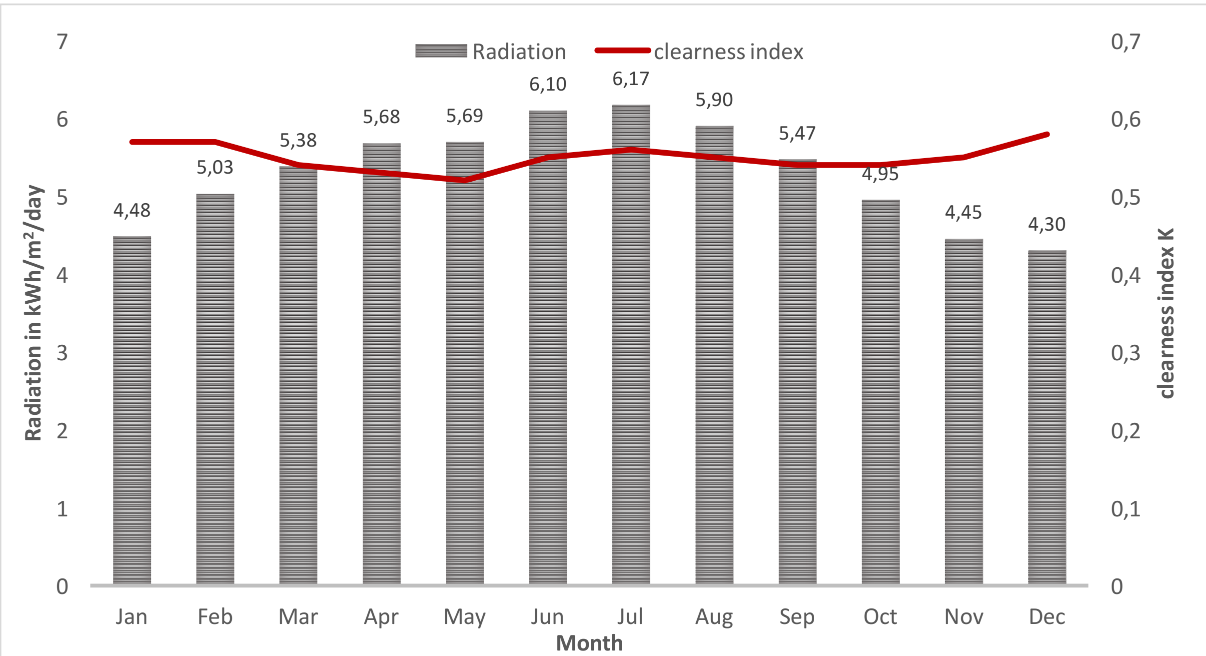


Figure 6: Annual global radiation and clearness index (Data from NASA)

2.2.4 Economy

The economical focus lies on the public sector, which includes mainly construction work and others not declared workspaces. 66% of the inhabitants in labor work in this sector. Agriculture and fishing is also an important aspect in Pedernales. Particularly beans, coffee, banana and yuka are planted.
Industrial activities however have very little presence. There are foreign mining companies settled which are mainly mining limestone and bauxite.

According to the "social-economic and environmental profile of Pedernales" by the United Nation Program for Development ("Perfil socio-economico y medio ambiental Pedernales", PNUD) the region is the 5th on national level with less households with energy access.

2.2.5 Power plant Pedernales

Pedernales is one of the isolated regions of the Dominican Republic. Most of the area is not yet connected to an electricity grid. EGE Haina is supplying the urban region, the city of Pedernales where there are round about half of the inhabitants of Pedernales living (15,000 people) in an area of 134,98 km^2, with an isolated power plant.
The plant is composed of three generator engines powered by HFO and LFO that generate at 2400V and feed the entire load of the town of Pedernales.
In 2016 the power plant covered a total demand of 18.3 GWh with a peak load of 4.05 MW (Rosario, 2015).

Table 2: Generators of the current power plant in Pedernales

Producer	**Year**	**Capacity, peak**	**Capacity, continuous**	**Hours worked**	**fuel**
Hyundai H1MSE-9H21/32	2002	1.7 MW	1.5 MW	100,000	HFO
Hyundai H2MSE-9H21/32	2014	1.7 MW	1.5 MW	8,000	HFO
Caterpiler CAT-3606	1997	1.7 MW	1.5 MW	48,000	LFO

The generators are connected directly to the load through two circuits that are coupled to a 2400V bar in delta connection. There is no transformer lift connected. The two power distribution circuits are owned and run by EDESUR (Figure 7). Before the energy is distributed to the consumer, the voltage is brought down to 110-120 V. The protections installed to protect these circuits are state-of-the-art Brand SEL model 751. And the operational meters are Hyundai brand HIMIX model.

The generators monitor the electrical parameters, and are enabled for their remote monitoring.

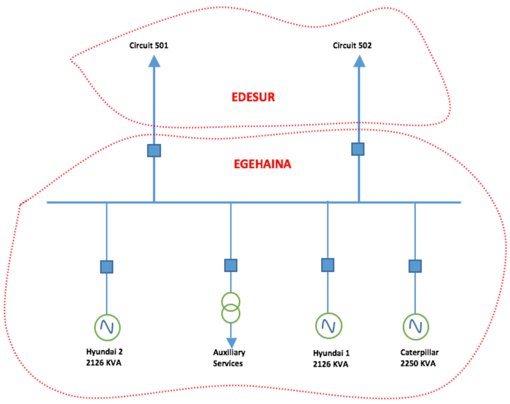


Figure 7: Connection of power plant - distribution grid (EGE Haina)

Most of the time the two Hyuandai motors are run to match the load demand whereas the Caterpilar serves as a backup supply for peak-demand-cases.

The capacity of the fuel tanks is 75.1 m^3 (20,000 gallons) for the Heavy Fuel Oil (HFO) and 18.9 m^3 (5,000 gallons) for Diesel (LFO). The newer Hyundai Generators run with an efficiency of 15.9 kWh/gallon which is equal to 4.20 kWh/Liter (Rosario, 2015).

2.2.6 Load demand

The power plant of EGE Haina in Pedernales supplies approximately 15000 people with electrical energy. In rural areas, the majority of the population spend most of their time outside the house for work purposes. The maximum demand of electrical energy takes place at night, when the families are at home. Figure 8 shows how the demand varies during the day with peak loads at 10 pm and demand depression at 7 am. There is no expected peak at noon and in the evening, because most of the people use gas for cooking. The peaks are caused by other electronic devices such as television. The curse of the hourly demand graph has, except of small deviations, on labor days the same curse as at the weekend (Figure 8) That means that the accuracy of the average values is sufficient to match the requirements for a realistic simulation.

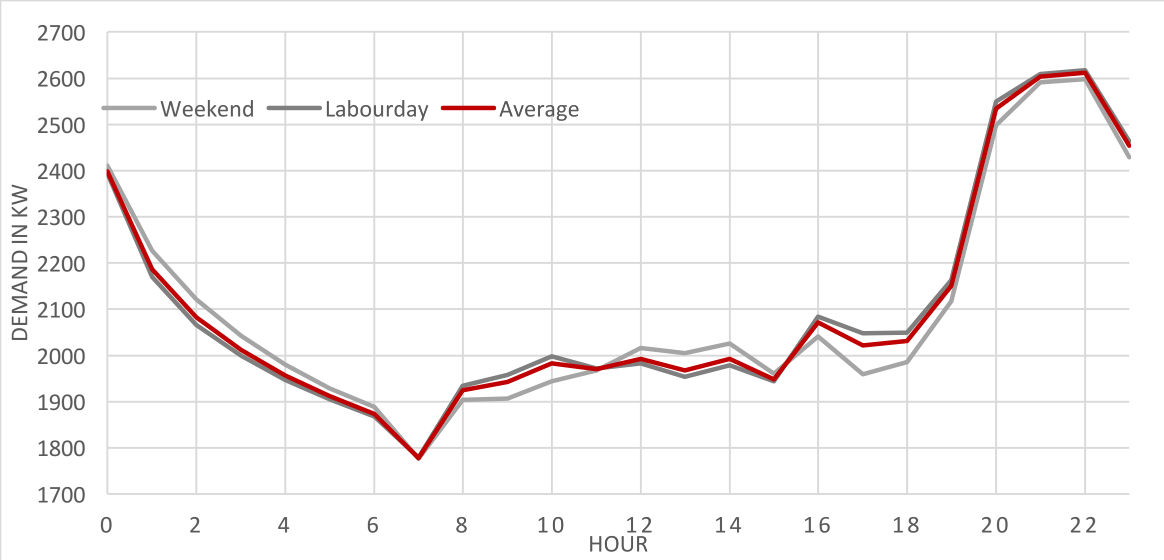


Figure 8: Average demand during the day per hour in kW(Data from EGE Haina)

During the year the month with the highest demand is August with a total demand of 1676 MWh. The lowest load demand is recorded in February with 1298 MWh (Figure 9). Comparing the demand from 2015 and 2016 the total annual demand has increase by 4.59 %. The total annual demand in 2016 was 18,833 MWh.

The load demand is evaluated on the basis of data measured by the current power plant of EGE Haina. The simulations carried out in this study refer to these values.

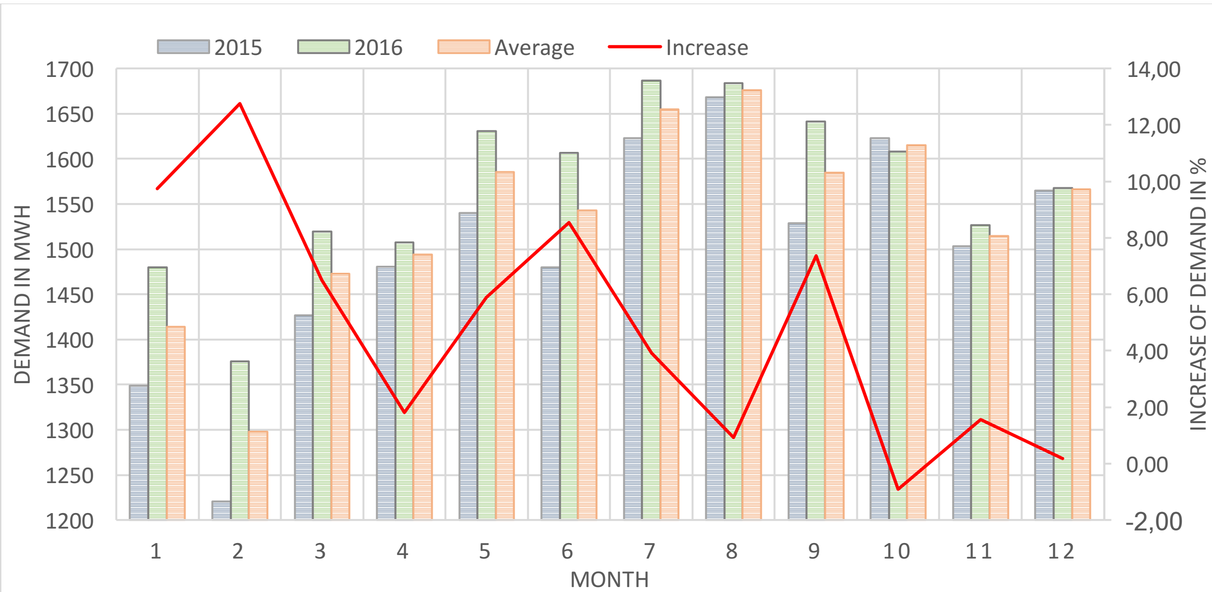


Figure 9: Average demand per month in MWh (Data from EGE Haina)

3. Hybrid Systems

To assure a through the year constant and permanent supply of energy in rural areas is a challenging task. On the one hand, seasonal and daily fluctuation of the energy bid of sun, wind and also water lead necessarily to high investments in energy storage solutions, for renewable energy systems (Strauß, et al., 2009). For the supply with diesel generators on the other hand, the main problem represents the remote location and often only barely existing infrastructure, which causes the transportation of fuel to be complicated and expensive.
In those areas where an extension of the grid is prohibitive and fuel prices increase drastically with the remoteness of location, the hybridization of conventional and renewable energy combined with a battery bank is the most promising application for power generation. Stand-alone energy systems that consist of more than one source of power generation are known as Hybrid Energy System (HES) or Integrated Renewable Energy Systems (IRES). Primarily owing to decreasing renewable energy costs, hybrid systems get more and more established for remote area electrification. Currently the most common systems installed are Photovoltaic-Diesel-Systems. The combination of conventional gen-sets with PV not only reduces the fuel consumption and the operation and maintenance (O&M) costs, but also improves a high reliability of energy generation. Alternatively, the hybridization is prevalent with other energy sources like wind turbines or hydroelectric power stations. (Wichert, 1997)
The application of hybrid systems is divided in two categories.

1. Application with primarily conventional generation
2. Application with primarily generation from renewable energy resources

In the first case the output of the renewable energy source is smaller than the average daily load requirement. Because engine-driven generators run throttled back with a low efficiency renewable energies supply the base load during periods of low demand. In case of Energy excess the available capacity is used to charge the batteries to a high stat of charge (SOC)
In the second case the main load is covered from the renewable energy source. The gen-set serves as backup if high peak loads appear or the renewable energy input is low. To cover a high percentage of the demand with renewable energies the storage systems and renewable generators need to be considerably larger than in case 1. To supply for example high load demands with 100% PV the solar array and battery bank need to be largely oversized to meet

the demand on cloudy days or when the energy demand is high. Oversizing to such a large scale is very expensive. (Hankins, Stand-Alone Solar Electric Systems)
The advantage of the integration of renewable energies into the system is, that conventional diesel systems are often not flexible to respond to drastic load changes. Renewable energies in combination with batteries however are more flexible and especially photovoltaic and wind applications can be extended easily if the long-term load demand increases.

The connection of the different attributes of a hybrid system, is classified in three distinct configurations:

- Series configuration
- Switched configuration
- Parallel configuration

3.1 Series hybrid system configuration

In the series configuration of hybrid systems, the diesel generator, the PV system and the battery are connected via a Direct Current (DC) bus. While PV-generator and battery provide DC output respectively require DC input (Battery charging) and thus can be connected to the DC-bus, for the connection of the diesel AC generators the interpose of an AC/DC-inverter is required. Figure 10 shows that to supply the AC load, all the electric energy produced from all sources are passed through a DC/AC-inverter, which has to be sized to the peak loads of the demand. Since there are not a number of AC-sources to be synchronized, the output interface is very simple. The desired frequency and voltage can be adjusted easily at the output inverter. With this topology load is covered without power interruption in the case that generator or PV are operating to charge the battery bank. Though due to the inversion of high loads, the inverter losses are high. The limitation of the system by the size of the DC/AC inverter another serious disadvantage. An expansion of the system is associated with high financial and technical effort (Saengprajak, 2007).

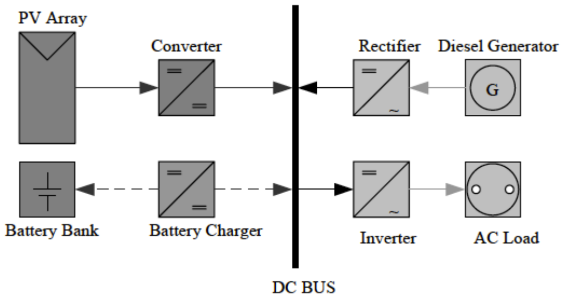


Figure 10: Series configuration of the hybrid system (Saengprajak, 2007)

3.2 Switched hybrid system configuration

Different to the series configuration, the switched topology consists of a DC- and an AC-bus. As seen in Figure 11 the generator is connected to the AC-bus while PV-array and battery bank are tied to the DC-bus. The two buses are connected via inverter respectively rectifier to convert PV or battery power to AC or diesel generated power to DC. Both sources can feed the load independently and directly. When the demand is low engines can be turned of so that the load is supplied with PV- or stored energy and low efficiencies of low running engines can be avoided. If the output power of the diesel generator however exceeds the load demand, the excess energy recharges the battery bank (Saengprajak, 2007).
This configuration allows the evasion of the rectifier if the charging of the battery by the gen-set is not required and the battery is charged by the PV-array.

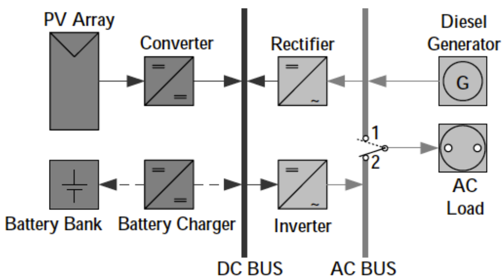


Figure 11: Switch configuration of the hybrid system (Saengprajak, 2007)

3.3 Parallel hybrid system configuration

The parallel hybrid configuration is characterized by connecting all components with the load via one AC-bus (Figure 12). Since the DC/AC inverter can be synchronized with the engine-driven generator, so that both can simultaneously supply the load, the parallel configuration significantly improves the performances with the implementation of an optimal control strategy. Due to more flexibility of the system the diesel- and PV-generator can be operated parallel to cover the demand during high peak times. An optimal operation of the gen-set and smaller sized inverters causes a high efficiency at a high level of energy availability.

Including a bi-directional battery inverter into the system the system simplifies the control and load dispatch problem. The bi-directional inverter can either receive load from the generator for storage or supply energy to the output.

The parallel system configuration can be easily adapted with DC- as well as AC- components in case of load increase or change of the demand profile (Saengprajak, 2007).

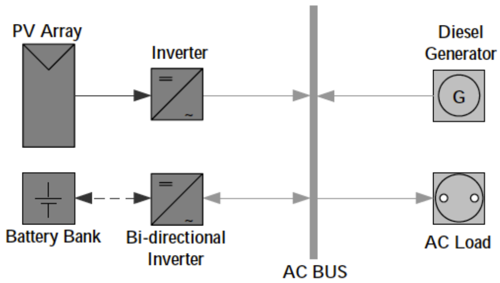


Figure 12: Parallel configuration of the hybrid system (Saengprajak, 2007)

3.4 First design concept of the Hybrid System for Pedernales

With the knowledge of the different application models of hybrid systems, a concept adapted to the project and the site can be designed.

Because the gen-sets are designed to cover the complete load demand a system is chosen with primarily conventional generation. Otherwise the PV-array would have to be design significantly larger and a large share of the available generator capacity would not be used.

How photovoltaic-system and battery bank have to be sized will be reviewed in the simulations in the following paragraphs.

As seen in Figure 7 the electrical system of Pedernales already consists of an AC-busbar to which the three fuel-driven generators and two demand loads are connected. It is the least

expensive and the simplest solution to design the hybrid system with a switched configuration hybrid system configuration from 2.3. Different to the description in 2.2 a rectifier can be omitted, since the generators are not planned to load the battery. The other configurations would require rectifiers and inverters dimensioned to cover a large capacity. Figure 13 shows the schematic of the system. While the right side contains the already existing attributes that represent the AC part of the system, on the left hand the DC-attributes, including PV-Array, battery bank as well as Inverters, are displayed.
The AC-bus is fed with a voltage of 2400 V and a frequency of 60 Hz. The application of a transformer might be necessary.

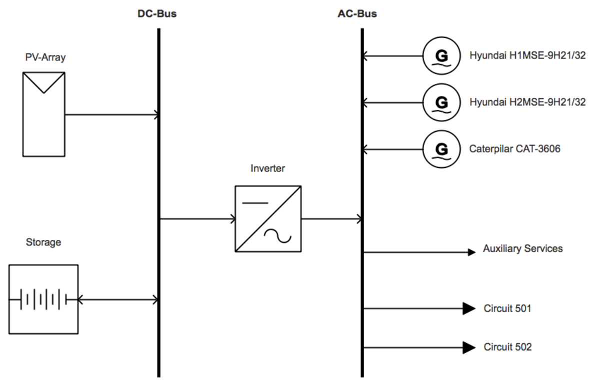


Figure 13: Circuit diagram of Pedernales Hybrid System

There are two main strategies employed in the operation of Hybrid Renewable Energy Systems. In Load Following strategies (LF) the PV-Array supplies the load and charges the battery in the event of PV-energy excess. The diesel gen-sets are only run to supply the load in the case there is not enough PV power available.
On the other hand, in the cycle charging strategy the generator runs throughout at the maximum rated capacity. It primarily supplies the load demand and with the excess energy charges the battery. The PV array manly replaces the load supply when there is solar energy available. (Halabi, Mekhilef, Olatomiwa, & Hazelton, 2017)
The ideal dispatch strategy for the system planed is determined in the simulation with the HOMER Pro software.
For both strategies an Overall Energy Management System is required to control flow of energy and to give highest priority to the PV-generation when the sun is up. Excess energy will be used to charge the batteries to a State of Charge of SOC = 100%. When there is insufficient energy available from the PV and fuel-driven generators especially in case of appearing peak loads the battery will be discharged up to its minimal SOC.

4. Parameters for the simulation of the Hybrid System

4.1 Electrical components of the Hybrid System

The evaluation of irradiation and demand leads to the expectation that a system including PV is possible and viable.
The idea of installing a hybrid system is to reduce the consumption of fuel. Because it is not efficient to run the fuel driven generators on a low level, the goal is to design a concept which allows to completely or partly turn of one of the main generators. There are two main models to be considered for the System in Pedernales.

As the evaluation of the demand shows, there is a peak demand load in the evening. One possible concept is to run two generators in the morning till sun rise and at night which share the load equally. The engines would not run with an efficiency of less than 60%. When around 4 am the demand decreases significantly, one engine will be shut down. During the day the load is supplied by the engine and PV-array, which in the morning and evening, when there is less photovoltaic- energy available is supported by the battery-bank. With the excess of energy around noon the battery will be charged again. This concept works with a renewable fraction of round about 20 %. A schematic of this course can be seen in Figure 14.

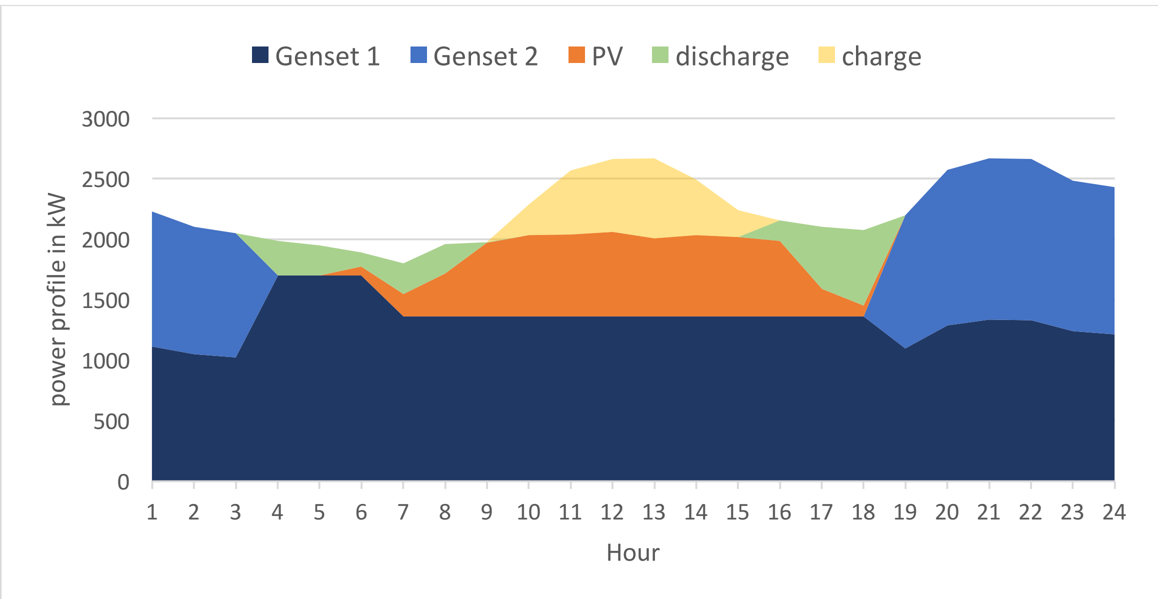


Figure 14: Scenario 1: 2 Gen-sets, PV, Battery

Another concept to drive the hybrid system is to completely waive one of the gen-sets. Only one fuel-generator in combination with the PV-Array and battery bank is operated to supply the demand-load.

In the time during sun-set and sun-rise the engine runs on full power, while during the day it is throttled down. (schematic in Figure 15). Compared to the first scenario in the second case the renewable fraction is significantly higher at about 30 %.

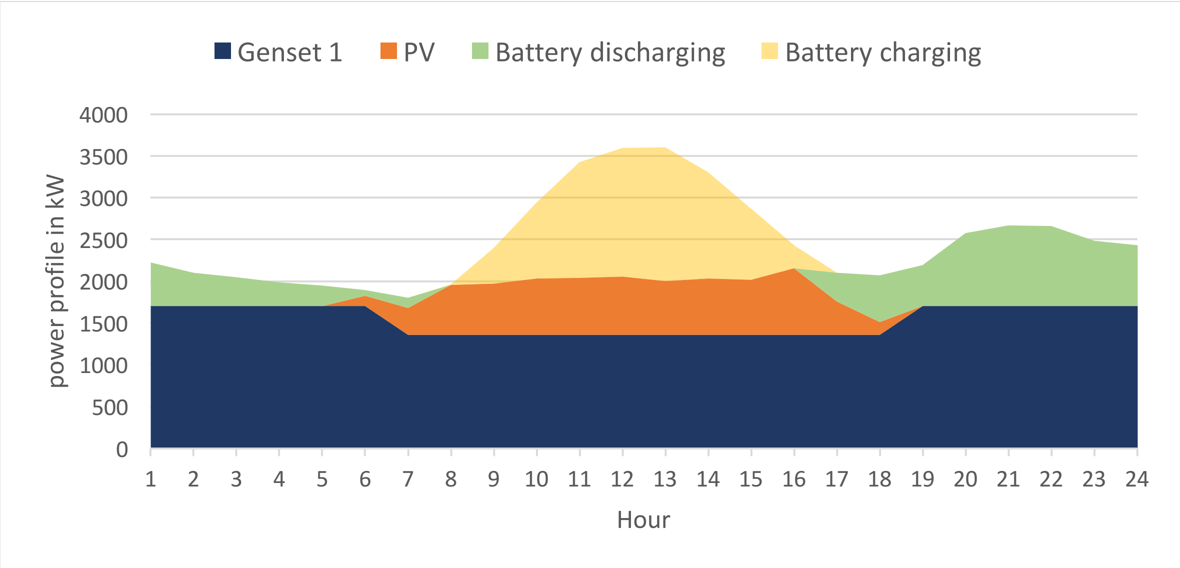


Figure 15: Scenario 2: 1 Gen-set, PV, Battery

For a simulation with HOMER Pro there are parameters for the different components required.

Most of the values especially concerning the fuel generator are concrete values from the files of EGE Haina. Other values however are determined with common values for the technologies or with reasonable assumptions. The focus of the simulation is a feasibility study of such a project in Pedernales. A final design of the power plant would exceed the scope of this elaboration. A detailed economic review for the application of different components and a comparison of different manufacturers and technologies is to be carried out in further studies. To get an impression of the feasibility of this project, regular components are chosen that in their characteristics represent the current state of the technology.

The definition of the parameters used in the simulations for each component from Figure 16 is listed below.

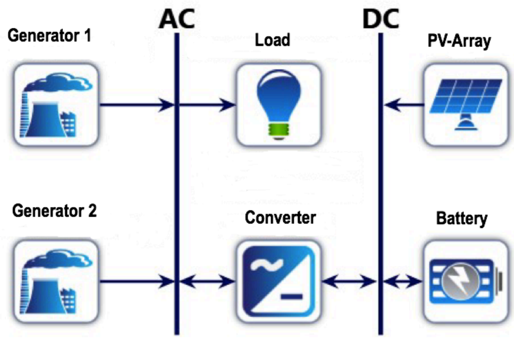


Figure 16: Components of Hybrid System (HOMER Pro)

For the simulation an operating reserve will be calculated of 10% of hourly load and 25% of solar output.

4.1.1 PV Array

For the simulation of the PV-module in the project many different aspects need to be considered.
The simulation is made with a generic polycrystalline-silicon-solar-module. Due to the fact that the planning of the hybrid system is an extension of the already existing power plant the decision to use the cheapest PV-module on the market results from economical reasons. The PV-array is being kept simple in this simulation not considering a sun-tracking because the conditions for PV-generation are already promising for a successful project.

Panels without tracking are generally oriented towards the equator, which in the case of Pedernales, located in the northern hemisphere, means that the panels are facing south. They should be set up with a minimal inclination angle of 15 ° to ensure drainage of the rain water and to prevent the accumulation of dirt on the edges of the panels. According to The German Energy Society the rule of thumb for the inclination angle is the angle of latitude of the project + 15 °. For Pedernales (19 ° N, 75 ° W) this implies an inclination of about 35 °. (Deutsche Gesellschaft für Sonnenenergie, 2008)

In the last few years PV-modules have undergone a drastic development especially in terms of cost and efficiency. And still the prices will probably drop in the next years (Chase, Wang, Radoia, & Bromley, 2017).

The International Finance Corporation publishes in the “Utility-Scale Solar Photovoltaic Power Plants” in 2015 an average capital expenture (capex) of 1400$/kW not including taxes, fees and legal costs (International Finance Corporation, 2015). Due to Bloomberg New Energy Finance the total capital cost in the United States for 2017 for PV-projects with utility scale purpose is 1.8 $/W including converters, balance of system (BOC) and enigineering, procurement and construction (EPC) which is equal to 1800 $/kW. Since all components (MPPT, Inverter …) are calculated seperately in the simulation, the costs of the PV-modules used in HOMER Pro is the plain module price. The actual pricing of the PV-module is 560 $/kW. (Bromley & Serota, 2017).
The price of the PV-modules is expected to drop even to 300 $/kW in 2017 (Chase, Wang, Radoia, & Bromley, 2017). An estimation of 560 $/kWh in the simulation is significantly higher than the prognosis of Bloomberg. Since the simulation with HOMER Pro is based on this value given by Bloomberg, it needs to be taken into account, that there are no PV-Modules nor other electrical components such as inverters or batteries directly produced in the Dominican Republic. The fact that all necesarry material has to be imported and delivered to Pedernales which is farely difficult to reach, elevates the price of the Components. On the other hand the cost of property is significantly lower than for projects in Europe or United States. In the simulation the component of transportation and cost of property are considered to even out. A possible decrease of the capex of PV-modules will be included in the sensitivity study of the simulation.
For the maintenance Bloomberg estimates in their “PV O&M Index 2016” a cost of 14000 $/MW/year in Europe and the United States. For the Dominican Republic a similar value can be assumed, because wages are lower, but cost of transportation for spare parts more expensive. (Hayim, 2017)
One important factor on which the maintenance and the power output depends is the cleaning of the PV-modules.
Due to the aforementioned high rainfall in Pedernales, the maintenance concerning the cleaning of the PV-panels is low. Since a high self cleaning can be expected due to the precipitation.

The simulation of the hybrid system is based on the data of the PV-module STP265 – 20/Wem of Suntech. One module with the surface dimension of 1.64 m x 0.992 m consists of 60 policristaline silicon solar cells. The PV-panel has a maximum power of 265 W and an efficiency at STC of 16.3 %. The efficiency of the panel decreases each year by 0.7% and ends at 80.7 % efficiency after 25 years. A lifetime of 25 years is for PV modules an ordinary value, and used in the simulation.

The fill factor is according to its formular: $FF = \frac{I_{mp} \cdot U_{mp}}{I_{sc} \cdot U_{oc}} = \frac{8.56\ A \cdot 31.0\ V}{9.02\ A \cdot 37.8\ V} = 0.778$. That means that at the maximum power point of 265 W the panel reaches 77.8 % of the theoretical possible outputpower of 341 W which is calculatetd by opencircuit voltage and shortcircuit current.

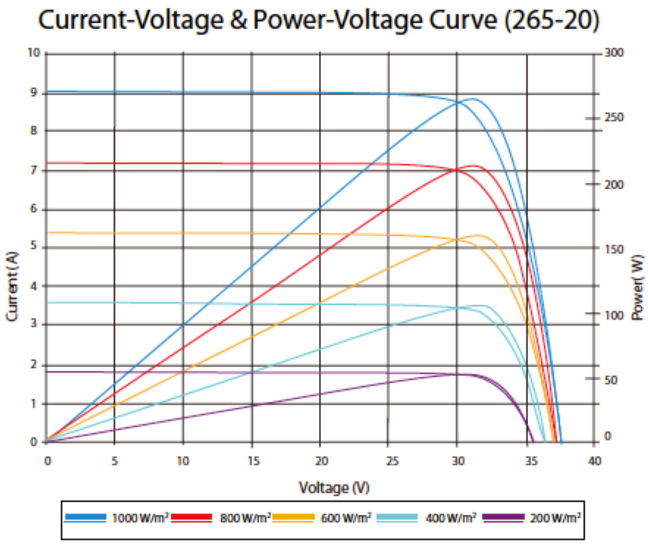


Figure 17: MPP-Curve for STP 265 (Sun Tech)

The solar-modules are designed according to the Standart-Testing-Conditions (STC). Operating at higher temperature means a decreas of the maximum-output-power of the module. Figure 17 shows the Voltage-Current-Power Curve of the panel.

The climate in Pedernales is basically characterized by the high temperatures. The annual average temperature is 24 °C. As Figure 6 shows, the minimum and maximum temperature never deviate by more than 7 °C. That means that the temperature can be considered as constant.

With higher operating temperature the the efficiency of the PV-module decreases by 0.41 % / °C cell temperature. From the data of the National Aeronatics and Space Administration it can be seen that the temperature in Pedernales does not exceed 28.2 °C. According to Koehl et al. the modul temperature can be approached with the following formula with $U_0 = 30.02$ and $U_1 = 6.28$ for polycristaline silicon PV-modules (Koehl, Heck, Wiesmeyer, & Wirth, 2011):

$$T_{cell}[°C] = T_{air}[°C] + \left(\frac{G \left[\frac{W}{m^2}\right]}{U_0 + U_1 \cdot v_{wind} \left[\frac{m}{s}\right]} \right).$$

The modul temperature varies with an average windspeed of 3.55 m/s during the year between 42.9 °C in july and 38.0 °C in december.

By virtue of the relatively high windspeed in Pedernales which is mainly caused by its coastal location, the cell-temperature stays the whole year in a value range for which no cooling must be considered since the Normal Operating Cell Temperature (NOCT) according to the data sheet of the PV-module is 45±2 °C

Losses that are caused by an elevated cell-temperature are calculated in the HOMER Pro simulation as well as with PVSyst. Table 3 sumerizes the most importante parameter for the simulation of the PV-array.

Table 3: Data pf the PV-Module Suntech STP 265

Capex	560 $/kW
Replacement	300 $/kW
Opex	14000 $/MW/year
Lifetime	25 years
Performance Ratio	80 %
Efficiency at STC	16.3 %
Tracking	No
Temperature effects on power	-0,41 %/°C
NOCT	45.0 °C

4.1.2 Generator

The advantages of establishing a system that includes a fuel run generator is that it applies a power control on demand into the system. This increases the reliability that with 100% PV would only be possible with expensive and oversized batteries. Still the operation of engine-generators also induces a couple of disadvantages. Not only to mention the exhaust and noise emission of the engines, the most important disadvantage of the engine is the dependence on fuel, which has to be transported to the power plant and stored in large tanks. Especially in areas like Pedernales the transportation of the fuel is a factor which increases the operating

costs significantly. Because of high pressures, and mechanical loads during the operation, a comprehensive and costly maintenance is indispensable.
Of the three available generators, there are currently only the two newer Hyundai engines operating constantly. This is why the study concentrates on these two Hyundai generators. The generators hold eight poles and run with 900 rounds per minute (rpm) to reach 60 Hz power frequency.

It is expected that the hybrid system designed for Pedernales is a Low- or Medium-Renewable-Energy-Penetration-System, that means that at least one of these fuel-generators is expected to run the hole time. The goal is to shut the other generator off as much as possible to save up fuel. Consequently, the main focus of the hybrid system is to supply the load demand with one gen-set and the PV-Array in combination with the battery bank. The second Hyundai engine will serve as a backup generator in case of maintenance or peak loads.
The Hyundai engines run with a theoretical specific consumption of 0.203 liter/kWh. Hitherto praxis performance shows a consumption of 0.257 liter/kWh. The average price of Heavy Fuel Oil in 2016 was 41.40 $/BBL which is equal to 0.26 $/liter. It is important to consider that the fuel price fluctuates significantly during the year – in 2016 between 0.20 $/liter and 0.33 $/liter. The more the fuel-price increases the more economically rewarding the hybrid system gets.

With a calorific value of the HFO of 11.44 kWh/l the efficiency $\eta = \frac{\frac{1}{consumption}}{calorific\ value} \cdot 100$ of the engine is between 43.1% for the theoretical consumption and 34.0 for the present performance.
The capital cost of the Hyundai generators amounts to 1470 $/kW. (EGE Haina, 2016)

Since the Caterpiler engine has been installed in 1998 and thus is almost 20 years old it is not operating frequently anymore. There fore there is not much data of operation or current numbers of costs available.
The engine will be included in one simulation to evaluate the existing system with Homer Pro to get an impression of how far the systems are comparable. In further simulations the Caterpilar-engine will not be included. Since the diesel-fuel is with approximately 0.55 $/liter more expensive and the specific consumption of fuel is with 0.281 liter/kWh clearly higher than the other engines, there are no advantages expected from an integration of this engine into the system.

The lifetime of the fuel driven engines depends on its operation plan and can be effected by different conditions.
Running the engines with partial load of under 40% of the nominal load increases the probability of corrosion in the wear due to the sulfur in the diesel which in turn can lead to a reduced operation performance at high operating costs.
At each start of the engine the possibility of a false start is given. With a high start/stop frequency the probability of a failure of the engine is elevated. As the hybrid system is based on the reliability of the engines, a false start could have an important impact on the availability of electricity.
It is recommended to avoid cold starts, as this possibly accelerates the wear owing to mechanical properties of lubrication oils on connecting points.
All in all, it is suggested to run the engines as constantly as possible on a high level with as little interruptions as possible. To guarantee a high efficiency of the engine and a long lifetime the generator should preferably be driven on a high level with $\frac{P}{P_{max}} > 70\%$. (Saengprajak, 2007). As Figure 18 shows, the fuel consumption per kWh increases and thus the effectivity of the generator decreases drastically, if the loading ratio falls below a value of 60%. According to Deshmukh and Deshmukh the most economically is to run the engine at 70-90%

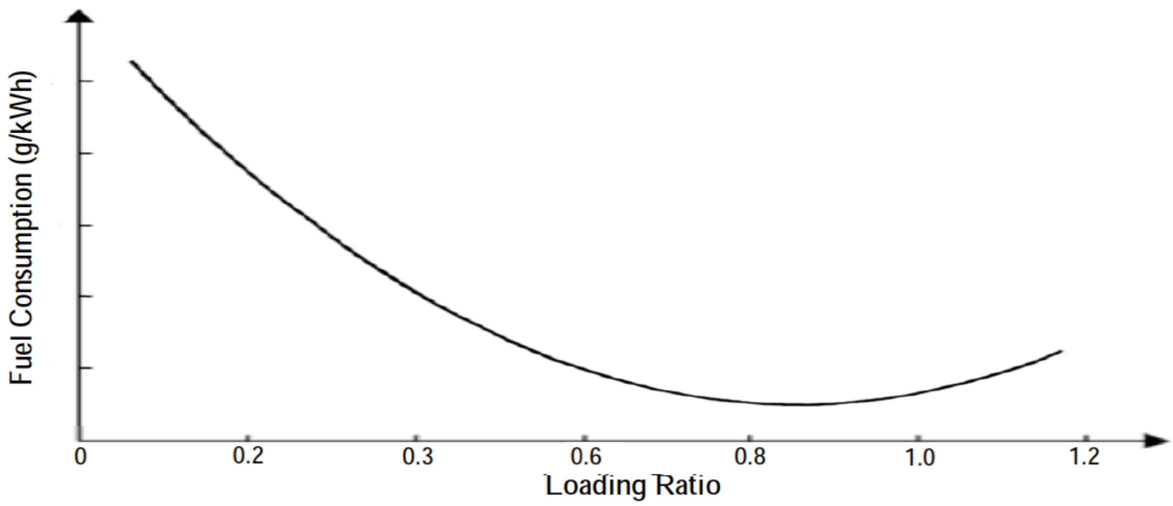


Figure 18: Fuel-consumption / Loading Ratio (schematic from Sendyka & Noga 2013) (Sendyka & Noga, 2013)

Table 4 sumerizes the most importante parameters for the simulation of the Fuel-Oil driven generators.

Table 4: Data of the Motors installed in Pedernales

	Hyundai	Hyundai	Caterpilar
Capex	1470 $/kW	1470 $/kW	1650 $/kW
Replacement	1470 $/kW	1470 $/kW	1650 $/kW
Opex	29,850 $/h	29,850 $/h	35000 $/h
Fuel	HFO	HFO	LFO
Lifetime	175,000	175,000	150,000

4.1.3 Battery Bank

Batteries are a factor that increases the LCOE in a hybrid system significantly. For the dimensioning of a battery bank the autonomy is a parameter widely used. The autonomy indicated for how long the battery can supply the load demand without having other sources of energy available. According to Deshmukh & Deshmukh the battery in a hybrid system should be sized to assure 2-3 days of autonomy. That means for Pedernales, that a battery with a capacity between 100 and 150 MWh is required to cover to load when the renewable energy sources are not available. To lower the size of the batteries and there by the costs of the system, the hybrid system accesses the fuel engines as a backup. Still first approximations to the problem suggest that a battery of at least round about 2 MWh is required. There are not many hybrid-projects with such large scale batteries yet.

Because of their longer lifetime, higher Depth of Discharge (DoD) and primarily an expected significant development in the next years lithium ion batteries where chosen for the project. It is expected that the price of batteries will decrease drastically in the next few years due to the fast development of their usage in the automotive industry. For standalone systems deep cycle batteries are required, that best suit for the use with inverters. Other than the starting battery the deep cycle battery is designed to assure a constant power output that results in a low State Of Charge (SOC) before it is charged again. Lithium ion batteries can be discharged up to 100%. (Saengprajak, 2007)

Lifetime and capacity losses of the battery are influenced by the operating circumstance of the battery. Especially the DoD and the operating temperature are significant for the condition of the battery.
Depth of Discharge is the opposite of the State Of Charge. As Figure 19 shows the lifetime or the cycles to life of the battery decrease significantly with a lower state of charge and at a higher temperature. (Leuthold, 2014)

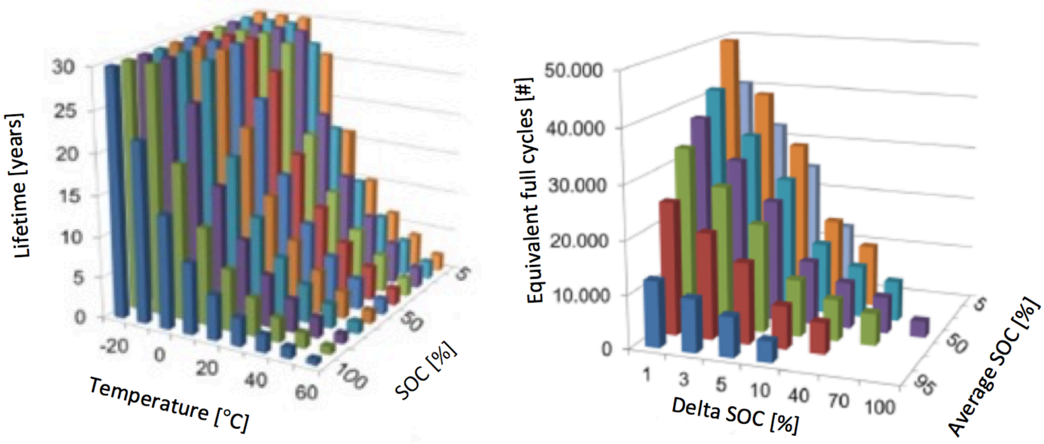


Figure 19: Effect of Temperature and SOC on lifetime of Li-Ion Battery   (Leuthold, 2014)

Since the battery bank has a great impact on the cost effectiveness of the hybrid power plant, it needs to be chose wisely which type of battery fits best for the application planed. According to The German Energy Society (DGS) the following features are essential for batteries in a stand-alone system:

- Good price/performance ratio: For Lithium-Ion batteries the price performance ratio is expected to make a great development.
- Low maintenance
- Long service life
- Low self-discharging: Because of constant chemical reactions taking place in the batteries, the Batteries are discharging them selves over the time. The self-discharge should not exceed 3%/month. Lithium-Ion batteries have a self-discharge-rate of only 1%/month
- High efficiency

These characteristics suggest that the use of Li-Ion batteries in hybrid systems is preferable. According to the 2016 lithium-ion battery price survey by Bloomberg in December 2016 the average price of lithium ion in $/kWh has dropped from 1000 to 273 since 2010 for utility scale batteries. The price includes wiring, housing and thermal management of the battery but no additional management systems or processing units. Bloomberg forecasts the price to drop to 109 $/kWh by 2025 and 73 $/kWh by 2030 (Figure 20) (Goldie-Scot, 2017). The estimation of Bloomberg is made with high scale battery projects mainly located with good access to infrastructure and thus an easy connection to the manufacturers. The price of the battery model used is 500 $/kWh in the commercially trade on the Internet. Since the price for the system in Pedernales is expected to be lower than the price in the commercial trade but due to transportation costs higher than the price estimated of Bloomberg, for the simulation the price of 380 $/kWh is exerted. The sensibility study will show the impact of the battery price on the Levelized Cost Of Energy (LCOE) (Curry, 2017).

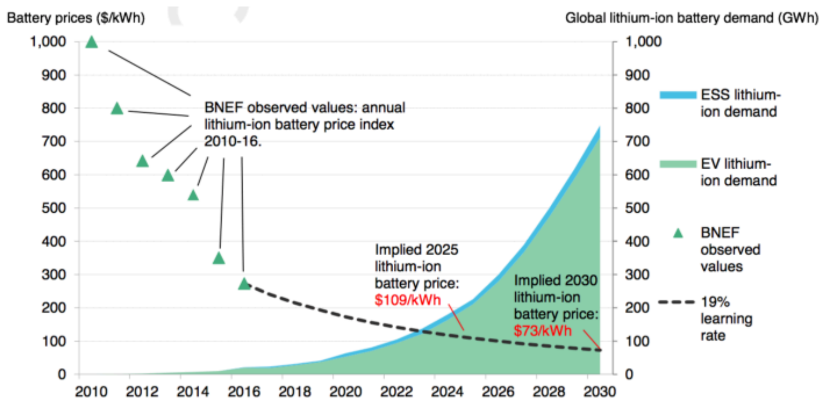


Figure 20: Price Developement of Li-Ion Batteries (Bloomberg New Energy Finance)

The Battery used in the simulation is the LG chem RESU 10H with a storage capacity of 9.8 kWh at 25 °C of which with a DoD of 94.5 % 9.3 kWh are available. The maximal instantaneous output- and input-power is 5 kW. The battery-charge current is set by the output current of the PV-array, whereas the battery output current depends on the load. What particularly qualifies this battery model for the integration into the hybrid system is the application on a high voltage level. Additionally can voltage and current be adapted to a multiple of the specific output by arranging the length of the series connected batteries and the number of strings. In this contects the voltage is multiplied by the number of batteries in series and the current by the number of parallel strings. The Voltage-rage of the LG chem RESU 10H is between 400 - 450 V_{DC} for charging and 350 - 430 V_{DC} for discharging cycles. To meet the power of 5 kW the discharging current varies between 14.3 A at 350 V and 11.9

A at 420 V. A maximal peak current of 18.9 A at 350 V is possible for 10 seconds and result in an output power of 7 kW peak.
The operating temperature of the Lithium Ion battery is between -10 °C and 45 °C. Yet it is recommended to operate in a temperature between 15 °C and 30 °C.

The recommended operating temperature of under 30 °C for the battery is very likely not fullfilled in Pedernales especially because the average temperature is 24°C and during the day even higher. Normally the Batteries are stored in housings to protect them from environmental influences. Since the batteries emit heat themselves when they are operating, and they do not consist of a coolingsystem, the building needs to be air-conditioned. Like this the ideal circumstances for the operation of the batery can be established, which will increase the lifetime. (Yingzhi, et al., 2015)
Since there are not many batteries installed in the system, the cooling can be implemented with simple air conditioners. The economic effect of a cooling system for the small-scale battery bank is neglected in this simulation.
The dependence of the lifetime of the battery on the SOC however is integrated into the simulation with HOMER Pro. The installation of a cooling system will increase the lifetime and efficiency of the project and will thus promote the economy of the project.
The LG chem RESU 10H has an in the datasheet given lifetime of 6000 cycles at 90% DoD and 10,000 cycles at 80% DoD. Assuming one cycle per day means a possible lifetime between 15 – 25 years.

The battery is designed to work with the inverters of SMA.
Table 5 sumerizes the most importante parameters for the simulation of the battery-bank.

Table 5: Data of the Lithium-Ion Battery LG chem RESU 10H

Capex	380 $/kWh
Replacement	230 $/kWh
Opex	1 $/kWh
Cycles of Life @ 90% DoD	6000
Roundtrip efficiency	95 %

4.1.4 Power Conditioning

The PV-Array as well as the battery bank supply or store direct current (DC). The load demand in Pedernales however is alternate current supplied with alternating current (AC), since there are less losses and more devices working with AC. It is absolutely indispensable to install an inverter into the hybrid system to make the energy from PV-array useable.
The German Energy Society names the following requirements for inverters in stand alone systems as important:

- Stable voltage and frequency which in Pedernales is 2400V and 60Hz
- Good conversation efficiency, at partial load range as well
- High overload capability
- Tolerance against battery and PV voltage fluctuation
- bidirectional operation to make a charging of the battery with the AC-generators possible (Converter = Inverter & Rectifier)

Considering theses points the inverter used in the simulation is based on the Sunny Central Inverter of SMA, since it is designed to work together with the lithium-ion battery mentioned.

Bloomberg estimates a Capital cost for utility inverters of 130 $/kW in 2017. (Wang & De Silva, 2014). The Solar Inverter Market Outlook even suggests an inverter cost of 70 $/kW (Chase & Swarbreck, Solar Inverter Market Outlook 2017, 2017). The simulation uses the higher price, since the feasibility with this inverter would mean the feasibility of the system with cheaper inverters anyway. Furthermore the transport to Pedernales increases the price. For these reasons the calculation is made with an inverter-price of 130 $/kW.
A bi-directional Inverter is not necessary. The batteries are expected to be charged with the excess energy of the sun during the day. This makes the whole concept easier.

In a stand alone system with power supply only by PV and battery the inverter must be sized by the demand of the AC-load a capacity margin. Since there are fuel generators in Pedernales supplying the load constantly, the dimension of the inverter only depends on the size of the PV-array and the battery. The best possible solar yield is to achieve when the output power of the inverter unit is maximized and supplied to load.

In addition to an inverter that converts the power from DC to AC for the system that is planed in Pedernales there is also a charge controller (or Maximum Power Point Tracker = MPP Tracker) required.

For small stand alone systems with 12 or 24 V batteries and solar panels of 36 respectively 72 cells a charge controller is not mandatory, because the two components are designed to work together. For the system planed in Pedernales with a Li-Ion battery of 51.8 V and a PV module consisting of 60 cells on the other hand the charge controller is an essential element, because otherwise the mismatches would cause large energy losses (Deutsche Gesellschaft für Sonnenenergie, 2008).

The installation of a so called MPP Tracker brings many advantages into the system. Mainly the current and voltage are adjusted by the DC-DC-inverter to reach maximum output power and to meet battery-charging requirements. Thereby the mismatch-losses can be minimized from 10% to 1-2%. At the same time the battery life is maximized with a charge controlling system by ideally managing the charge and discharge.

The charge voltage of the battery has to be distinctly higher than the battery voltage so that the MPP voltage is still sufficient when it drops with increasing cell temperatures. To prevent a discharge of the battery into the PV-array in case of voltage breakdowns during low radiation or at night, reverse current diode is installed to protect the system. So the charge controller fulfills a function as electronic load protection as well. (Deutsche Gesellschaft für Sonnenenergie, 2008)

The cost of a charge controller is according to the German Energy Society barely low compered to costs of inverters and battery. In the simulation it is estimated with 50 $/kW.

Table 6 sumerizes the most importante parameters for both power conditioning devices together for the simulation of the power conditioning.

Table 6: Data of the Inverter

Capex	180 $/kWh
Replacement	130 $/kWh
Opex	10 $/kWh/year
Efficiency Inverter	98.6 %
Efficiency Rectifier	95 %

4.2 Losses

For a renewable power system there have to be taken different losses into account. In general it is distinguished between two types of losses:

- Capture losses: That are losses of electricity at capturing the energy
- System losses: Losses that are caused by the different components the electricity passes until reaching the demand load.

4.2.1 Capture Losses

Generating electricity with a PV-panel not all oft the energy emitted reaching the surface can be captured. There are many losses that already occur, by trying to capture the sun such as:

Shading losses: Are losses due to shading of the PV-panel. The shading of a PV-panel can have a large impact not only on one module, but also on the modules connected in the same string. The output energy is reduced, which in turn leads to mismatches within the PV generator because of non-uniform irradiation distribution over entire array.

Module orientation losses: During the day the sun changes it position from east at sunrise to west at sunset. Since the modules of the Project elaborated are fixed and without a sun tracker a difference between module disposition and perpendicular to incoming sun rays occurs. That means that the sunbeams do not fall directly onto the panel at any time of the day. This circumstance causes the so called module orientation losses

Spectral Losses: AM 1.5 stands for Air Mass 1.5 and is a standard value in the solar industry. It stands for the fact, that the sunbeams do not reach the earth surface at an angle of 90 so that they traverse a distance trough the ozone layer which is round about 1.5 times the distance it would take directly through it. This longer distance causes a loss of the theoretical available radiation spectrum.

Reflection Losses: Although PV-modules already have a special surface a part of the sunlight reaching the panel is reflected.

Surface soiling losses: Dirt on PV surface prevents a full functionality of the module. Some of the sun beams simply do not reach the panel.

(Saengprajak, 2007)

4.2.2 System Losses

Inverter and battery charger losses: Generally the efficiency of the battery charger of rectifier (AC to DC) is lower than the efficiency of the inverter (DC to AC). With the Standby consumption included the inverter has a efficiency of 95 % whereas the rectifier has an efficiency of 90 %.

Battery storage losses: During the conversion of electrical energy into chemical energy an vice versa some of the energy get converted into energy that is not usable for the system such as heat. Lithum-Ion batteries show a loss of only 5 % in one complete cycle (charge and discharge) That leads to a cycle efficiency of 95 % at Standard Testing Conditions
The amount of battery losses depends on the type of battery, the operating temperature, charging circumstances like the Depth of Discharge and the number of cycles.

Auxiliary generator losses: The efficiency of a fuel driven generator depends on its operating mode. The losses can be minimized when the gen-set is either run on a high level between 80-100% or shut off.

PV-battery mismatch losses: Mismatch losses between the PV-array and the battery result from changes in voltage during operation.
On the one hand the battery require different voltages respectively to their SOC. On the other hand the PV-array provides different voltages according to the cell temperature and the radiance. The Drifting of voltage (or mismatch) is estimated to cause losses of 10%, which it can be reduced to 1-2 % by including a MPPT (charge controller).

PV-array mismatch losses: PV-array mismatch losses are caused by deviation of I-V-curve of interconnected PV modules. The overall output is smaller than sum of outputs of each module at a given operating point, because of slight variations in production of the modules even if they are the same type. It can also be caused by shadowing, what not only leads to mismatch due to different radiation but also because the modules are operating at different cell temperatures.

Wiring losses: The wiring losses sum up all ohmic losses between system components that are caused by DC cable resistance, relays and switches. Because of usually high voltages and low AC currents the losses caused by the AC wiring are very low and can be neglected.

In the simulation all the losses that are not specifically calculated by the software, are combined to a performance ratio of 80 %.

4.3 Software

There are numerous types of simulation software for PV modeling. The task of the planner is it to choose the correct program for the specific site requirements. Different programs have different purposes and are used for sizing of the components, simulation of threshold values and operating states and exact yield forecasts.

Stand-alone systems are generally more complex in their operation behavior than grid connected systems. To get an exact impression of the energetic, economic and ecological performance of the system, the software predicts all the important impacts on the operation of a PV power plant such as weather, shadings, losses, load demand and all kind of costs.
The result of the simulation depends on the parameters entered into the software interface. These can be very complex whereby the programs are very error-prone. Thus the values used should be well investigated and checked exactly. Incorrect sizing might have a large impact on the credibility of the result and can easily imply a non-functional system. To avoid errors, it is recommended to undertake a preliminary yield estimation to assess the results that are expected.
Results of the simulations should be compared with the values of similar projects to verify their plausibility.
The programs used in this evaluation are so called time-step simulation programs, since they are more accurate
To design the Hybrid System in Pedernales two different Programs will be utilized. The programs serve on the one hand to compare the results of the yield report, on the other hand

they serve different purposes. The simulation with two or more simulation programs is common practice in the evaluation of power plants.

For the economical simulation and dimension of the system the program HOMER will be used. PVSyst is used to create a design model of the dimensioned Hybrid System and to simulate factors like shading, angles of the panels and to calculate the size of the PV-array to get a realistic image of the power production that can be expected. (Deutsche Gesellschaft für Sonnenenergie, 2008)

DigSILENT is used to check the operating behavior of the designed system in the existing structures.

4.3.1 HOMER Pro

HOMER Pro is a micro grid-design software developed by National Renewable Energy Laboratory and distributed by HOMER Energy.

The software is specialized for hybrid system simulation and thus attempts a viable simulation for all different combinations of the equipment that is considered to be used in the project. One of the features is the optimization, which automatically dimensions the different components identifying least cost options. A useful attribute of the program is the sensitivity analysis, which allows to run the same model with varying values for different parameter. This allows to simulate an impact of for example an increase of fuel price or an expected decrease of capital costs. (Homer Energy, kein Datum)

4.3.2 PVSyst

PVSyst is one of the classic simulation software which has been developed in 1992 and is under permanently development since then. The software designs grid connected projects as well as off-grid systems. There are two basic modes in PVSyst:

- Pre-dimensioning mode: for a quick first estimation
- Project design mode: comprises more parameters and options.

PVSyst simulates parameters such as: shadowing, all types of losses that are likely to occur in a photovoltaic-plant, losses due to pollution, mismatch losses and reflection losses.

PVSyst was the first simulation software able to simulate 3D shading.

The results of the simulation are presented in a final report and can be exported to and excel file. (Deutsche Gesellschaft für Sonnenenergie, 2008)

4.3.3 DigSILENT

The DigSILENT Power Factory is a software for modeling the interaction between generation, transmission and distribution for electrical grids. The program includes static and dynamic calculation oft the models, which means that all different cases of for example PV excess or shortage can be simulated. (DigSILENT, 2015)

5. The simulations

Different simulations are carried out, to evaluate different parameters of the project. The main simulation is done with HOMER Pro. It represents the economical part of the evaluation as well as it offers a model of the generation available with the PV-array.

The simulation with PVSyst serves to get an impression of the dimension of the area that is needed. Since PVSyst provides a detailed model of the generation of a PV System, the values received by HOMER Pro can be compared and checked. PVSyst additionally simulates the shadowing on the array by surrounded objects.

The final step of the simulation is a review of the electrical feasibility of the project. This step is accomplished with DigSILENT.

5.1 Results of the HOMER simulation

5.1.1 Indicators of Simulation with HOMER Pro

The key indicators to determine the viability of a power plant project are the Net Present Cost (NPC) and the Levelized Cost Of Energy. HOMER Pro compares all different combination of applying the hybrid system and presents the systems with the lowest NPC and LCOE in the results.

Net Present Cost: The NPC represents a dynamic value in the calculation of the investment. It refers to the increase in assets related to the start date of the project. The Net Present Cost is the sum of cash in- and outflows of each period divided by the corresponding discount rate (Das, Hoque, Mandal, Pal, & Raihan, 2017).

$$NPC = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

- with N for the number of periods, which in the case of the project is 25 for 25 years lifetime,
- t describes each corresponding year.
- i is the annual discount rate that is calculated by the nominal discount rate i' and the inflation rat f $i = \frac{i'-f}{1+f}$. In simulation presented the discount rate is considered 8% and the inflation rat 2%. (Trading Economics, 2017) consequently a annual discount rate of 5.9% is obtained.

Levelized Cost Of Energy: The LCOE is the ratio of the annual costs of the system during the lifetime (C_a = Opex + Capex) to the energy supplied to the load E_a (excess energy excluded). The resulting value describes the unit cost in $ for each kWh produced.

$$LCOE = \frac{C_a}{E_a}$$

5.1.2 Results of the Simulation

With the components that have been described before the simulation with HOMER Pro leads to the results shown in Table 7.

To be able to compare the results to the system existing the current power plant in Pedernales has been designed in Homer as well. The result of simulating the present system, correspond with the data of EGE Haina. The LCOE given by EGE Haina is 0.131 $/kWh at a fuel price of 0.3 $/l not including the Capex. A simulated value of 0.138 $/kWh is a realistic representation of the data of EGE Haina. Since these values match or are even lower than the true values it can be assumed that the simulation made, base on a realistic example and are thus meaningful for the success of the project.

Table 7: Results of the SImulation with HOMER Pro

	Present system	Case 1	Case 2
# of fuel-driven Generators	3	2	1
Dispatch	LF	CC	CC
Size of PV-Array	-	3.5 MW	5.0 MW
MPP Tracker capacity	-	2,000 kW	3,000 kW
# of LG chem RESU 10H	-	120	2100
Autonomy	-	0 h 31 min	9 h 0 min
Inverter Capacity	-	1,700 kW	3,000 kW
Renewable Fraction	0 %	23.0 %	32.2 %
Annual HFO consumption	4,659,524 liter	3,631,407 liter	3,152,550 liter
Annual LFO consumption	61,241 liter	0	0
kWh Engines	18,393,715	14,161,414	12,457,555
LCOE	0,138 $/kWh	0,119 $/kWh	0,136 $/kWh
NPC	32,926,900 $	28,234,470 $	32,421,830 $
Opex	6,396,824 $	5,842,398 $	4,928,558 $
Capex	7,800,000 $	7,753,757 $	13,825,757 $

Both cases simulated are Cycle Charging dispatch systems. That means that fuel gen-sets are driven at a constant rated capacity, assuring the primary supply. When there is PV-power available it replaces part of the energy generated by the engines. The batteries will be charged with excess energy generated during the day and mainly discharged in the case of high peak loads.

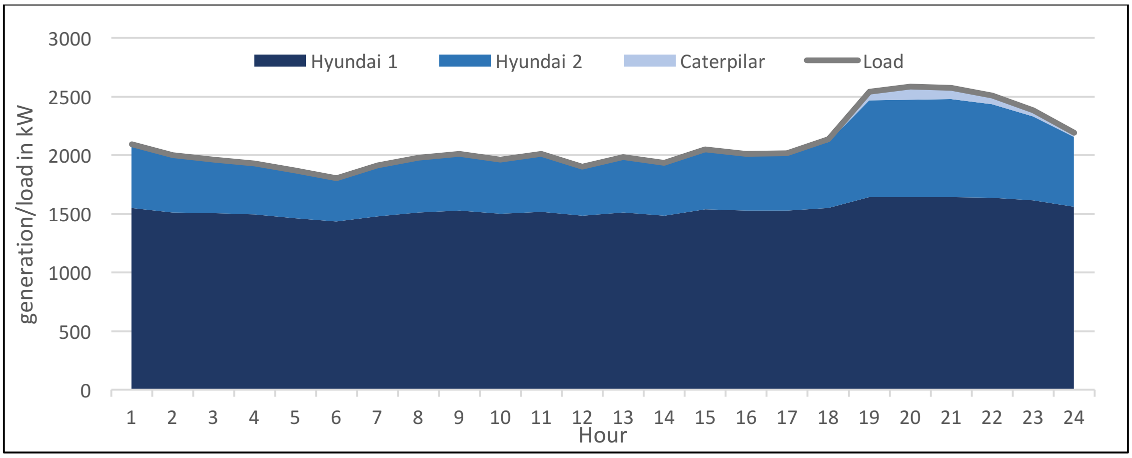


Figure 21: Installed power plant generation with 3 gen-sets

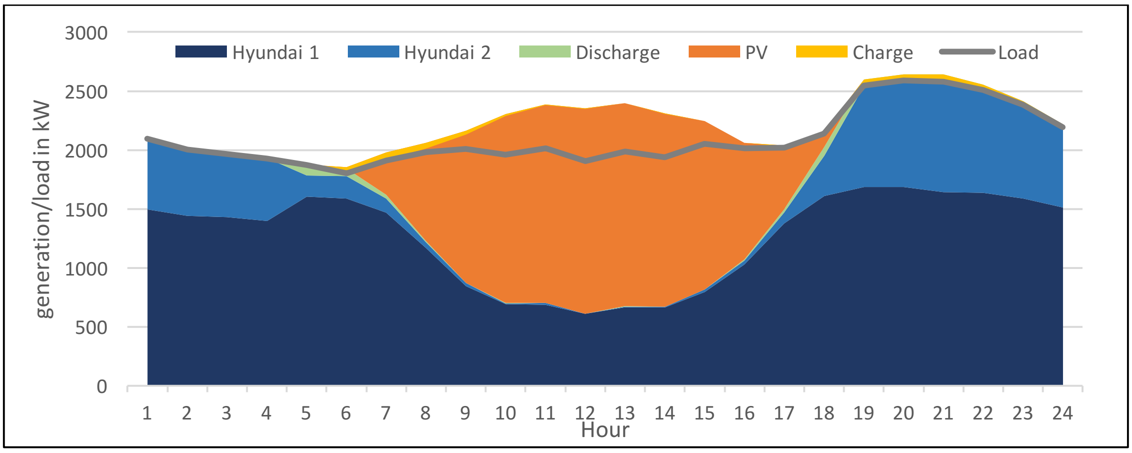


Figure 22: Case 1 - HES with 2 gen-sets, PV and battery bank

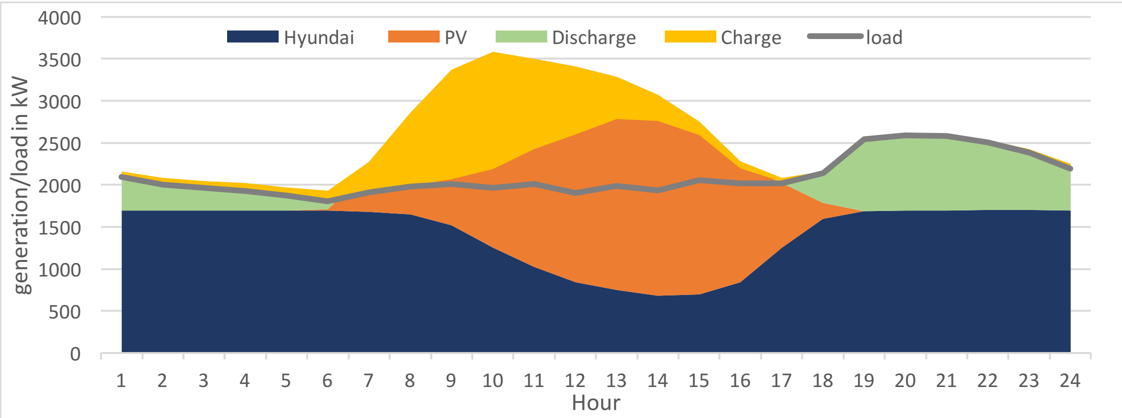


Figure 23: Case 2 - HES with 1 gen-set, PV and battery bank

Figure 21-23 show the different applications of the system - the daily load supply for the current system (Figure 21 and the two cases that were simulated (Figure 22, Figure 23). As Figure 22 and Figure 23 show, the results of the simulations match very well the in chapter 4.1 presented concept of the power profile for the different systems that were planned to simulated.

The yellow areas in Figure 22 and Figure 23 represent the share of the PV generated that is used to charge the batteries. The orange part instead is directly used to supply the load demand. Still there is an orange area above the graph of the load. This means that in afternoon hours there is an excess of PV-energy available. Since there is no further grid close that this energy can be supplied to, the energy is not usable unless further components are installed. The excess of energy could be stored in further batteries and used to cover the own consumption of the power plant. Specific plans of using the excess energy should be elaborated in further studies.

The system in case 1 consists of a 3.5 MW PV-array and a total battery capacity of 1200 kWh. With this capacity of the battery installed the system could run autonomously for 31 minutes. Since the batteries serve to cover peak load this time of possible autonomy is sufficient to supply the demand, without having to expect large unmet loads. Compared to the current system an operation of the system from case 1 could reduce the consumption of Heavy Fuel Oil by more than 1,100,000 liter per year.

The case-2-system has a higher renewable friction. With 5.0 MW the PV array is 1.5 MW larger than in case 1. Since there is only one engine in the simulation included, the battery bank is with 21,000 kWh sized vastly bigger. To meet the loads in the morning and at night when the sun is not up yet but the demand cannot be covered by one engine, the batteries supply a big part of the load. In this case the batteries need to compensate the missing of one Hyundai engine. The operation of the batteries shows a frequent discharge of the batteries under a SOC of 40%, partly the batteries are even discharged completely. The batteries in case 1 how ever are discharged to an SOC of 60 % only in the morning and in the evening. Figure 24 shows the cycles of the batteries in both cases for each time of the day over the whole year.

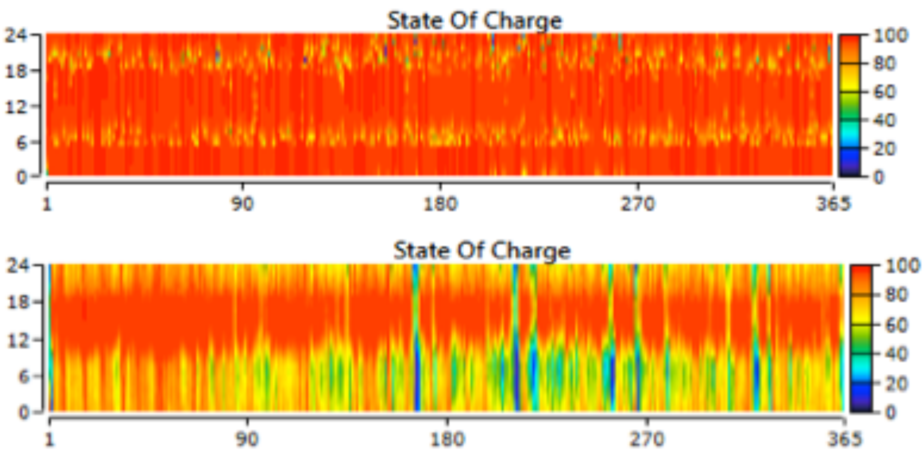


Figure 24: Operation of Battery a) Case 1 ; b) Case 2 (HOMER Pro)

The Net Present Cost for both projects is positive, which means that from an economical point of view they both are feasible. The project that is operating with one motor less has an even higher NPC than the system operating with both engines. This might be cause by the fact one motor is not considered in the calculation of the NPC by the program although it would exist in the system anyway since it is installed already.

The most economical system design is with a LCOE of 0,119 $/kWh the system with two gen-sets running, a PV-Array of 3.5 MW and 120 Li-Ion batteries installed. According to the simulation made the Levelized Cost Of Energy can be reduced with this system by $\left(1-\frac{0{,}119}{0{,}138}\right)\cdot 100 = 13.8\ \%$.

The Frankfurt School – UNEP Collaborating Centre for Climate and Sustainable Energy Finance presented a study in 2015 about: "Renewable energy in hybrid mini grids and isolated grids: Economic benefits and business cases". One of the cases presented was a region in the Dominican Republic called Las Terrenas. The simulation made with HOMER for this project had similar circumstances of load demand as the project in Pedernales. Las Terrenas is a little bit bigger and more touristic. Yet the simulation showed that a change in the power supply to a PV-Gen-set-Hybrid System can imply a turn-of off the Generators for 3.5 hours per day and thus reduce the LCOE by 12 % from 37.6 cents/kWh to 33.0 cents/kWh. (Al-Hammad, Becker, Bode, Srishti, & Kreibiehl, 2015). The LCOE estimated in this project is a lot higher than in Pedernales, yet the result is close to identical.
A decrease of the LCOE of 13 % by installing a PV-Diesel-Hybrid System can be considered as absolutely conceivable in the Dominican Republic.

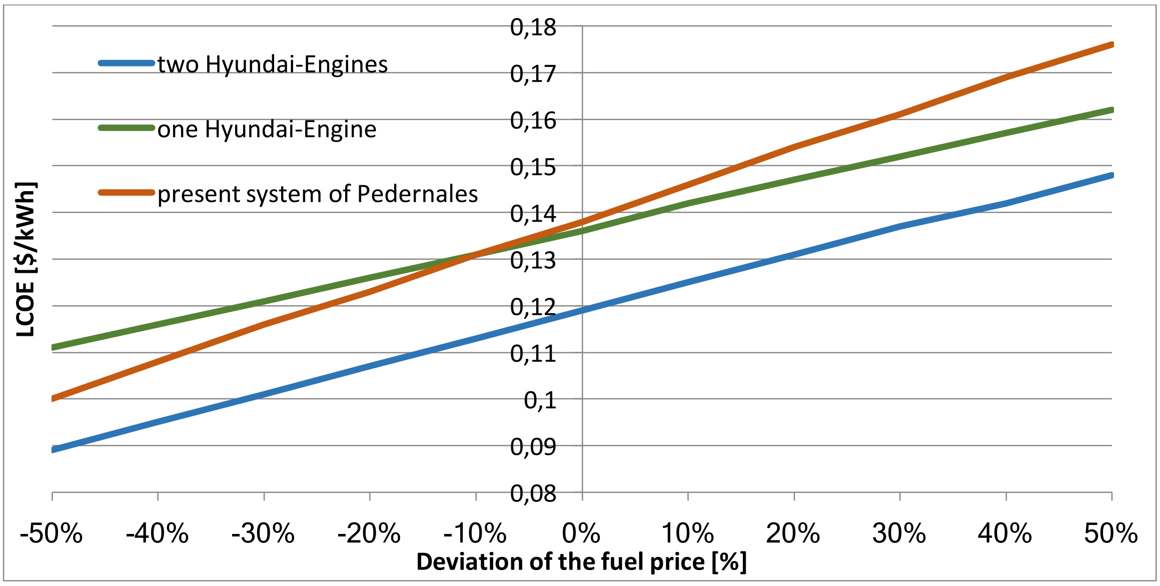


Figure 25: Behavior of the LCOE with deviation fuel prices

Even the system with one of the Hyundai engines completely turned off and a PV-Array of 5.0 MW is economically more convenient than the present power planed. Although the LCOE is with 0.136 $/kWh only 0.2 cent/kWh (1.5%) cheaper, still the Figure 25 shows that with an increasing fuel price the hybrid systems get more profitable than pure engine operation. Correspondingly an increase of 50% on the fuel price, of which an occurrence during the year is very much plausible and to which future prognoses of the fuel price tend, results in a LCOE for a hybrid system with one engine which is already 8 % lower than from the present plant. The cost of Energy for a hybrid system with 2 fuel engines would be even 16 % lower.

Assuming that the system installed consists of one engine with the capacity of 2.1 MW which runs constantly 8760 h/a, the runtime of this hypothetical engine can be compared with the other systems. For case 1 the notional gen-set can be turned off round about 2000 h/a, for case 2 even 2800 h/a. That means renewable fraction and thus a theoretical saving of fuel and exhaust fumes of 23 % respectively 32.2%.

Further investigations especially concerning sensitivity studies will concentrate on the elaboration the most economical system which is the system using two fuel gen-set, a PV-array of 2.5 MW and 1.2 MWh of battery capacity.
The sensitivity study will include an analysis of impact on the LCOE of the following parameters:

- Capex Solar
- Capex Battery
- Opex Solar
- Fuelprice
- Radiation
- Demand
- Project lifetime

Changing the parameter HOMER usually changes the dimension of the system according to the system with the lowest cost for each system. In order to be able to make a comparison, the system is set to the values mentioned above.

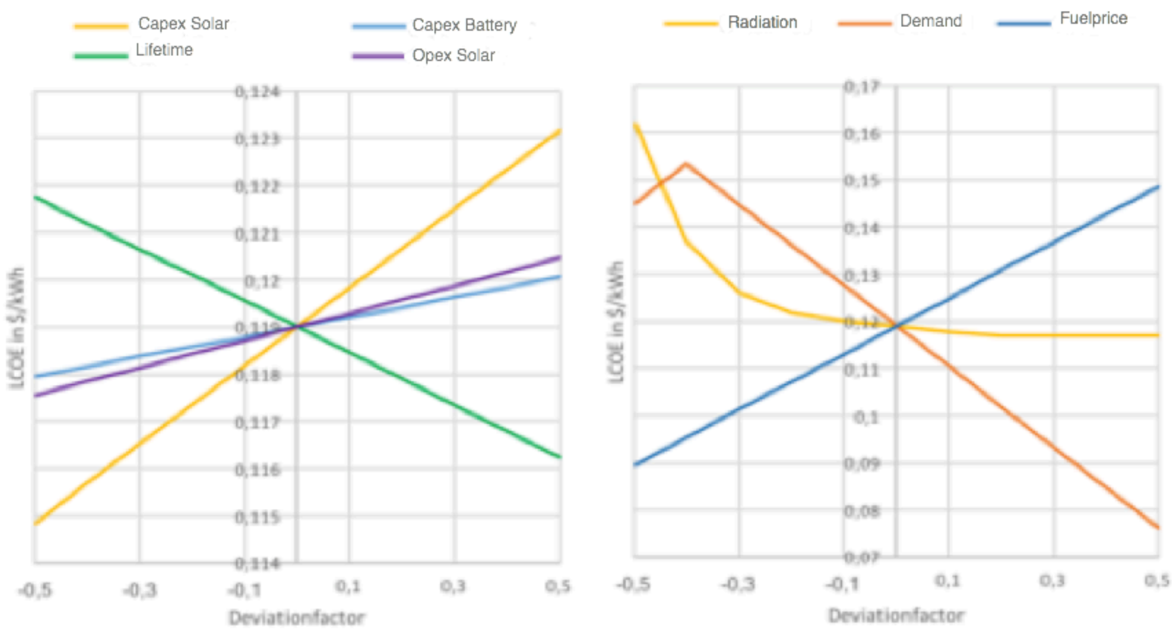


Figure 26: Influence of deviation of parameters on LCOE

Figure 26 shows the influences of varying parameters on the Levelized Cost Of Energy according to the sensitivity studies carried out with HOMER Pro.

- Sensitivity studies show that the biggest impact on the planned system has the fuel price. Since there are not many batteries installed in the system the expected decrease of Li-Ion batteries does not cause a significant change in the LCOE. For the system running with only one engine, 5 MW PV and 2100 batteries however the impact is vastly higher.
- The Capex of the solar panels has a greater effect on the cost of the energy. Still the Capital Cost of the panels could increase by 230% before the LCOE is equal to 0,138 $/kWh (the current cost of electricity). So even though if the Capex of the PV panels was estimated with a perspective to the future and is thus a little bit low, the project will still be feasible with a capital cost that is higher than the assumed.

The results for a fluctuation sensitivity evaluation of the demand and radiation are basically theoretical. A marked change of these values may cause a need of re-dimensioning of the power plant since in case of lower demand the system can be planned smaller or in case of higher demand load larger. Figure 24 shows a veer of the demand curve at -40%, which is cause by waiving one of the fuel engines when the demand drops.

A high variation of the radiation is usually not expected in a short time period. Still the impact is displayed to show the dependence of the system on the weather conditions. The impact of the radiation does not show a linear course. A fluctuation of the radiation between -20% and

+50% shows only a small impact. Lower radiation values influent the cost of energy significantly more.

The system in the simulation is presented as if it was a completely new system. If the capital costs of the gen-sets, that are already existing in Pedernales, is set to zero and the current value of the generators is ignored, the cost of energy drop significantly to 0.098 $/kWh for case 1 and 0.126 $/kWh for case 2.
Under this circumstance the system in case 1 saves 4 ct/kWh produced and is thus with an annual generation of 18.8 kWh paid off in round about 4 years.

5.2 Description of the model

5.2.1 Design concept and simulation with PVSyst

The simulation with PVSyst gives a more detailed idea of the dimension and the design of the system. Still it appears that the program is not ideal for a simulation of the hybrid system as it is planned. PVSyst is specialized for simulations of PV Systems, which are supported by a generator for charging the batteries. (Figure 27). The application as implemented, running with gen-sets for a basic load supply, the PV-array as substitute when the sun is up and batteries for peak hour supply cannot be simulated in this way with PV syst. The software however bases its calculations on a system, where engines only serve for battery charging and thus supply only a small amount of the load demand. In this case the dimension of the batteries and the size of the gen-sets that were assumed before would not correspond with the requirements that are needed to assure an operation without serious losses. A PV-array of 3.5 MW and a battery bank of 1200 kWh are not enough to supply a load demand of 50 MWh/d when the generators are just run to charge the battery. Many charging cycles would shorten the battery lifetime significantly. It appears that PVSyst is more suitable for the simulation of photovoltaic systems that are supported by the fuel generators and batteries but not for hybrid mix of generation.
Although the configuration in PVSyst is not congruent with the system planned, the results of simulation match very well concerning the points of annual PV-production and weather estimations. This supports the credibility of the simulation made with HOMER Pro.

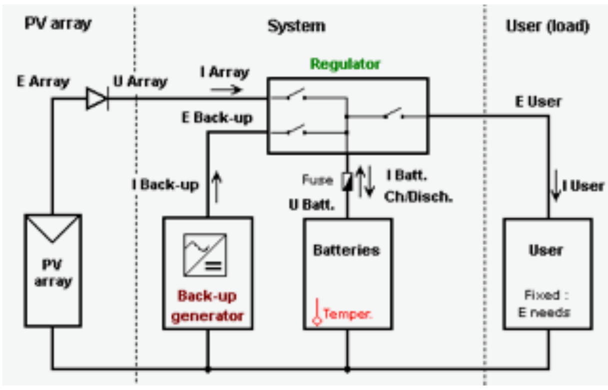


Figure 27: Configuration of system in PVSyst (PVSyst)

For a more specific design of the project an area has to be chosen, that has the right dimension for the project and is located nearby. To avoid long cabling and consequently high transmission losses an area verging on the power plant is chosen. To find a suitable area for the realization of the project, the area of the system planed needs to be required. Therefore the minimum distance required between the panels to avoid shading has to be determined. Mertens describes the formula for the distance between the panels:

$$d = b \cdot \frac{\sin(\gamma_s + \beta)}{\sin \gamma_s}$$

with b for the width of the PV, γ_s for the angle of the sun at 12:00 on December 21st which is according to the NASA $\gamma_s = 48\,°$ and β for the angle of the panels which has been estimated with $\beta = 35\,°$ before. (Mertens, 2015)

The width of the PV-row in this case is two times the width of the PV panels $b = 2 \cdot 0.998 = 1.996$ since the expected application is as seen in Figure 28.

Panel 1	**Panel 3**	**…**	**…**	**…**
Panel 2	**…**	**…**	**…**	**…**

Figure 28: Arrangements of PV-panels in array

The distance between the PV-module rows amount to at least $d = 2.67\ m$ to avoid high shading losses.

With a distance as described before PVSyst calculates a total area needed for the PV System of 3.5 MW and 13,200 modules of about 23,000 m^2.
The areas that qualify for the project are shown in Figure 29. The shading was simulated with the software PVSyst, where the site of the project was reconstructed in the program.
In either one of these areas there is no shading of surrounding objects to expect, since there is enough space available to keep the distance required to avoid shadings on the PV-array. The trees that are surrounding “Area 2” are small trees that do not exceed a height of 5 m.

Figure 29: Project Areas (Google Earth)

Both areas are easy to access for a solar project, since there is no dense vegetation. The trees in Area 2 are mainly low and dry shrubbery. Both areas are at a distance of about 150 m away from the power plant Pedernales (Figure 29).
To generate a voltage with the PV-plant, that matches the input voltage of the batteries that is 450 V, PVSyst recommends a connection of 20 PV panels per string in series with 660 parallel strings. This results in an output voltage of 634 V in the conditions of the STC. The actual value is expected to be lower, depending on the cell temperature during the operation. The output current of 660 parallel strings fluctuates between 5,600 A and 4,500 A. This current still is to high to charge the 120 parallel connected Li-Ion batteries with a maximum charge current of 11.9 A ($4{,}500\ A \div 120 = 37.5\ A$). To bring the Output voltage and current to the expedient values for the battery charging a charge controller needs to be included into the system. This charge controller or MPP Tracker also regulates variation of voltage and current due to irradiance and shading over the day.

To verify the electrical feasibility of the system the system is modeled with the software DigSILENT.
To assure the safety of the system, there will be implemented more inverters that work independently and assure load supply, even if one of the inverters fails or needs maintenance. If the system would work with one inverter only in case of maintenance or failure the whole renewable part of the system would break down. Instead of one 3 MW inverter it is planned to install 50 x 60 kW inverters.

5.2.2 Electrical model with DigSILENT

For simulating the electrical model of the project the dimensions of the components from HOMER Pro are taken into account. To assure an energy supply even if the inverter fails, the idea is to install instead of one inverter of 1.7 MW 34 parallel inverters with 50 kW each. As mentioned before the PV-array is formed by 660 parallel strings of 20 PV-panels each. In conditions of the STC this would lead to a voltage of 620 V at Nominal Operating Cell Temperature conditions to 566 V. The voltage is controlled with the charge controller.

There is a transformer required in the system that elevates the Voltage of the DC-Renewable-Bus of 400 V to the Voltage of the existing system of 2400 V. The transformer is not included into the economical calculation. The electrical model shows that the application as it is estimated in HOMER Pro is absolutely operable. The capacity of the inverter however is due to the electrical simulation too low for the peak hours. The simulation shows that up to 2.2 MW of the total energy generated by the PV-array can be supplied directly to the load. If the size of the inverter would be augmented by 500 kW, the power of the gen-sets could be reduced and replaced by more solar energy. The effect of an expansion of the inverter capacity is expected to have only a marginal impact on the economical suitability of the system and is likely to be compensated by the savings of fuel. The excess of energy generated by the PV-array will be used to charge the batteries, so that no bi directional inverter will be required.

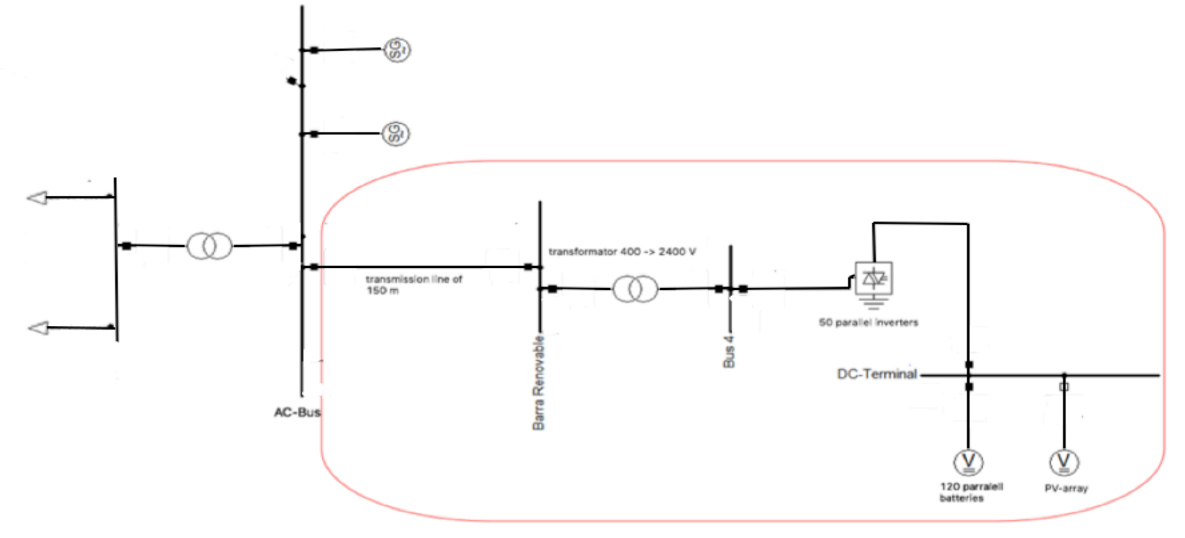


Figure 30: electrical model with DIGSilent

6. Discussion

The results of the simulation promise a success of the hybrid system. Still there are factors that might have an impact on the operation of the system and thereby influent the economy. Since the average Temperature is 24 °C fluctuations of ±3 °C the high temperature might cause efficiency losses especially on the PV-array and the battery bank.

The optimal operating temperature of the battery, which is recommended between 15 °C and 30 °C is in the project very likely to be reached and exceeded. Since there are not many batteries planned to be installed the cooling of the battery can be realised with simple air conditioning systems, that ensures the optimal operating climate for the Lithium-Ion batteries. By this the efficiency and the lifetime of the battery is maximized and maintenance cost can be minimized. The cost of cooling are not included into the calculation, especially as they account for only a small part of the costs and have no significant influence on the economic viability of the system.
Further investigations need to contrive an operation plan for the lithium ion batteries and evaluate the exact effect on the lifetime and cost under the given conditions.

Although the temperature might have the most substantial impact on the efficiency of the system, there are other parameters like wind and precipitation that influence the operation. Because most of the components are protected from weather conditions by housings, the PV-array is mainly exposed to natural events.

Even though the radiation in Pedernales is among the highest in the Dominican Republic, the precipitation is with 1085 mm/year on 253 days is considered as high as well. The rainfalls are short and heavy and followed by many sun hours. The annual precipitation is enough and frequently to assure the self-cleaning effect of the modules, with the right angle of over 15 °. The wind primarily causes cooling of the modules - the lower the operating temperature the higher the efficiency. As much as the power plant benefits from the windy condition in Pedernales, it brings also a risk into the project. In the past years Pedernales was affected by severe environmental disasters. That means that the hybrid system needs to be constructed compellingly to resist extreme weather conditions.

Apart from occasional extreme weather conditions the climate in Pedernales favors the operation of the project.

As Figure 26 shows the lifetime of the components has a large impact on the LCOE. If the lifetime can be increased by implementing a detailed O&M plan, the cost of energy can still be decreased.

Other factors that bring uncertainty for the success into the system by having a larger influent on the cost of energy are in particular the capital cost (in the main system from the study especially of the PV array, since the battery bank is small), and the fuelprice.

The capex of the componennts used are predicted to keep decreasing in the next years, so that a feasibility for hybrid system according to this parameter gets more possible in future. The operational cost of the solar-array has a barely low impact on the economic success of the project.

The sensitivity studies of the investigations examined however agree on the fact that the competitiveness of the hybrid systems depends on the fuel costs for conventional generation. Hybrid systems are particularly worthwhile in the case of high fuel prices. As the study of Nour & Rohani evaluating the feasibility for different fuel prices in United Arabian Emirates shows the fuel price can decide over the success of a project. Cader et al proclaim that especially in countries that do not have their own fossil sources the hybrid systems have a high potential to lower the cost of energy. Oil producing countries like Angola or Colombia however often do not achieve high cost savings, since the costs for the installation of required components cannot compete yet with the low cost of fuel in this countries (Cader, Bertheau, Blechinger, Huyskens, & Breyer, 2015).

Still due the expected price development of the different components of renewable systems the implementation of a hybrid system is expected to get more rewarding for a greater variety of conditions in the future.

The sensitivity study carried out shows that in the case of drastically increasing fuel prices in the future an extension of the renewable part of the system might be recommendable. Thanks to simple adaption of PV modules and batteries this can easily be accomplished at any time. Thus, the second case with only one engine used in the system can still be set up without much effort.

7. Conclusion

This study has investigated the evaluation of converting the 5 MW Fuel Oil Power Plant into a Hybrid System with the present engines and additional PV- array and battery bank as energy sources. The project is located in the Dominican Republic in an isolated remote region called Pedernales.

Due to low population and geographical circumstances Pedernales is not connected to the national grid oft he Dominican Republic.

The system that is planned, has to assure a stabile energy supply for about 15,000 people with an average power of 2.2 MW and an annual demand of 18.8 GWh.

The condition in Pedernales suit very well the requirements of a PV-project, since it is a very dry region with a high irradiance of 0.73 kW/m^2 and an annual irradiation of 1935 kWh/m^2. A high PV-generation can be expected.

Two cases of applying the hybrid system were simulated. Both systems are switched connected hybrid system with a cycle charging dispatch. In case 1 and case 2 the PV-array charges the battery and supplies parts of the load demand during the day when there is enough PV-energy generated.

- The first system runs with two fuel driven gen-sets, of which one supplies a relatively constant load during the day, whereas the other system supports the demand supply in the morning and evening when the load is high but there is no solar energy available. In case one there are 3.5 MWp of PV-modules installed with a battery capacity of 1.18 MWh. The system generates electricity at a cost of 0.119 $/kWh.

- The second case system renounces completely one of the Hyundai engines. The only fuel driven generator supplies a constant power to the load. The peaks that do not match the solar production are covert by the battery which have to be dimensioned vastly bigger than in case 1. The PV-array has a size of 5 MW combined with a battery bank of 20.6 MWh. The cost of energy in the second case is at a fuel price of 0.3 $/l 0.136 $/kWh which is also below the current cost of energy of 0.138 $/kWh.

Both systems ensure a high reliability of 99,95 % (or for case 1 even higher), so that the comfort of the current systems high reliability is not risked by including renewable energies.

Since for EGE Haina as an electricity company it is essential to produce electricity at the lowest cost possible, the evaluation of the results focuses on the more economic system with a lower LCOE and a higher NPC taken into account that actually both systems consist of the two fuel-driven gen-sets.

An evaluated PV-array of 3.5 MW acquires an installation of 13,200 PV modules of the Type Suntech STP 265, which occupies an area of 23,000 m^2. The panels are connected in 660 parallel strings with 20 panels in series for each string. The expected annual generation of the PV-generator exceeds 5 GWh.
The battery as the most flexible component in the system and the fastest available to respond to load changes is primarily used to cover peak loads. 120 Li-Ion batteries with a total capacity of 1180 kWh and a maximal total output power 600 kW are connected in 120 parallel strings with one battery per string.

Seen that the metropolitan region in Pedernales is not very populated, there are free areas available right in the neighborhood of the power plant of EGE Haina (located in the city entrance), which can be used to realize the project. Possible areas are located in a radius of 150m, which means that the installation of a transmission line is not necessary.

For the simulation with HOMER Pro the evaluation of different components was carried out. To get a general impression of the feasibility of such a project in this region, ordinary components are chosen in all simulations. Comparing the parameters of this study with the case study of Bloomberg New Energy Finance for a micro grid in Lake Victoria the results are unambiguous (Edwards, 2017). The economic parameters that are used in the simulation of BNEF in their simulation with HOMER Pro are deviating very little from the values used in the simulation for Pedernales. Some of the costs used by Bloomberg are even lower, which matches with the expectation of the prices to be higher in the Dominican Republic due to transportation costs.

From the economic point of view an installation of a hybrid system would be a clear advantage for the power plant. With a calculated LCOE of 0.119 $/kWh the cost of energy can be decrease by about 13% or 2 ct/kWh. These results are consistent with the investigations carried out in great numbers up to the present time. The Frankfurt School – UNEP Collaborating Centre for Climate and Sustainable Energy Finance estimated in 2015 in Las Terrenas in the Dominican Republic a potential of the LCOE to drop by 12% by converting a Standalone Fuel Driven power plant into a Hybrid system with 6.75 MWp installed.

There are many studies dealing with the electrification of rural areas for different parts of the world. In most of the investigations the hybrid system shows the best performance compared to other generation scenarios (Rajbongshi, Borgohain, & Mahapatra, 2017).

In general the conclusion can be made that of cases especially in countries that have a high availability of renewable energy sources and where the cost of fossil fuels is high, an installation of hybrid systems in the remote areas is likely to be effective. Unlike ten years ago when similar projects could not compete with the systems that are only basing on conventional generation, seeing for example the study of Kahn and Iqbal in 2004 in Newfoundland, the enormous development in the cost, affectivity and lifetime of the components used for renewable energy generation leads to the fact that projects of this kind are now largely successful.

Most of the projects described are in the rage between 10-200 kWp, for these small systems the cost of energy is mostly significantly larger. Depending on the year of the elaboration (the price of the components), the fuel price, the region and the size of the hybrid system the prices vary between 0.10 and 0.80 $/kWh. Although results of Husain & Sharma in Nepal (Husain & Sharma, 2014) and Adaramola et al. in Nigeria ((Adaramola, Paul, & Oyewola, 2014) do not achieve the concrete same values as simulated for Pedernales but with a higher LCOE, the trend of the outcome is consistent.

Large-scale projects in the MW rage are very little described. SMA presented in 2016 a project for the electrification of the island St. Eustatius in the Caribbean. The circumstances of the project were with an annual demand of 13.6 GWh/a similar to the conditions presented in this study (18.8 GWh/a). 1.9 MW PV combined with a battery capacity of 1 MW was installed to safe 850,000 liters of diesel during the year and to decrease the cost of energy (Krueger, 2016). Even if SMA does not provide concrete economic values, the feasibility of both projects can be compared. Since the demand in Pedernales and the size of the PV system are slightly higher than in St. Eustatius a reduction of the fuel consumption by moren than 1,000,000 is absolutely reasonable.

Only by including the PV-array into the system it is estimated to safe 2,500 tons of CO_2 per year. This result also goes hand in hand with the results of SMA. And still it does not include the CO_2 that is saved because of the fact that less fuel has to be transported by ship and trucks.

To complete the evaluation of this project, further steps need to be taken. In the following steps a check of the radiation values is advisable. Since the irradiation data was taken from the NASA and measured by satellite, a long-term measurement can provide more precise values. Another aspect that needs to be checked is the pricing of the components. Although compared with other studies the prices used seem to give a realistic assessment of the project, parameters like governmental subsidies, exact transportation costs and land prices as well as construction costs are not included into this study. Further more a detailed plan for the operation and maintenance must be developed.
In addition, the environmental law has to be reviewed to see what restrictions exist for the implementation of the project. Possible regulations, especially regarding nature conservation areas and governmental financing support, can have a decisive influence on the decision-making process.
Although currently Pedernales is a region with a relatively low population and resulting a barely low energy demand, a development of the region in future has a high probability. With many virgin beaches and extraordinary landscapes the region has a high potential of domestic and especially touristic growth, leading to an increase of the energy demand. Following investigation should evaluate applications of the power plant in Pedernales for an increased load profile scenario.

To conclude, a MW-scale fuel-oil-PV hybrid system with a Lithium-Ion battery bank is not only effective, meaning serving successfully its purpose, but it is also efficient by generating energy at the lowest costs possible, when compared with conventional systems. Although there are still aspects that need to be investigated to get a complete and detailed impression of all the factors influencing the projects feasibility, the sensitivity studies show that the success of the system is indeed very insensitive to tolerances in different parameters.

Literature

Adaramola, M. S., Paul, S. S., & Oyewola, O. (2014). Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. *Energy for Substainable Development*, 72-82.

Al-Hammad, H., Becker, T., Bode, A., Srishti, G., & Kreibiehl, S. (2015). *Renewable Energy in Hybrid Mini-Grids and Isolated Grids: Economic Benefits and Business Cases.* Frankfurt: FS-UNEP Colaborating Centre.

Bromley, H., & Serota, N. (2017, 6 1). 1H 2017 U.S. PV Market Outlook. *Back to the drawing board* . USA: Bloomberg New Energy Finance.

Cader, C., Bertheau, P., Blechinger, P., Huyskens, H., & Breyer, C. (2015). Global cost advantages of autonomous solar-battery-diesel systems compared to diesel only systems. *Sustainable Development*, 15-22.

Chase, J., & Swarbreck, J. (2017). *Solar Inverter Market Outlook 2017.* Bloomberg New Energy Finance.

Chase, J., Wang, X., Radoia, P., & Bromley, H. (2017). *Q1 2017 Global PV Market Outlook.* USA: Bloomberg New Energy Finance.

Curry, C. (2017). *2016 Lithium-Ion Battery Price Survey.* USA: Bloomberg New Energy Finance.

Das, B., Hoque, N., Mandal, S., Pal, T., & Raihan, A. (2017, 6 7). A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh. *Energy*.

Deshmukh, M., & Deshmukh, S. (2006). Modeling of hybrid renewable energy systems. *Renevable & Sustainable Energy Reviews*, 235-249.

Deutsche Gesellschaft für Sonnenenergie. (2008). *Planning and Installing Photovoltaic Systems.* Berlin: Earthscan.

DigSILENT. (2015). *Power Factory 15 Basic Software Features.* DigSilent Power Factory.

Edwards, I. (2017). *Micro - Grids in Lake Victoria: Case Study.* Lake Victoria: Bloomberg New Energy Finance.

EGE Haina. (2016). Data tecnica de la planta Pedernales. Santo Domingo, Dominican Republic.

Goldie-Scot, L. (2017). *Storage System Costs: More than Just a Battery* . Bloomberg New Energy Finance.

Halabi, L., Mekhilef, S., Olatomiwa, L., & Hazelton, J. (2017). *Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study Sabah, Malaysia.* Malaysia: Energy Conversion and Management 144.

Hayim, L. (2017). *PV O&M 2016: Falling prices, increasing refinement.* USA: Bloomber New Energy Finance.

Homer Energy. (n.d.). *Homer Energy*. Retrieved 9 5, 2017, from Products, HOMER Pro, Information: http://www.homerenergy.com/HOMER_pro.html

Husain, M., & Sharma, D. K. (2014). Techno-economic Analysis of Solar PV/Diesel Hybrid Energy System for Electrification of Television substation- "A Case Study of Nepal Television Substation at llam". *IOE Gratuate Conference*, 420-428.

Instituto de Investigaciones Socioeconómicas de la Universidad Autónoma. (2012). *Perfil Socio-Economico y Medio Ambiental Pedernales.* Santo DOmingo: Programa de las Naciones Unidas para el Desarrollo.

International Finance Corporation. (2015). Utility-Scale Solar Photovoltaic Power Plants. Washington D.C., Washington D.C., USA.

Kahn, M., & Iqbal, M. (2004). Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. *Renewable Energy*, 836-855.

Koehl, M., Heck, M., Wiesmeyer, S., & Wirth, J. (2011, January). Modeling of the Nominal Operating Cell Temperature based on Outdoor Weathering. *Solar Energy Materials and Solar Cells*.

Krueger, W. (2016, 05 24). *Flagship Project in the Caribbean: PV Hybrid System on the Island of St. Eustatius*. Retrieved 10 15, 2017, from http://en.sma-sunny.com/en/flagship-project-in-the-caribbean-pv-hybrid-system-on-the-island-of-st-eustatius/.

Leuthold, M. (2014). *Energy Storage Technologies Battery Storage for Grid Stabilization.* Berlin: Institute for Power Generation & Storage Systems (PGS).

Mertens, K. (2015). *Photovoltaik.* Steinfurt: Carl Hanser Verlag München.

Nour, M., & Rohani, G. (2014, 09 07). Prospect of Stand-Alone PV-Diesel Hybrid Power System for Rural Electrification in UAE. *International Journal of Renewable Energy Research*, 749-757.

Rajbongshi, R., Borgohain, D., & Mahapatra, S. (2017). Optimization of a PV-Biomass-Diesel and grid base Hybrid Energy System for rural electrification by using HOMER. *Energy*, 462.

Rosario, C. (2015). *Especificaciones técnicas de la Central Pedernales.* Santo Domingo: EGE Haina.

Saengprajak, A. (2007). *Efficiency of Demand Side Management Measures in Small Village Electrification Systems.* Kassel: kassel university press GmbH.

Sendyka, B., & Noga, M. (2013). *Advances in Internal Combustion Engines and Fuel Technologies.* Polen: Intech.

Strauß, P., Landau, M., Vandenbergh, M., Bopp, G., Ortiz, B., Vetter, M., . . . Wollny, M. (2009). Netzferne Stromversorgung und weltweite Elektrifizierung. 94-100.

Trading Economics. (2017, 7). *Dominican Republic Inflation Rate*. Retrieved 9 15, 2017, from Trading Economics: https://tradingeconomics.com/dominican-republic/inflation-cpi

Wang, X., & De Silva, R. (2014). *Analist Reaction – Solar Spot Price Index.* Bloomberg New Energy Finance.

Wichert, B. (1997). *PV-Diesel Hybrid Energy Systems for Remote Area Power Generation - A Review of Current Practice and Future Developments.* Perth: Renewable and Sustainable Energy Review.

World Energy Outlook. (2017, - -). *Resources: Energy Access*. Retrieved 07 14, 2017, from Modern Energy for All: http://www.worldenergyoutlook.org/resources/energydevelopment/

World Weather Online. (2017, 7). *Pedernales Monthly Climate Averages*. Retrieved 8 29, 2017, from https://www.worldweatheronline.com/pedernales-weather-averages/pedernales/do.aspx

Yingzhi, C., Chunyu, D., Geping, Y., Yunzhi, G., Zhang, L., Ting, G., . . . Wang, F. (2015). Multi-stress factor model for cycle lifetime prediction of lithium ion batteries with shallow-depth discharge. *Journal of Power Sources*, 123-132.

Annex

Content

1. Datasheet of PV-panel

STP265 - 20/Wem
STP260 - 20/Wem
STP255 - 20/Wem

SUNTECH
BE UNLIMITED

265 Watt
POLYCRYSTALLINE SOLAR MODULE

Features

High module conversion efficiency (16.3%)
Module efficiency up to 16.3% achieved through advanced cell technology and manufacturing capabilities

High PID resistant (PID Resistant)
Advanced cell technology and qualified materials lead to high resistance to PID

Positive tolerance (0/+5W)
Positive tolerance of up to 5W delivers higher output reliablity

Suntech current sorting process (2%)
System output maximized by reducing mismatch losses up to 2% with modules sorted & packaged by amperage

Extended wind and snow load tests (3800Pa 5400Pa)
Module certified to withstand extreme wind (3800 Pascal) and snow loads (5400 Pascal) *

Withstanding harsh environment (Harsh environment)
Reliable quality leads to a better sustainability even in harsh environment like desert, farm and coastline

Certifications and standards:
IEC 61215, IEC 61730, conformity to CE

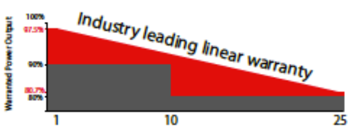
Trust Suntech to Deliver Reliable Performance Over Time

- World-class manufacturer of crystalline silicon photovoltaic modules
- Unrivaled manufacturing capacity and world-class technology
- Rigorous quality control meeting the highest international standards: ISO 9001: 2008, ISO 14001: 2004 and ISO17025: 2005
- Regular independently checked production process from international accredited institute/company
- Tested for harsh environments (salt mist, ammonia corrosion and sand blowing testing: IEC 61701, IEC 62716, DIN EN 60068-2-68)***
- Long-term reliability tests
- 2 x 100% EL inspection ensuring defect-free modules

Special 4 busbar design

The unique cell design leads tremendous reduction in electrodes resistance and raise in conversion efficiency. Less residual stress, less cell micro-cracks and hotspot risks.

Industry-leading Warranty based on nominal power



- 97.5% in the first year, thereafter, for years two (2) through twenty-five (25), 0.7% maximum decrease from MODULE's nominal power output per year, ending with the 80.7% in the 25th year after the defined WARRANTY STARTING DATE.****
- 12-year product warranty
- 25-year linear performance warranty

IP68 Rated Junction Box

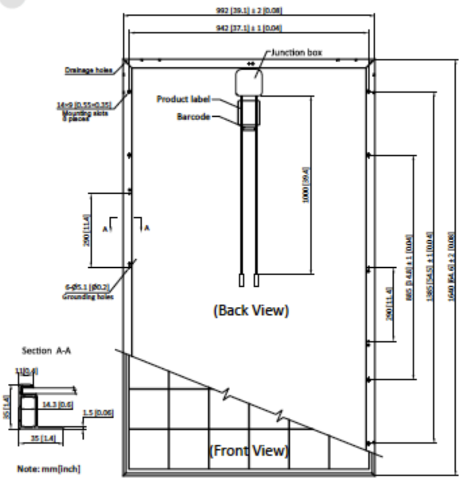
The Suntech IP68 rated junction box ensures an outstanding waterproof level, supports installations in all orientations and reduces stress on the cables. High reliable performance, low resistance connectors ensure maximum output for the highest energy production.

* Please refer to Suntech Standard Module Installation Manual for details. **PV Cycle only for EU market.
*** Please refer to Suntech Product Near-coast Installation Manual for details. **** Please refer to Suntech Product Warranty for details.

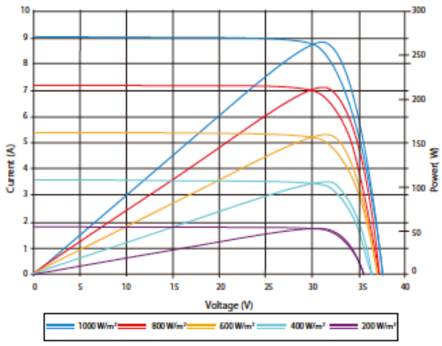
www.suntech-power.com IEC-STP-Wem-NO1.01-Rev 2016

STP265 - 20/Wem
STP260 - 20/Wem
STP255 - 20/Wem

SUNTECH
BE UNLIMITED



Current-Voltage & Power-Voltage Curve (265-20)



Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), **96.5%** or higher of the STC efficiency (1000 W/m²) is achieved

Dealer information

Electrical Characteristics

STC	STP265-20/Wem	STP260-20/Wem	STP255-20/Wem
Maximum Power at STC (Pmax)	265 W	260 W	255 W
Optimum Operating Voltage (Vmp)	31.0 V	30.9 V	30.8 V
Optimum Operating Current (Imp)	8.56 A	8.42 A	8.28 A
Open Circuit Voltage (Voc)	37.8 V	37.7 V	37.6 V
Short Circuit Current (Isc)	9.02 A	8.89 A	8.76 A
Module Efficiency	16.3%	16.0%	15.7%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1000 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 W		

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP265-20/Wem	STP260-20/Wem	STP255-20/Wem
Maximum Power at NOCT (Pmax)	194 W	191 W	188 W
Optimum Operating Voltage (Vmp)	28.3 V	28.2 V	28.1 V
Optimum Operating Current (Imp)	6.86 A	6.76 A	6.68 A
Open Circuit Voltage (Voc)	34.8 V	34.8 V	34.7 V
Short Circuit Current (Isc)	7.32 A	7.19 A	7.12 A

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.41 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Isc	0.067 %/°C

Mechanical Characteristics

Solar Cell	Polycrystalline silicon 156 × 156 mm (6 inches)
No. of Cells	60 (6 × 10)
Dimensions	1640 × 992 × 35mm (64.6 × 39.1 × 1.4 inches)
Weight	18.2 kgs (40.1 lbs.)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP68 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007)
	4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000mm (39.4 inches) and (+) 1000 mm (39.4 inches)
Connectors	MC4 compatible

Packing Configuration

Container	20' GP	40' HC
Pieces per pallet	30	30
Pallets per container	6	28
Pieces per container	180	840

Information on how to install and operate this product is available in the installation instruction. All values indicated in this data sheet are subject to change without prior announcement. The specifications may vary slightly. All specifications are in accordance with standard EN 50380. Color differences of the modules relative to the figures as well as discolorations of/in the modules which do not impair their proper functioning are possible and do not constitute a deviation from the specification.

2. Datasheet of Hyundai gen-set

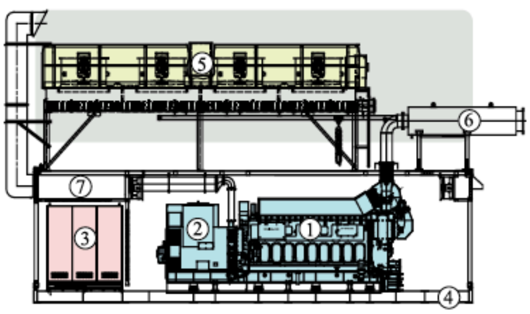
Features

- Base load operation
- Diesel oil / Heavy fuel oil / Natural gas use
- Compact 40 ft container size
- Easy transportation
- Earth-friendly
- Low cost of operating and maintenan

Application

- Captive power
- Construction site
- Isolated area
- Rental business
- Pumping station
- Independent power produce

STRUCTURE



① Engine
② Generator
③ Control panel
④ Enclosure
⑤ Radiator
⑥ Exhaust gas silencer
⑦ Ventilation air exhaust fan

GENERAL SPECIFICATION

Engine Model	6H17/28	8H17/28	6H21/32	8H21/32	9H21/32
Engine (kW)	690 / 720	920 / 960	1,200	1,600	1,800
Generator (kW)	645 / 673	865 / 902	1,140	1,520	1,710
Total Weight (ton)	24	30	42	48	50
Dimension (WxHxL)	2.4mx3.4mx12m (Container Size)				
Cooling Method	Radiator / Cooling Tower				
Speed (rpm)	900 / 1,000				
Fuel	**Diesel Oil / Heavy Fuel Oil**				

Engine Model	5H17/24G	6H17/24G	7H17/24G	8H17/24G	9H17/24G
Engine (kW)	455 / 550	546 / 660	637 / 770	728 / 880	819 / 990
Generator (kW)	428 / 817	513 / 620	599 / 723	684 / 827	770 / 930
Total Weight (ton)	22	24	25	26	28
Dimension (WxHxL)	2.4mx2.9mx12m (Container Size)				
Cooling Method	Radiator / Cooling Tower				
Speed (rpm)	1,000 / 1,200				
Fuel	**Natural Gas**				

※ The MCR will be based on ISO condition.

3. Datasheet of Lithium-Ion battery

LG Chem

Product Specification (1/2)

RESU10H — **Solaredge compatible**

Electrical Characteristics		
Total Energy		9.8 kWh @25°C (77°F)
Usable Energy[1]		9.3 kWh @25°C (77°F)
Voltage Range	Charge	400 ~ 450 VDC
	Discharge	350 ~ 430 VDC
Absolute Max. Voltage		520VDC
Max. Charge/Discharge Current		11.9A@420V / 14.3A@350V
Max. Charge/Discharge Power [2]		5kW
Peak Power (only discharging)[3]		7kW for 10 sec.
Peak Current (only discharging)		18.9A@370V for 10 sec.
Communication Interface		RS485
DC Disconnect		Circuit Breaker, 25A, 600V rating
Connection Method		Spring Type Connector
User interface		LEDs for Normal and Fault operation
Protection Features		Over Voltage / Over Current / short circuit / Reverse Polarity

Operating Conditions	
Installation Location	Indoor(Wall-Mounted) / Outdoor
Operating Temperature	14 ~ 113°F (-10 ~ 45°C)
Operating Temperature (Recommended)	59 ~ 86°F (15 ~ 30°C)
Storage Temperature	-22 ~ 131°F (-30 ~ 55°C)
Humidity	5%~95%
Altitude	Max. 6,562ft (2,000m)
Cooling Strategy	Natural Convection

Certification		
Safety	Cell	UL1642
	Battery Pack	UL1973 / CE / RCM / TUV (IEC 62619)
Emissions		FCC
Hazardous Materials Classification		Class 9
Transportation		UN38.3 (UNDOT)
Ingress Rating		IP55

※ Test Conditions - Temperature 25°C, at the beginning of life
※ Total Energy is measured under specific condition from LGC(0.3CCCV/0.3CC)
※ DC/DC Discharge Efficiency 94.5%

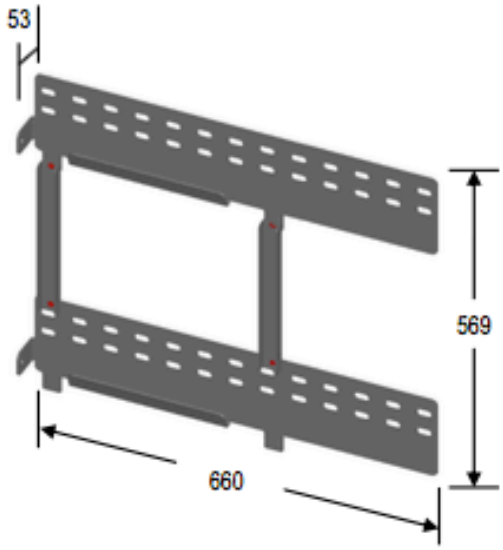
1) Value for Battery Cell Only (Depth of Discharge 95%), 2kW charge/discharge power.
2) LG Chem recommends 3.3kW for maximum battery lifetime
3) Peak Current excludes repeated short duration (less than 10 sec. of current pattern).

Product Specification (2/2)

RESU10H

Solaredge compatible

Mechanical Characteristics		
Dimensions	Width	744 mm (29.3")
	Height	907 mm (35.7")
	Depth	206 mm (8.1")
Weight		97 kg (214lbs)



4. Simulation Report Case 1

System Simulation Report

www.homerenergy.com

File: Pedernales.homer

Author:

Location: Avenida Libertad, Pedernales 84000, Dominican Republic (18°2,0'N, 71°44,3'W)

Total Net Present Cost: 28.234.468,02 $

Levelized Cost of Energy ($/kWh): 0,119 $

Notes:

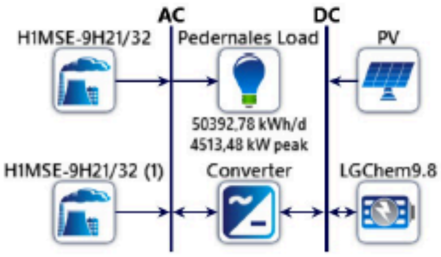
Sensitivity variable values for this simulation

Variable	Value	Unit
ExpectedInflationRate	2,00	%

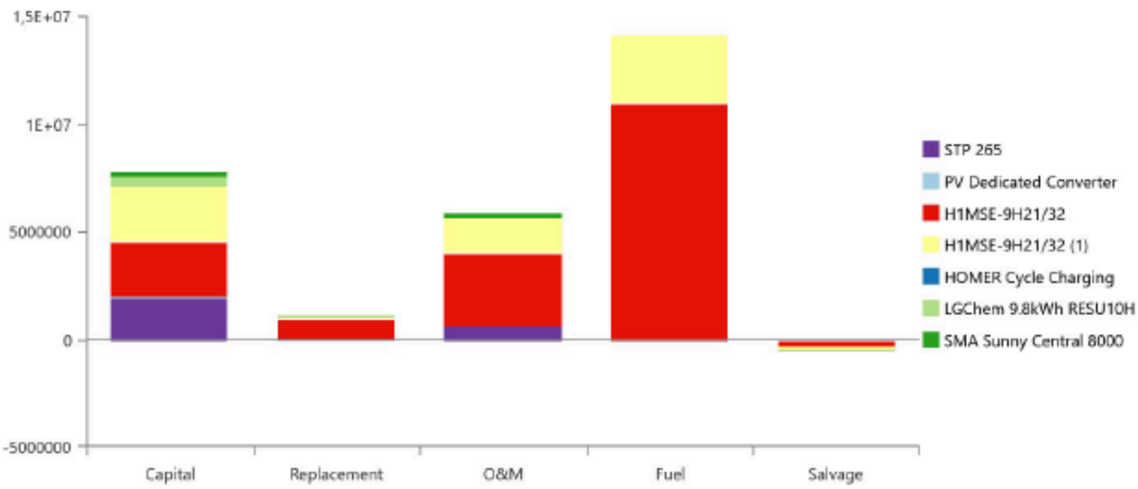
System Architecture

Component	Name	Size	Unit
Generator #1	H1MSE-9H21/32	1.700	kW
Generator #2	H1MSE-9H21/32 (1)	1.700	kW
PV	STP 265	3.500	kW
Storage	LGChem 9.8kWh RESU10H	60	strings
System converter	SMA Sunny Central 8000	1.700	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



Cost Summary



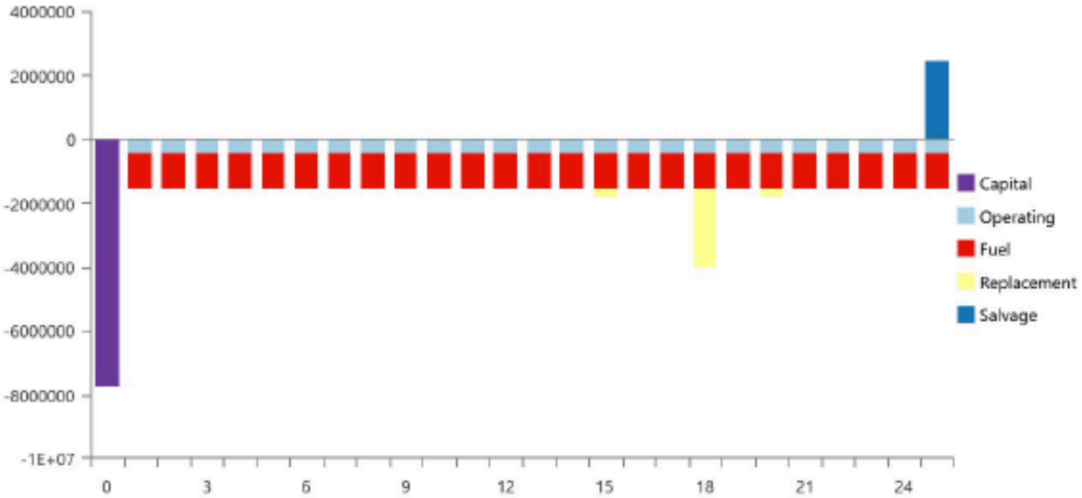
Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
STP 265	1,96 $M	0,00 $	633.448 $	0,00 $	0,00 $	2,59 $M
PV Dedicated Converter	100.000 $	42.427 $	25.855 $	0,00 $	-7.985 $	160.297 $
H1MSE-9H21/32	2,50 $M	939.461 $	3,38 $M	10,9 $M	-323.403 $	17,4 $M
H1MSE-9H21/32 (1)	2,50 $M	0,00 $	1,57 $M	3,16 $M	-192.644 $	7,04 $M
LGChem 9.8kWh RESU10H	455.758 $	87.946 $	12.405 $	0,00 $	-49.563 $	506.545 $
SMA Sunny Central 8000	238.000 $	72.127 $	219.768 $	0,00 $	-13.575 $	516.319 $
System	7,75 $M	1,14 $M	5,84 $M	14,1 $M	-587.171 $	28,2 $M

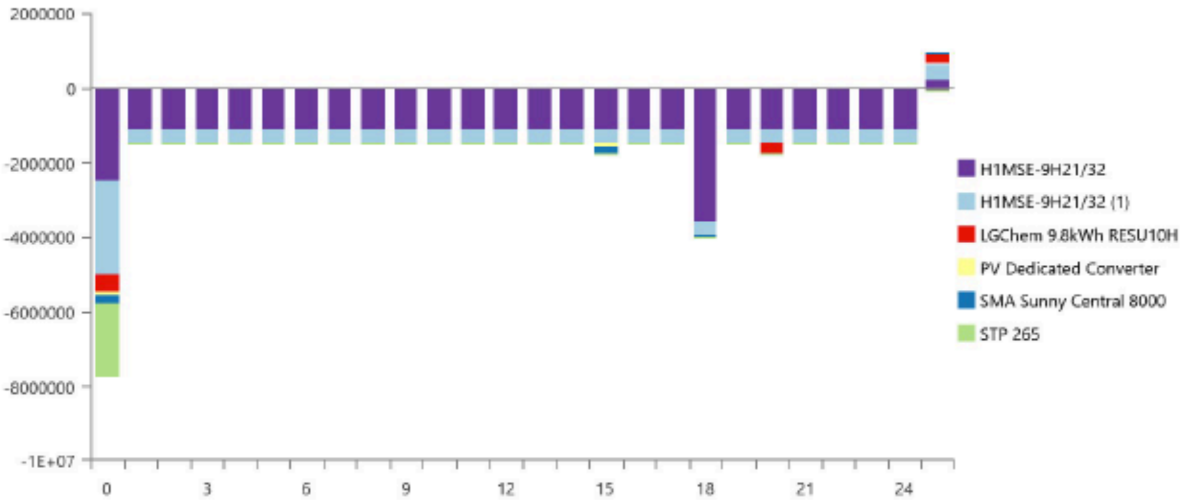
Annualized Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
STP 265	151.615 $	0,00 $	49.000 $	0,00 $	0,00 $	200.615 $
PV Dedicated Converter	7.735 $	3.282 $	2.000 $	0,00 $	-617,69 $	12.400 $
H1MSE-9H21/32	193.386 $	72.671 $	261.486 $	844.756 $	-25.017 $	1,35 $M
H1MSE-9H21/32 (1)	193.386 $	0,00 $	121.490 $	244.666 $	-14.902 $	544.639 $
LGChem 9.8kWh RESU10H	35.255 $	6.803 $	959,60 $	0,00 $	-3.834 $	39.184 $
SMA Sunny Central 8000	18.410 $	5.579 $	17.000 $	0,00 $	-1.050 $	39.940 $
System	599.787 $	88.336 $	451.935 $	1,09 $M	-45.420 $	2,18 $M

Cash Flow



4000000
2000000
0
-2000000
-4000000
-6000000
-8000000
-1E+07
0
3
6
9
12
15
18
21
24
Capital
Operating
Fuel
Replacement
Salvage



2000000
0
-2000000
-4000000
-6000000
-8000000
-1E+07
0
3
6
9
12
15
18
21
24
H1MSE-9H21/32
H1MSE-9H21/32 (1)
LGChem 9.8kWh RESU10H
PV Dedicated Converter
SMA Sunny Central 8000
STP 265

Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	789.009	kWh/yr
Unmet Electric Load	2.256	kWh/yr
Capacity Shortage	15.169	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
STP 265	5.094.957	26,5
H1MSE-9H21/32	11.062.739	57,4
H1MSE-9H21/32 (1)	3.098.675	16,1
Total	19.256.371	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	18.391.107	100
DC Primary Load	0	0
Total	18.391.107	100

Generator: H1MSE-9H21/32 (HFO)

H1MSE-9H21/32 Electrical Summary

Quantity	Value	Units
Electrical Production	11.062.739	kWh/yr
Mean Electrical Output	1.263	kW
Minimum Electrical Output	425	kW
Maximum Electrical Output	1.700	kW

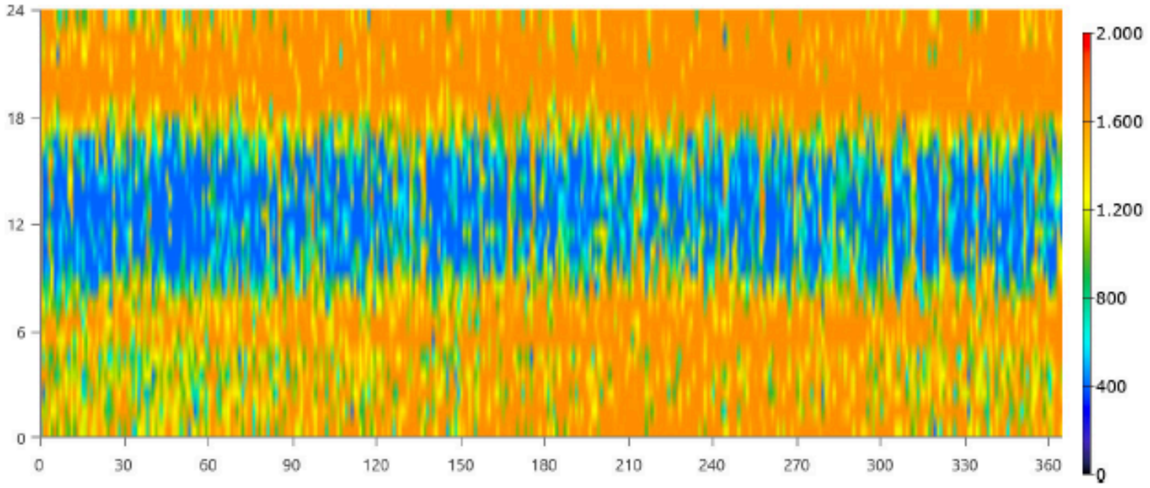
H1MSE-9H21/32 Fuel Summary

Quantity	Value	Units
Fuel Consumption	2.815.855	L
Specific Fuel Consumption	0,255	L/kWh
Fuel Energy Input	30.912.673	kWh/yr
Mean Electrical Efficiency	35,8	%

H1MSE-9H21/32 Statistics

Quantity	Value	Units
Hours of Operation	8.760	hrs/yr
Number of Starts	1,00	starts/yr
Operational Life	17,1	yr
Capacity Factor	74,3	%
Fixed Generation Cost	51,5	$/hr
Marginal Generation Cost	0,0724	$/kWh

H1MSE-9H21/32 Output (kW)



Generator: H1MSE-9H21/32 (1) (HFO)

H1MSE-9H21/32 (1) Electrical Summary

Quantity	Value	Units
Electrical Production	3.098.675	kWh/yr
Mean Electrical Output	761	kW
Minimum Electrical Output	425	kW
Maximum Electrical Output	1.700	kW

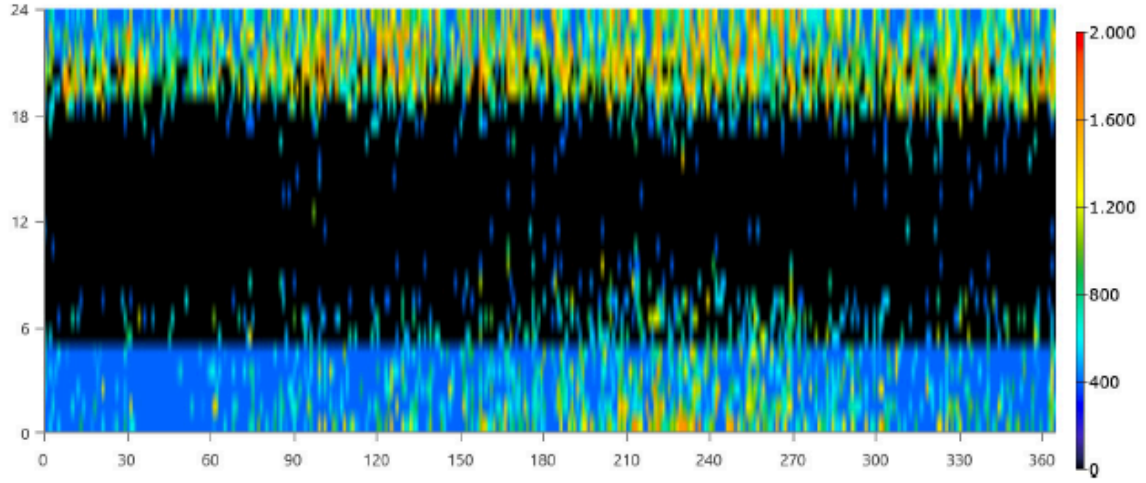
H1MSE-9H21/32 (1) Fuel Summary

Quantity	Value	Units
Fuel Consumption	815.552	L
Specific Fuel Consumption	0,263	L/kWh
Fuel Energy Input	8.953.196	kWh/yr
Mean Electrical Efficiency	34,6	%

H1MSE-9H21/32 (1) Statistics

Quantity	Value	Units
Hours of Operation	4.070	hrs/yr
Number of Starts	665	starts/yr
Operational Life	36,9	yr
Capacity Factor	20,8	%
Fixed Generation Cost	51,5	$/hr
Marginal Generation Cost	0,0724	$/kWh

H1MSE-9H21/32 (1) Output (kW)



PV: STP 265

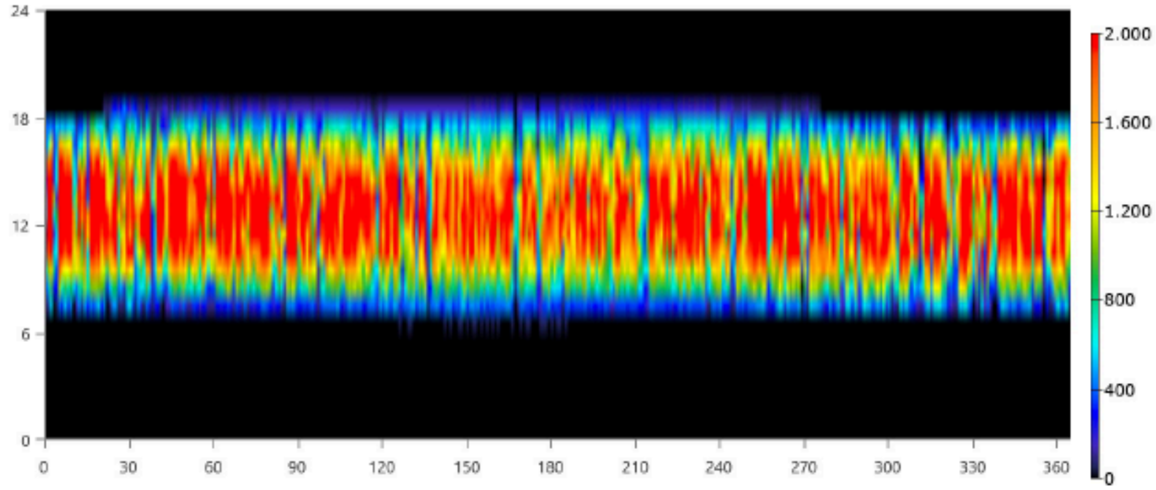
STP 265 Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2.000	kW
PV Penetration	27,7	%
Hours of Operation	4.374	hrs/yr
Levelized Cost	0,0418	$/kWh

STP 265 Statistics

Quantity	Value	Units
Rated Capacity	3.500	kW
Mean Output	582	kW
Mean Output	13.959	kWh/d
Capacity Factor	16,6	%
Total Production	5.094.957	kWh/yr

STP 265 Output (kW)



Storage: LGChem 9.8kWh RESU10H

LGChem 9.8kWh RESU10H Properties

Quantity	Value	Units
Batteries	120	
String Size	2,00	
Strings in Parallel	60,0	
Bus Voltage	800	

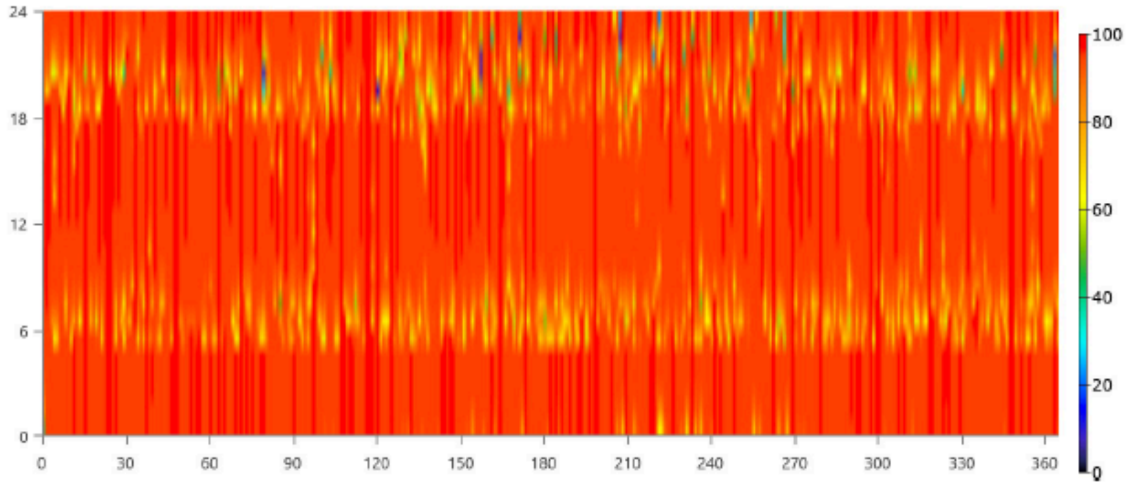
LGChem 9.8kWh RESU10H Result Data

Quantity	Value	Units
Average Energy Cost	0,0756	$/kWh
Energy In	180.218	kWh/yr
Energy Out	178.416	kWh/yr
Storage Depletion	0,0000340	kWh/yr
Losses	1.802	kWh/yr
Annual Throughput	179.314	kWh/yr

LGChem 9.8kWh RESU10H Statistics

Quantity	Value	Units
Autonomy	0,514	hr
Storage Wear Cost	0,0420	$/kWh
Nominal Capacity	1.200	kWh
Usable Nominal Capacity	1.080	kWh
Lifetime Throughput	3.586.290	kWh
Expected Life	20,0	yr

LGChem 9.8kWh RESU10H State of Charge (%)



Converter: SMA Sunny Central 8000

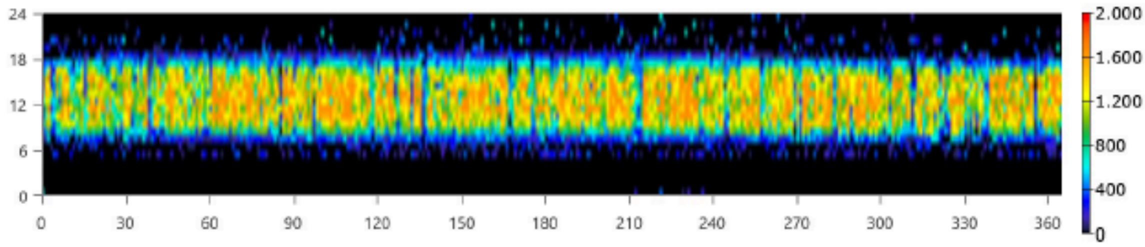
SMA Sunny Central 8000 Electrical Summary

Quantity	Value	Units
Hours of Operation	4.816	hrs/yr
Energy Out	4.357.694	kWh/yr
Energy In	4.419.568	kWh/yr
Losses	61.874	kWh/yr

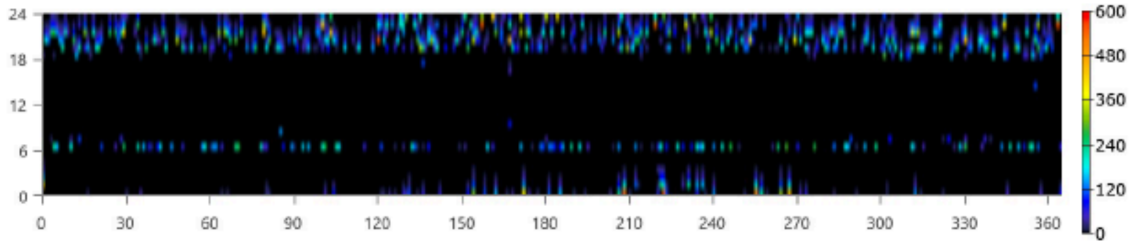
SMA Sunny Central 8000 Statistics

Quantity	Value	Units
Capacity	1.700	kW
Mean Output	497	kW
Minimum Output	0	kW
Maximum Output	1.700	kW
Capacity Factor	29,3	%

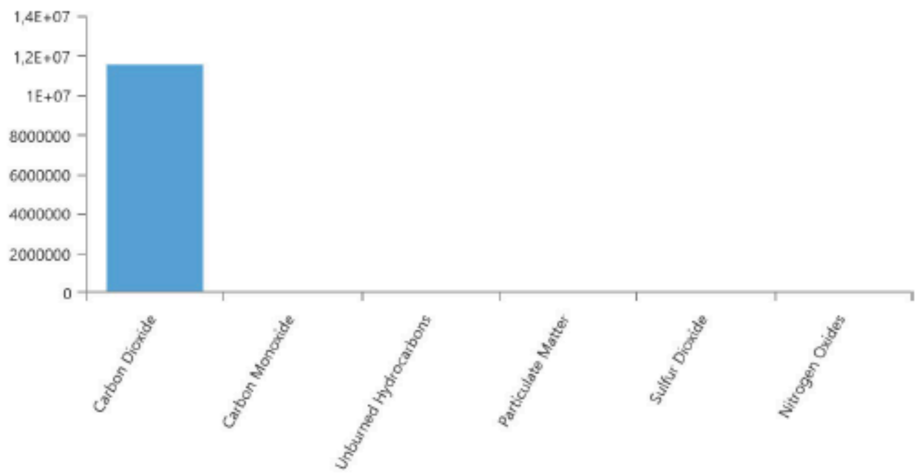
SMA Sunny Central 8000 Inverter Output (kW)



SMA Sunny Central 8000 Rectifier Output (kW)



Emissions Summary



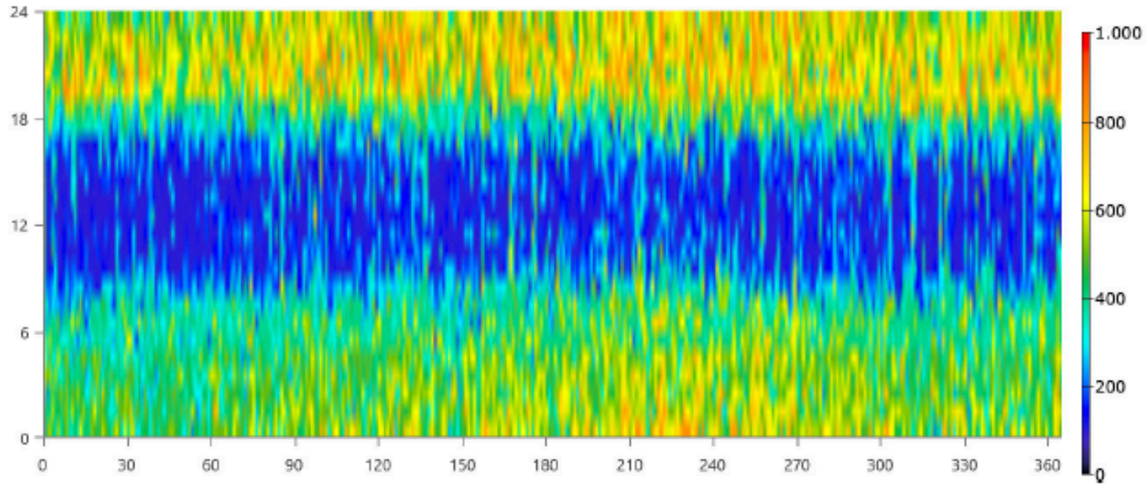
Pollutant	Quantity	Unit
Carbon Dioxide	11.521.924	kg/yr
Carbon Monoxide	51.878	kg/yr
Unburned Hydrocarbons	2.615	kg/yr
Particulate Matter	3.112	kg/yr
Sulfur Dioxide	28.136	kg/yr
Nitrogen Oxides	48.766	kg/yr

Fuel Summary

HFO Consumption Statistics

Quantity	Value	Units
Total fuel consumed	3.631.407	L
Avg fuel per day	9.950	L/day
Avg fuel per hour	415	L/hour

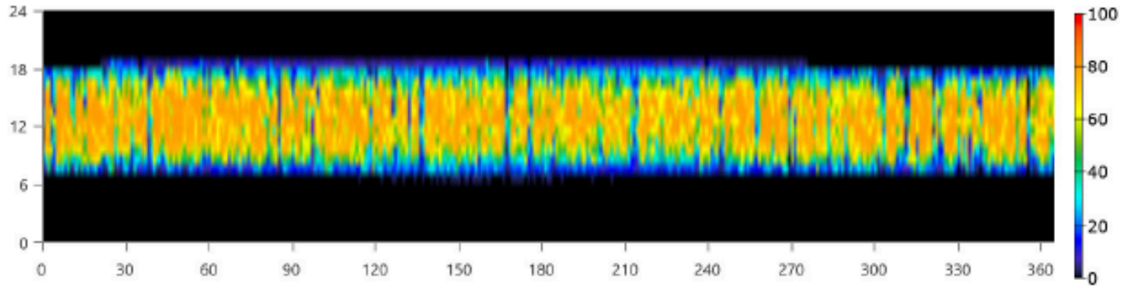
HFO Consumption (L/hr)



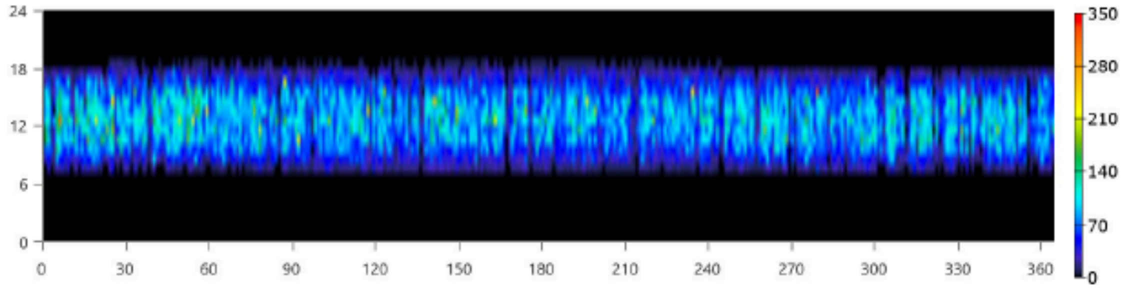
Renewable Summary

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	50,7	%
Usable renewable capacity divided by total capacity	45,2	%
Energy-based metrics	**Value**	**Unit**
Total renewable production divided by load	27,7	%
Total renewable production divided by generation	26,5	%
One minus total nonrenewable production divided by load	100	%
Peak values	**Value**	**Unit**
Renewable output divided by load (HOMER standard)	330	%
Renewable output divided by total generation	82,5	%
One minus nonrenewable output divided by total load	80,0	%

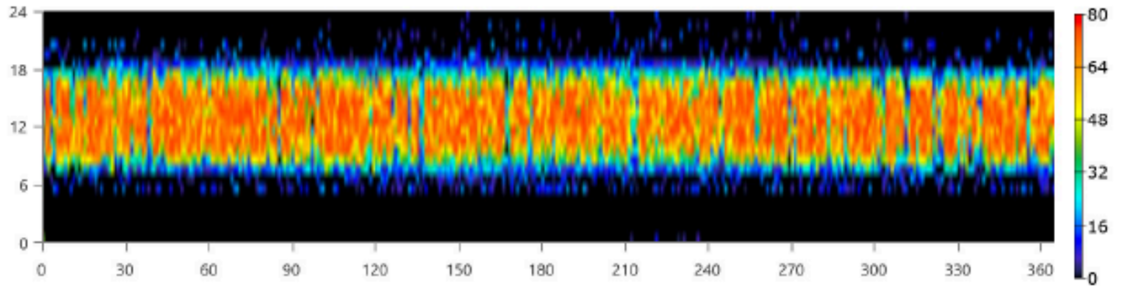
Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load



5. Simulation Report Case 2

System Simulation Report

www.homerenergy.com

File: Pedernales.homer

Author:

Location: Avenida Libertad, Pedernales 84000, Dominican Republic (18°2,0'N, 71°44,3'W)

Total Net Present Cost: 32.421.829,16 $

Levelized Cost of Energy ($/kWh): 0,136 $

Notes:

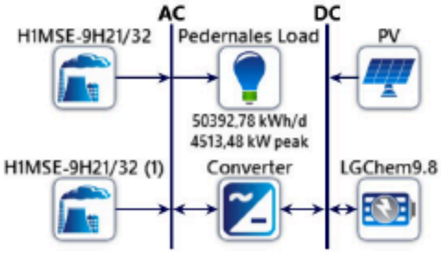
Sensitivity variable values for this simulation

Variable	Value	Unit
ExpectedInflationRate	2,00	%

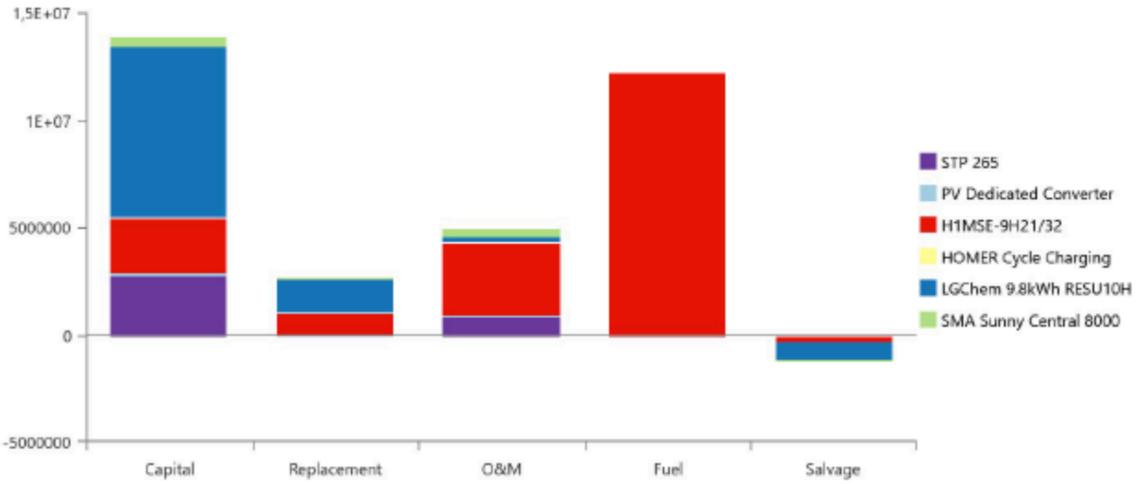
System Architecture

Component	Name	Size	Unit
Generator #1	H1MSE-9H21/32	1.700	kW
PV	STP 265	5.000	kW
Storage	LGChem 9.8kWh RESU10H	1.050	strings
System converter	SMA Sunny Central 8000	3.000	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



Cost Summary



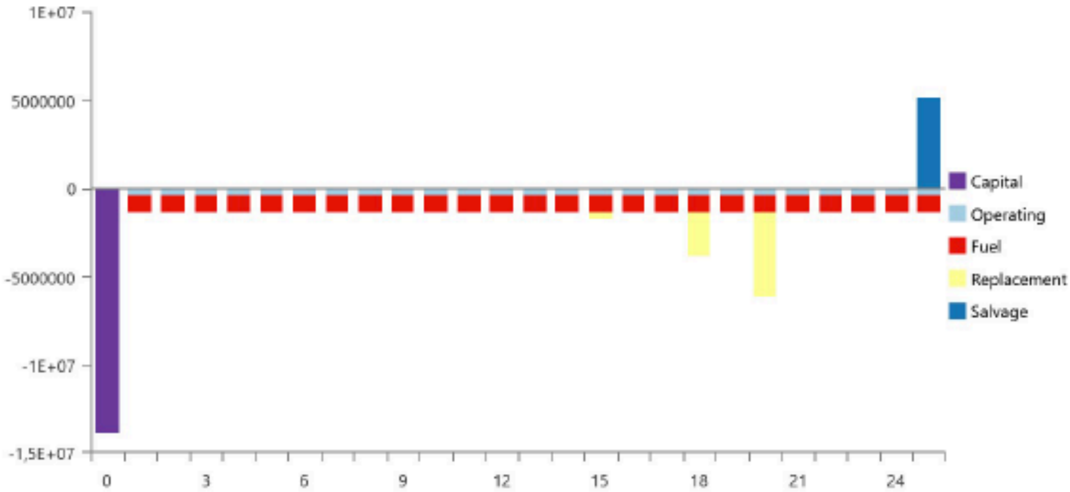
Net Present Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
STP 265	2,80 $M	0,00 $	904.926 $	0,00 $	0,00 $	3,70 $M
PV Dedicated Converter	150.000 $	63.641 $	38.783 $	0,00 $	-11.978 $	240.446 $
H1MSE-9H21/32	2,50 $M	939.461 $	3,38 $M	12,2 $M	-323.403 $	18,7 $M
LGChem 9.8kWh RESU10H	7,96 $M	1,54 $M	216.660 $	0,00 $	-865.258 $	8,84 $M
SMA Sunny Central 8000	420.000 $	127.282 $	387.825 $	0,00 $	-23.956 $	911.152 $
System	13,8 $M	2,67 $M	4,93 $M	12,2 $M	-1,22 $M	32,4 $M

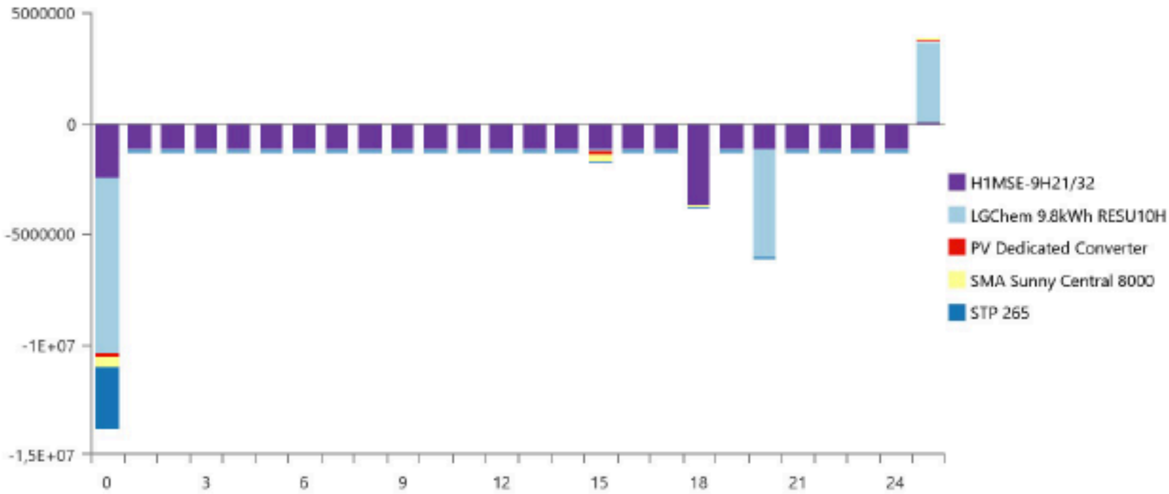
Annualized Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
STP 265	216.592 $	0,00 $	70.000 $	0,00 $	0,00 $	286.592 $
PV Dedicated Converter	11.603 $	4.923 $	3.000 $	0,00 $	-926,54 $	18.600 $
H1MSE-9H21/32	193.386 $	72.671 $	261.486 $	945.765 $	-25.017 $	1,45 $M
LGChem 9.8kWh RESU10H	615.413 $	118.765 $	16.760 $	0,00 $	-66.931 $	684.005 $
SMA Sunny Central 8000	32.489 $	9.846 $	30.000 $	0,00 $	-1.853 $	70.482 $
System	1,07 $M	206.205 $	381.246 $	945.765 $	-94.728 $	2,51 $M

Cash Flow



1E+07
5000000
0
-5000000
-1E+07
-1,5E+07
0
3
6
9
12
15
18
21
24
Capital
Operating
Fuel
Replacement
Salvage



5000000
0
-5000000
-1E+07
-1,5E+07
0
3
6
9
12
15
18
21
24
H1MSE-9H21/32
LGChem 9.8kWh RESU10H
PV Dedicated Converter
SMA Sunny Central 8000
STP 265

Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	1.320.269	kWh/yr
Unmet Electric Load	9.144	kWh/yr
Capacity Shortage	16.280	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
STP 265	7.389.755	37,2
H1MSE-9H21/32	12.457.555	62,8
Total	19.847.310	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	18.384.220	100
DC Primary Load	0	0
Total	18.384.220	100

Generator: H1MSE-9H21/32 (HFO)

H1MSE-9H21/32 Electrical Summary

Quantity	Value	Units
Electrical Production	12.457.555	kWh/yr
Mean Electrical Output	1.422	kW
Minimum Electrical Output	425	kW
Maximum Electrical Output	1.700	kW

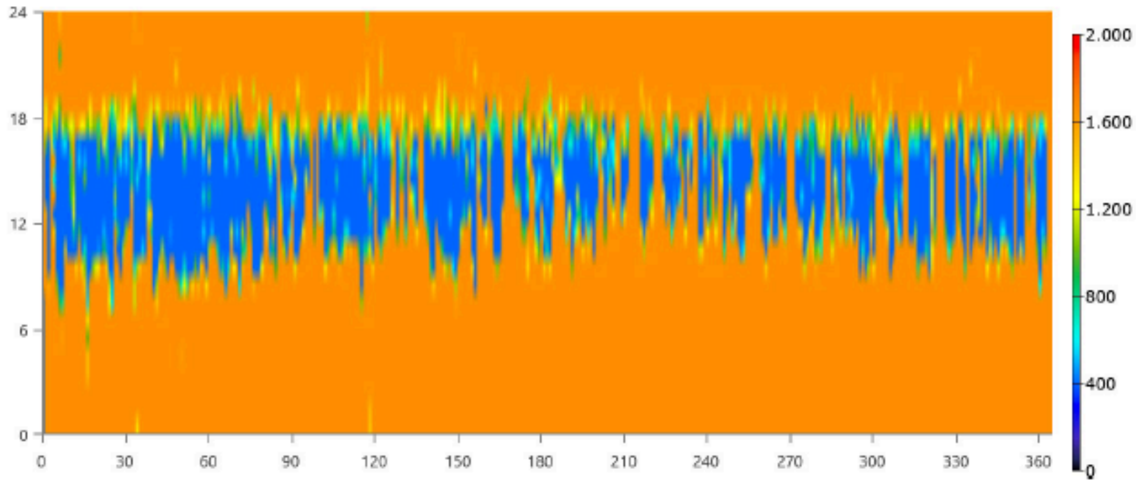
H1MSE-9H21/32 Fuel Summary

Quantity	Value	Units
Fuel Consumption	3.152.550	L
Specific Fuel Consumption	0,253	L/kWh
Fuel Energy Input	34.608.937	kWh/yr
Mean Electrical Efficiency	36,0	%

H1MSE-9H21/32 Statistics

Quantity	Value	Units
Hours of Operation	8.760	hrs/yr
Number of Starts	1,00	starts/yr
Operational Life	17,1	yr
Capacity Factor	83,7	%
Fixed Generation Cost	51,5	$/hr
Marginal Generation Cost	0,0724	$/kWh

H1MSE-9H21/32 Output (kW)



PV: STP 265

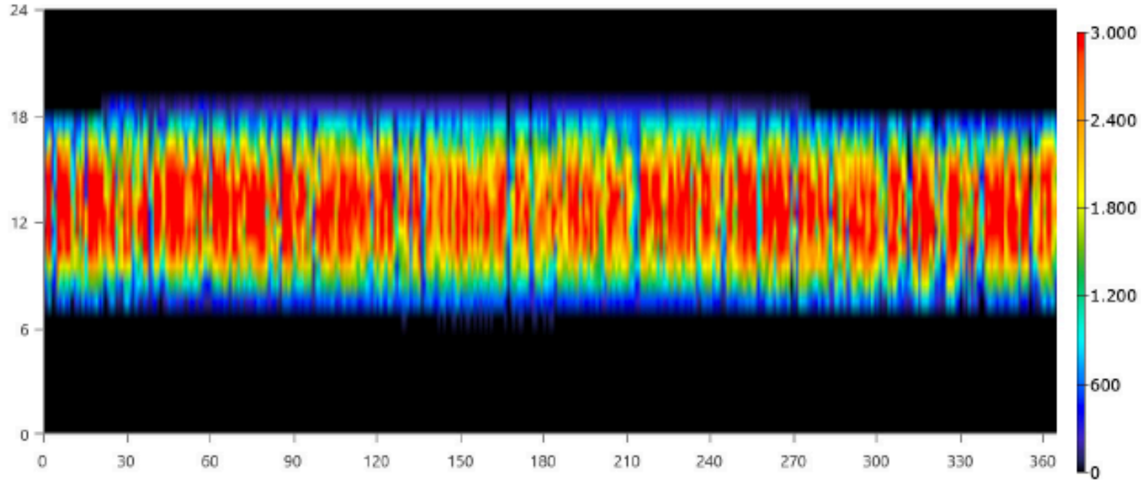
STP 265 Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	3.000	kW
PV Penetration	40,2	%
Hours of Operation	4.374	hrs/yr
Levelized Cost	0,0413	$/kWh

STP 265 Statistics

Quantity	Value	Units
Rated Capacity	5.000	kW
Mean Output	844	kW
Mean Output	20.246	kWh/d
Capacity Factor	16,9	%
Total Production	7.389.755	kWh/yr

STP 265 Output (kW)



Storage: LGChem 9.8kWh RESU10H

LGChem 9.8kWh RESU10H Properties

Quantity	Value	Units
Batteries	2.100	
String Size	2,00	
Strings in Parallel	1.050	
Bus Voltage	800	

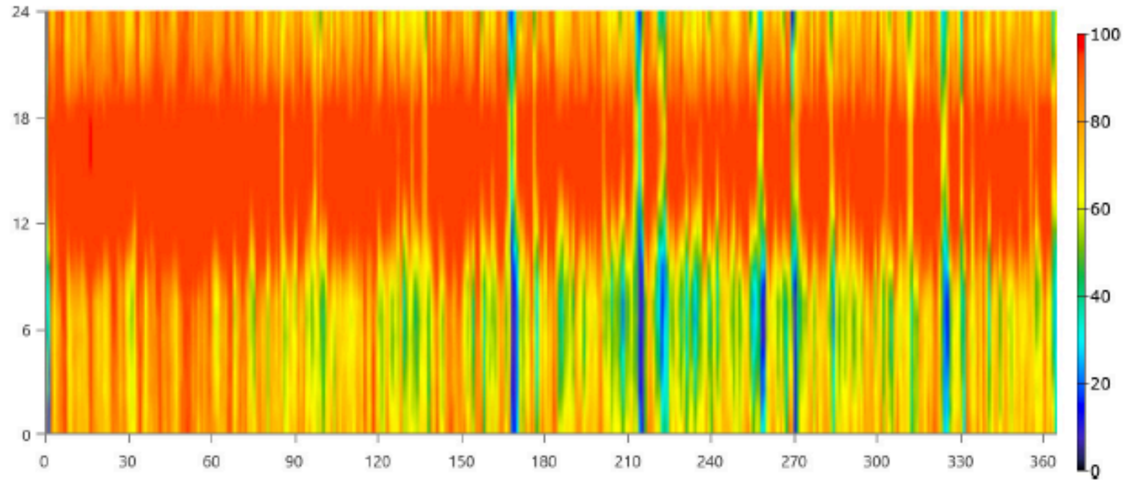
LGChem 9.8kWh RESU10H Result Data

Quantity	Value	Units
Average Energy Cost	0,0500	$/kWh
Energy In	2.733.595	kWh/yr
Energy Out	2.713.852	kWh/yr
Storage Depletion	7.631	kWh/yr
Losses	27.374	kWh/yr
Annual Throughput	2.727.524	kWh/yr

LGChem 9.8kWh RESU10H Statistics

Quantity	Value	Units
Autonomy	9,00	hr
Storage Wear Cost	0,0419	$/kWh
Nominal Capacity	21.000	kWh
Usable Nominal Capacity	18.900	kWh
Lifetime Throughput	54.550.472	kWh
Expected Life	20,0	yr

LGChem 9.8kWh RESU10H State of Charge (%)



Converter: SMA Sunny Central 8000

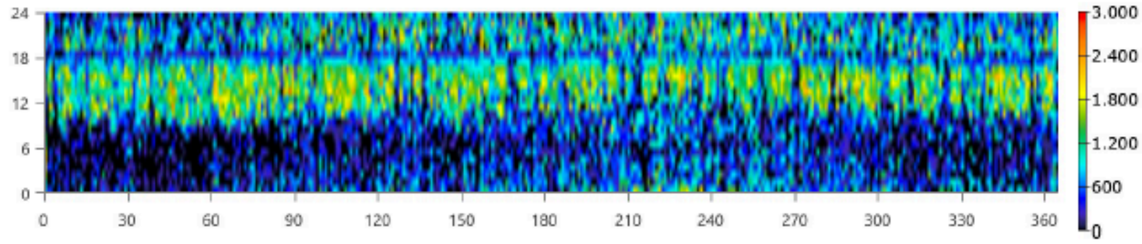
SMA Sunny Central 8000 Electrical Summary

Quantity	Value	Units
Hours of Operation	7.473	hrs/yr
Energy Out	6.267.529	kWh/yr
Energy In	6.356.520	kWh/yr
Losses	88.991	kWh/yr

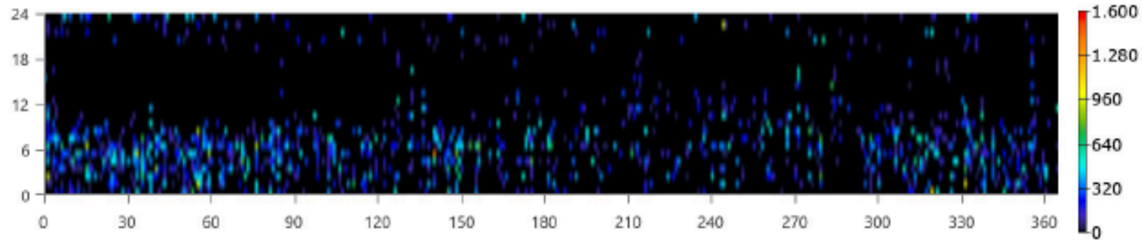
SMA Sunny Central 8000 Statistics

Quantity	Value	Units
Capacity	3.000	kW
Mean Output	715	kW
Minimum Output	0	kW
Maximum Output	2.891	kW
Capacity Factor	23,8	%

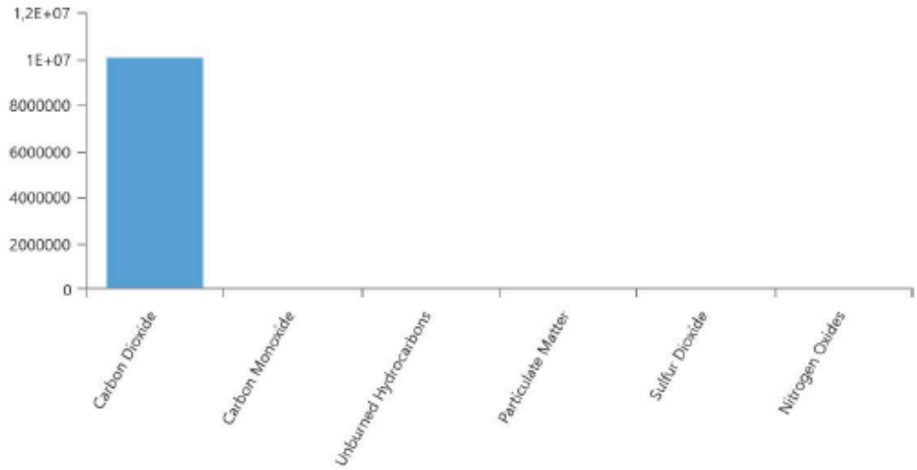
SMA Sunny Central 8000 Inverter Output (kW)



SMA Sunny Central 8000 Rectifier Output (kW)



Emissions Summary



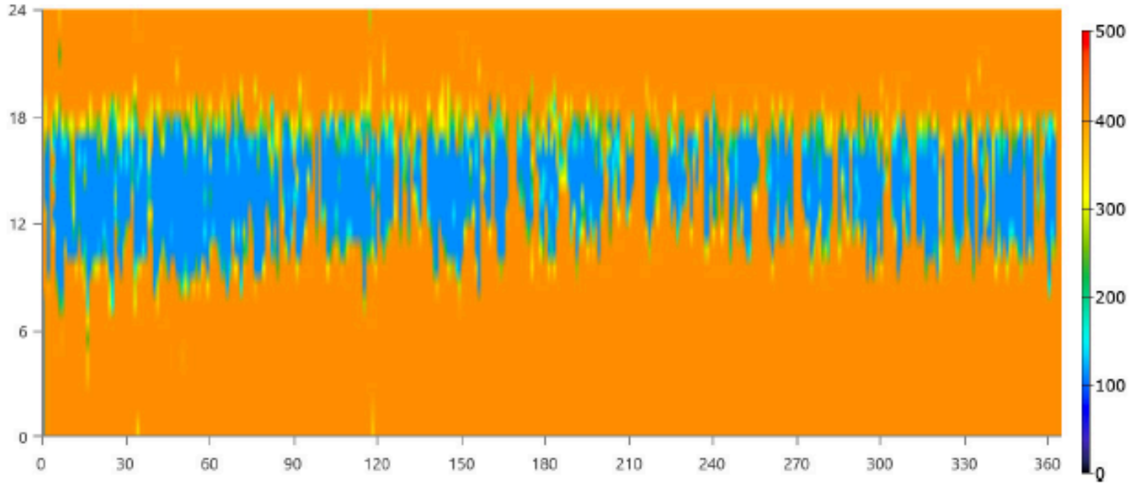
Pollutant	Quantity	Unit
Carbon Dioxide	10.002.580	kg/yr
Carbon Monoxide	45.037	kg/yr
Unburned Hydrocarbons	2.270	kg/yr
Particulate Matter	2.702	kg/yr
Sulfur Dioxide	24.425	kg/yr
Nitrogen Oxides	42.336	kg/yr

Fuel Summary

HFO Consumption Statistics

Quantity	Value	Units
Total fuel consumed	3.152.550	L
Avg fuel per day	8.638	L/day
Avg fuel per hour	360	L/hour

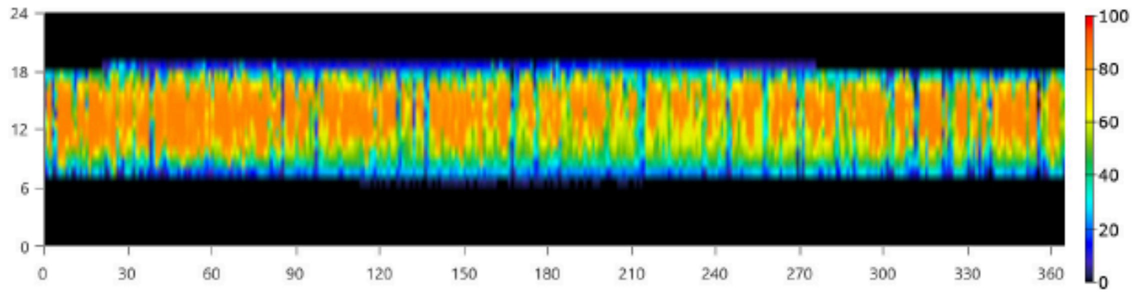
HFO Consumption (L/hr)



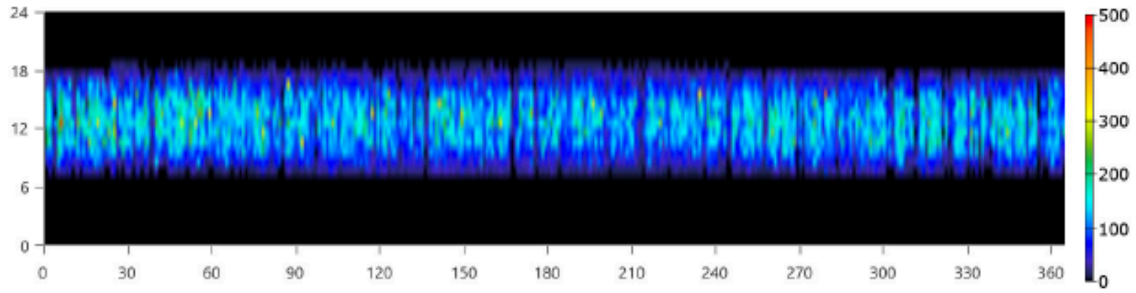
Renewable Summary

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	74,6	%
Usable renewable capacity divided by total capacity	70,2	%
Energy-based metrics	**Value**	**Unit**
Total renewable production divided by load	40,2	%
Total renewable production divided by generation	37,2	%
One minus total nonrenewable production divided by load	100	%
Peak values	**Value**	**Unit**
Renewable output divided by load (HOMER standard)	494	%
Renewable output divided by total generation	87,6	%
One minus nonrenewable output divided by total load	86,1	%

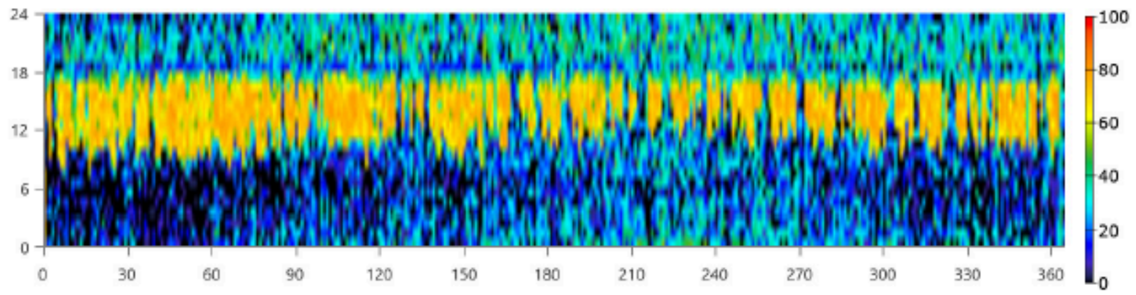
Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load



6. Simulation Report of the current system

System Simulation Report

www.homerenergy.com

File: Pedernales only Motor.homer

Author:

Location: (0°0,0'N, 0°0,0'W)

Total Net Present Cost: 32.926.897,57 $

Levelized Cost of Energy ($/kWh): 0,138 $

Notes:

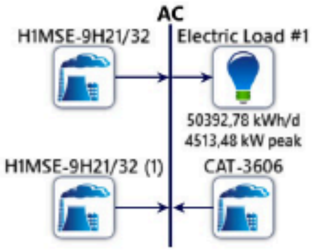
Sensitivity variable values for this simulation

Variable	Value	Unit
HFO Fuel Price	0,300	$/L

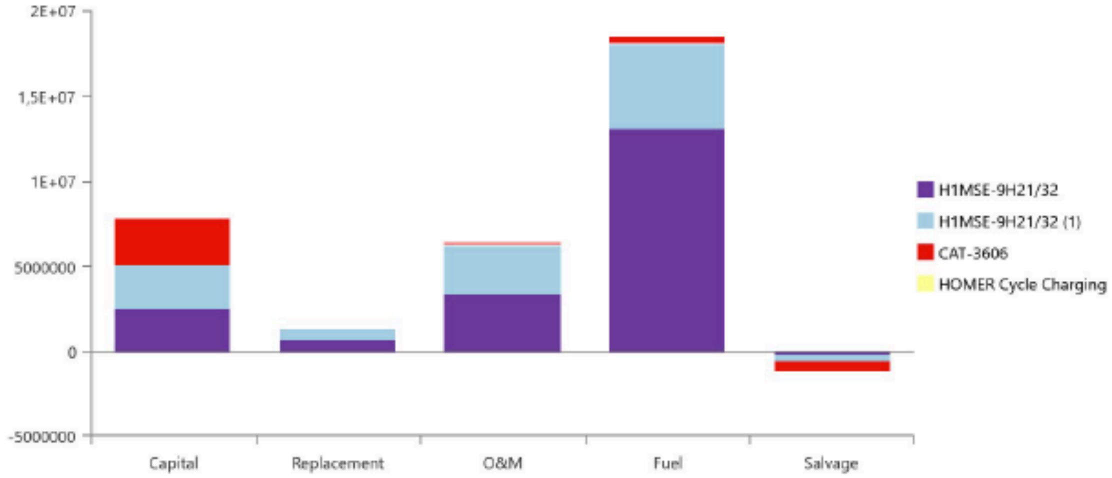
System Architecture

Component	Name	Size	Unit
Generator #1	H1MSE-9H21/32	1.700	kW
Generator #2	H1MSE-9H21/32 (1)	1.700	kW
Generator #3	CAT-3606	1.700	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



Cost Summary



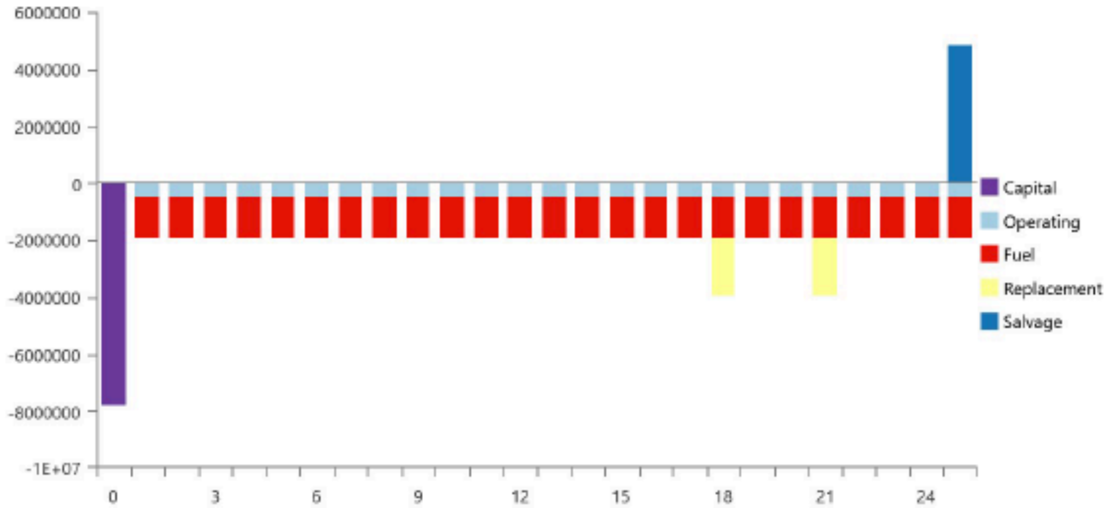
Net Present Costs

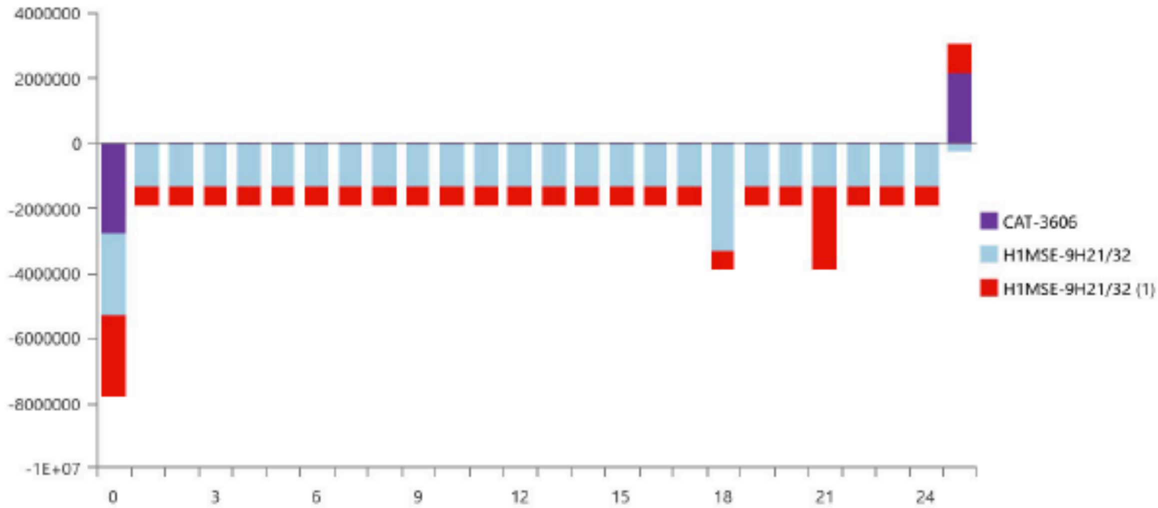
Component	Capital	Replacement	O&M	Fuel	Salvage	Total
H1MSE-9H21/32	2,50 $M	751.569 $	3,38 $M	13,2 $M	-258.722 $	19,5 $M
H1MSE-9H21/32 (1)	2,50 $M	630.196 $	2,86 $M	4,90 $M	-365.406 $	10,5 $M
CAT-3606	2,80 $M	0,00 $	151.640 $	435.464 $	-533.848 $	2,85 $M
System	7,80 $M	1,38 $M	6,40 $M	18,5 $M	-1,16 $M	32,9 $M

Annualized Costs

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
H1MSE-9H21/32	193.386 $	58.137 $	261.486 $	1,02 $M	-20.013 $	1,51 $M
H1MSE-9H21/32 (1)	193.386 $	48.748 $	221.606 $	379.319 $	-28.266 $	814.794 $
CAT-3606	216.592 $	0,00 $	11.730 $	33.685 $	-41.295 $	220.712 $
System	603.364 $	106.886 $	494.822 $	1,43 $M	-89.575 $	2,55 $M

Cash Flow


6000000
4000000
2000000
0
-2000000
-4000000
-6000000
-8000000
-1E+07
0
3
6
9
12
15
18
21
24
Capital
Operating
Fuel
Replacement
Salvage


4000000
2000000
0
-2000000
-4000000
-6000000
-8000000
-1E+07
0
3
6
9
12
15
18
21
24
CAT-3606
H1MSE-9H21/32
H1MSE-9H21/32 (1)

Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	352	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
H1MSE-9H21/32	13.462.475	73,2
H1MSE-9H21/32 (1)	4.727.434	25,7
CAT-3606	203.806	1,11
Total	18.393.715	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	18.393.363	100
DC Primary Load	0	0
Total	18.393.363	100

Generator: H1MSE-9H21/32 (HFO)

H1MSE-9H21/32 Electrical Summary

Quantity	Value	Units
Electrical Production	13.462.475	kWh/yr
Mean Electrical Output	1.537	kW
Minimum Electrical Output	425	kW
Maximum Electrical Output	1.700	kW

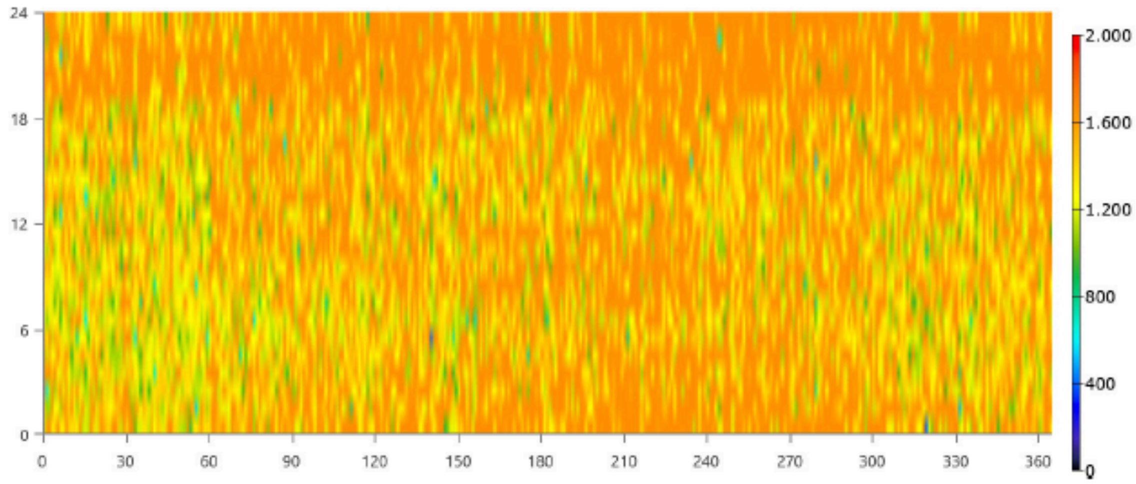
H1MSE-9H21/32 Fuel Summary

Quantity	Value	Units
Fuel Consumption	3.395.128	L
Specific Fuel Consumption	0,252	L/kWh
Fuel Energy Input	37.773.251	kWh/yr
Mean Electrical Efficiency	35,6	%

H1MSE-9H21/32 Statistics

Quantity	Value	Units
Hours of Operation	8.760	hrs/yr
Number of Starts	1,00	starts/yr
Operational Life	17,1	yr
Capacity Factor	90,4	%
Fixed Generation Cost	48,2	$/hr
Marginal Generation Cost	0,0724	$/kWh

H1MSE-9H21/32 Output (kW)



Generator: H1MSE-9H21/32 (1) (HFO)

H1MSE-9H21/32 (1) Electrical Summary

Quantity	Value	Units
Electrical Production	4.727.434	kWh/yr
Mean Electrical Output	637	kW
Minimum Electrical Output	425	kW
Maximum Electrical Output	1.700	kW

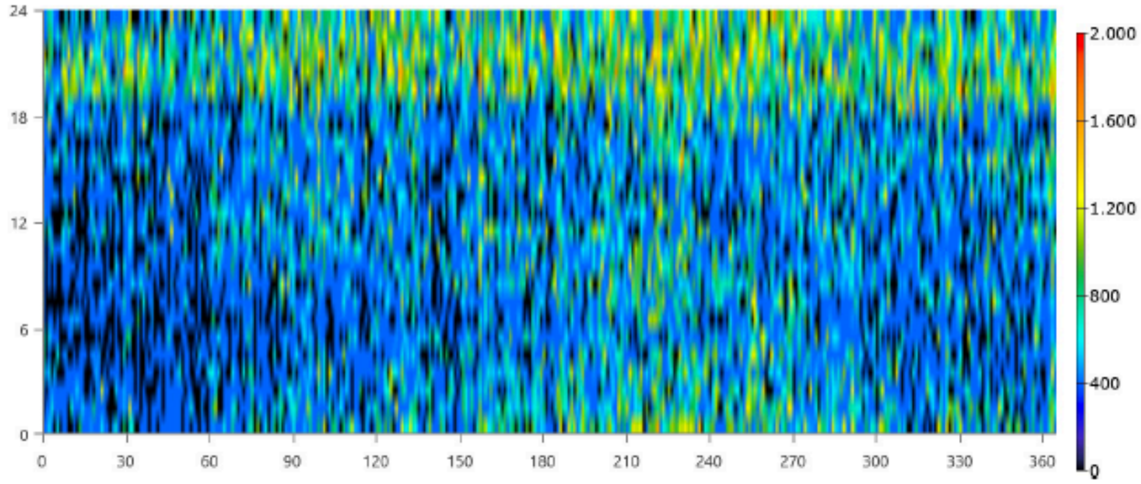
H1MSE-9H21/32 (1) Fuel Summary

Quantity	Value	Units
Fuel Consumption	1.264.395	L
Specific Fuel Consumption	0,267	L/kWh
Fuel Energy Input	14.067.313	kWh/yr
Mean Electrical Efficiency	33,6	%

H1MSE-9H21/32 (1) Statistics

Quantity	Value	Units
Hours of Operation	7.424	hrs/yr
Number of Starts	967	starts/yr
Operational Life	20,2	yr
Capacity Factor	31,7	%
Fixed Generation Cost	48,2	$/hr
Marginal Generation Cost	0,0724	$/kWh

H1MSE-9H21/32 (1) Output (kW)



Generator: CAT-3606 (Diesel)

CAT-3606 Electrical Summary

Quantity	Value	Units
Electrical Production	203.806	kWh/yr
Mean Electrical Output	521	kW
Minimum Electrical Output	510	kW
Maximum Electrical Output	1.113	kW

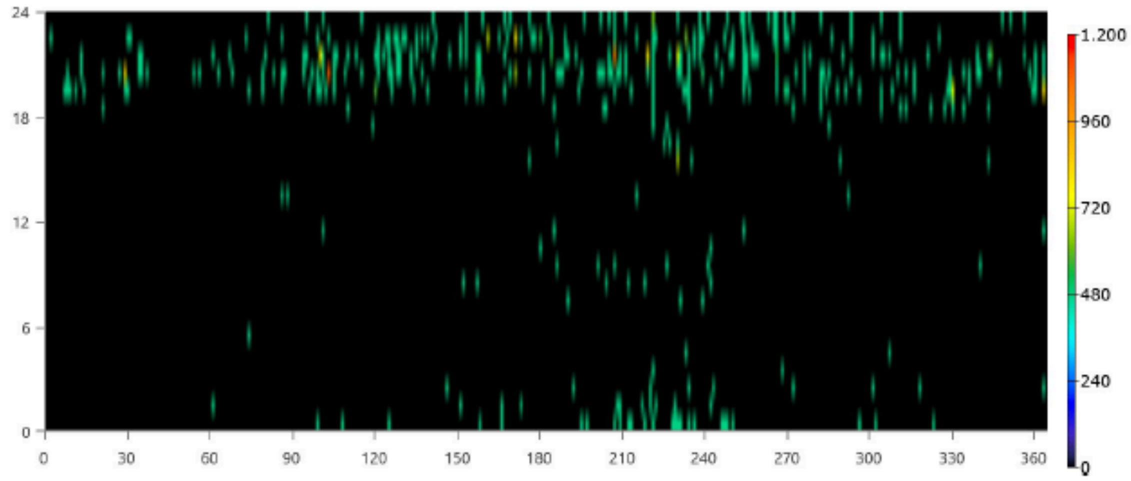
CAT-3606 Fuel Summary

Quantity	Value	Units
Fuel Consumption	61.246	L
Specific Fuel Consumption	0,301	L/kWh
Fuel Energy Input	602.656	kWh/yr
Mean Electrical Efficiency	33,8	%

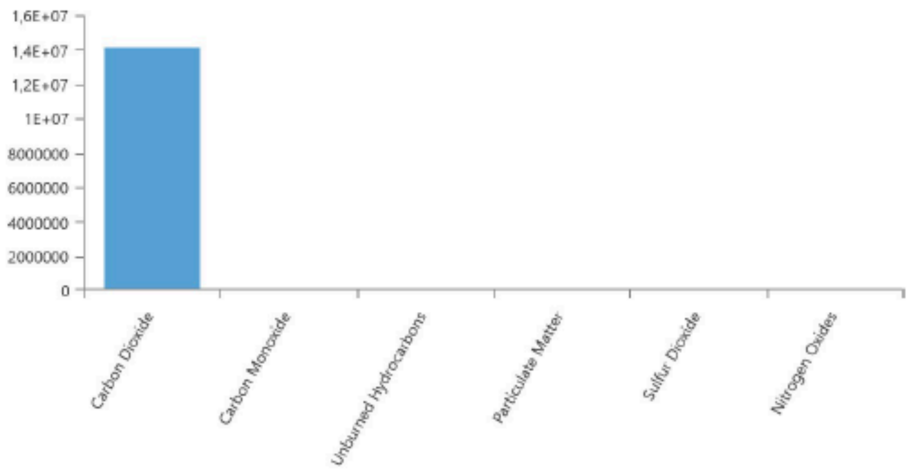
CAT-3606 Statistics

Quantity	Value	Units
Hours of Operation	391	hrs/yr
Number of Starts	302	starts/yr
Operational Life	230	yr
Capacity Factor	1,37	%
Fixed Generation Cost	68,2	$/hr
Marginal Generation Cost	0,145	$/kWh

CAT-3606 Output (kW)



Emissions Summary



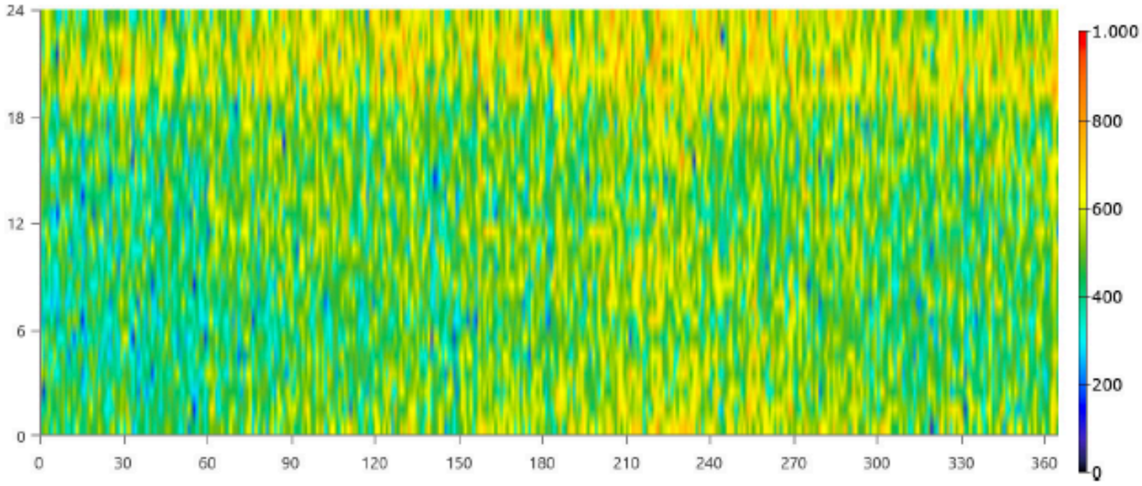
Pollutant	Quantity	Unit
Carbon Dioxide	14.149.030	kg/yr
Carbon Monoxide	66.665	kg/yr
Unburned Hydrocarbons	3.358	kg/yr
Particulate Matter	4.003	kg/yr
Sulfur Dioxide	34.562	kg/yr
Nitrogen Oxides	64.142	kg/yr

Fuel Summary

HFO Consumption Statistics

Quantity	Value	Units
Total fuel consumed	4.659.523	L
Avg fuel per day	12.767	L/day
Avg fuel per hour	532	L/hour

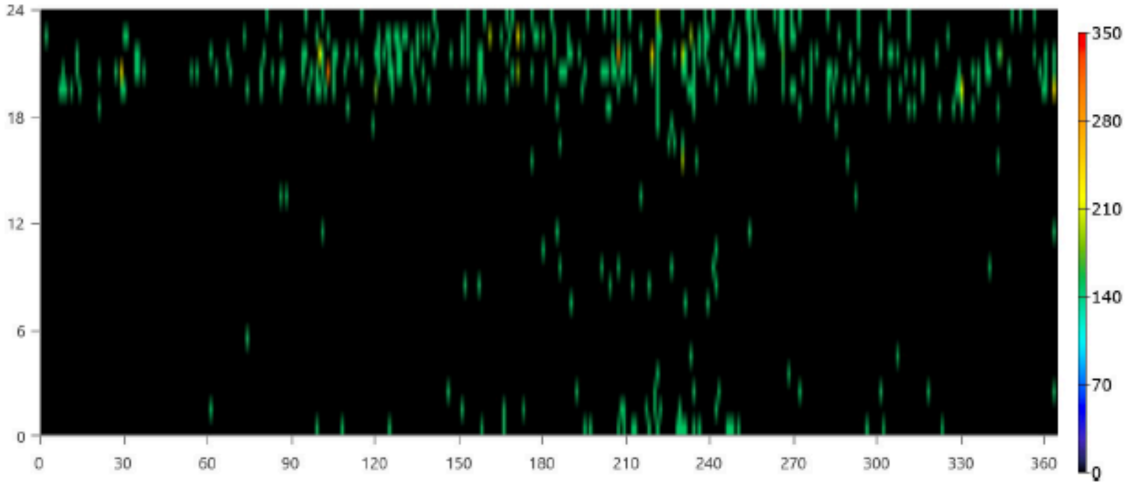
HFO Consumption (L/hr)



Diesel Consumption Statistics

Quantity	Value	Units
Total fuel consumed	61.246	L
Avg fuel per day	168	L/day
Avg fuel per hour	6,99	L/hour

Diesel Consumption (L/hr)



7. Simulation Report of PVSyst

Version 1 Perez

Stand Alone System: Simulation parameters

Project :	**Pedernales 3.0**			
Geographical Site	**Pedernales**		Country	**Dominican Republic**
Situation	Latitude	18.03° N	Longitude	-71.74° W
Time defined as	Legal Time	Time zone UT-4	Altitude	11 m
	Albedo	0.20		
Meteo data:	**Pedernales**	Meteonorm 7.1 (1991-2010), Sat=100% - Künstlich		
Simulation variant :	**Neue Simulationsvariante4**			
	Simulation date	15/09/17 11h41		
Simulation parameters				
Collector Plane Orientation	Tilt	30°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Near Shadings	Linear shadings			
PV Array Characteristics				
PV module Si-poly	Model	**STP 265-20/Wem**		
Custom parameters definition	Manufacturer	Suntech		
Number of PV modules	In series	22 modules	In parallel	601 strings
Total number of PV modules	Nb. modules	13222	Unit Nom. Power	265 Wp
Array global power	Nominal (STC)	**3504 kWp**	At operating cond.	3138 kWp (50°C)
Array operating characteristics (50°C)	U mpp	605 V	I mpp	5184 A
Total area	Module area	**21511 m²**	Cell area	19309 m²
PV Array loss factors				
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	2.0 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
System Parameter	System type	**Stand alone with back-up generator System**		
Battery	Model	**RESU 10**		
	Manufacturer	LG chem		
Battery Pack Characteristics	Voltage	400 V	Nominal Capacity	3000 Ah
	Nb. of units	120 in parallel		
	Temperature	Given monthly values		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	354.8 / 304.5 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	240.5 / 299.1 V
	Back-Up Genset Command	SOC = 0.25/0.45	i.e. approx.	243.1 / 369.2 V
Back-up generator (genset)	Model	3 kW		
	Manufacturer	Back-up generator		
	Nominal power	3400 kW		

Stand Alone System: Simulation parameters (continued)

System Parameter	System type	**Stand alone with back-up generator System**		
Battery	Model	**RESU 10**		
	Manufacturer	LG chem		
Battery Pack Characteristics	Voltage	400 V	Nominal Capacity	3000 Ah
	Nb. of units	120 in parallel		
	Temperature	Given monthly values		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0/95.0 %		
Battery management control	Treshold commands as	SOC calculation		
	Charging	SOC = 0.90 / 0.75	i.e. approx.	354.8 / 304.5 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	240.5 / 299.1 V
	Back-Up Genset Command	SOC = 0.25/0.45	i.e. approx.	243.1 / 369.2 V
Back-up generator (genset)	Model	3 kW		
	Manufacturer	Back-up generator		
	Nominal power	3400 kW		
User's needs :	daily profile	Monthly normalizations		
	average	51.6 MWh/Day		

Version 1 Perez

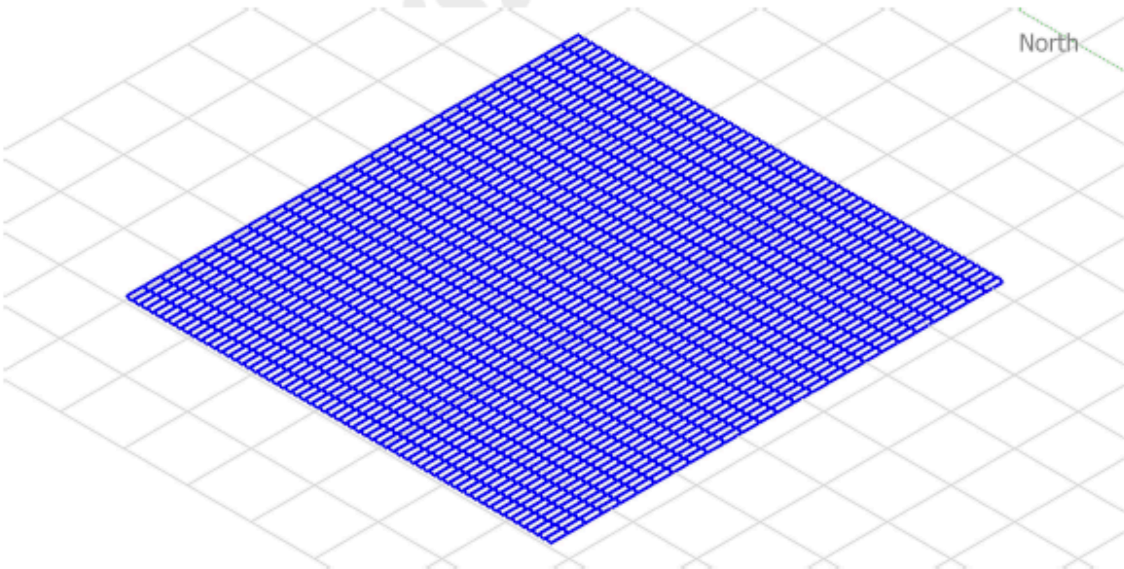
Stand Alone System: Near shading definition

Project : **Pedernales 3.0**

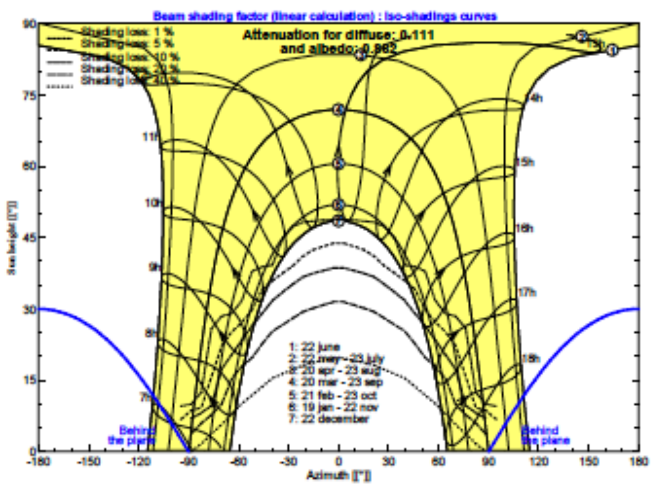
Simulation variant : **Neue Simulationsvariante4**

Main system parameters	System type	**Stand alone with back-up generator**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	STP 265-20/Wem	Pnom	265 Wp
PV Array	Nb. of modules	13222	Pnom total	**3504 kWp**
Battery	Model	RESU 10	Technology	general
battery Pack	Nb. of units	120	Voltage / Capacity	**400 V / 3000 Ah**
User's needs	daily profile	Monthly normalizations	global	18834 MWh/year

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Stand Alone System: Detailed User's needs

Project : **Pedernales 3.0**

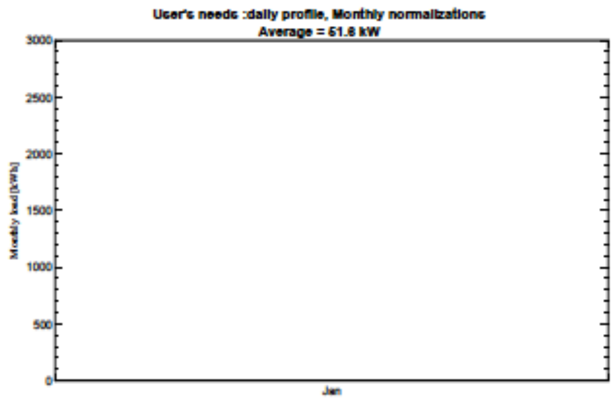
Simulation variant : **Neue Simulationsvariante4**

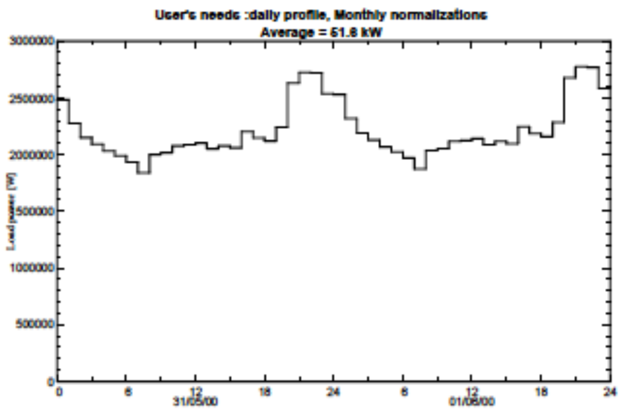
Main system parameters	System type	**Stand alone with back-up generator**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	STP 265-20/Wem	Pnom	265 Wp
PV Array	Nb. of modules	13222	Pnom total	**3504 kWp**
Battery	Model	RESU 10	Technology	general
battery Pack	Nb. of units	120	Voltage / Capacity	**400 V / 3000 Ah**
User's needs	daily profile	Monthly normalizations	global	18834 MWh/year

daily profile, Monthly normalizations, average = 51.6 kW

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
*79890	*76000	*19000	*08000	*30000	*06000	*87000	*84000	*41000	*08000	*27000	*68000	*33890	kW

	0 h / 12 h	1 h / 13 h	2 h / 14 h	3 h / 15 h	4 h / 16 h	5 h / 17 h	6 h / 18 h	7 h / 19 h	8 h / 20 h	9 h / 21 h	10 h / 22 h	11 h / 23 h	
Hourly load	2321	2127	2008	1954	1898	1858	1808	1719	1869	1885	1941	1949	kW
	1964	1916	1941	1924	2060	2006	1981	2096	2458	2546	2542	2370	kW



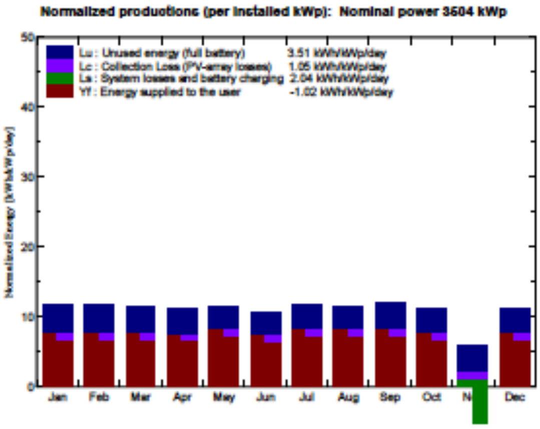


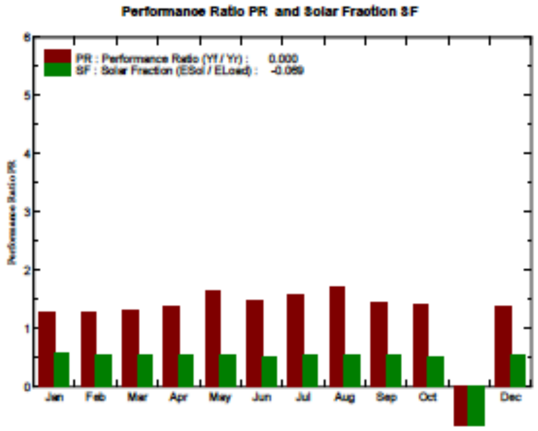
Stand Alone System: Main results

Project : **Pedernales 3.0**
Simulation variant : **Neue Simulationsvariante4**

Main system parameters	System type	**Stand alone with back-up generator**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	STP 265-20/Wem	Pnom	265 Wp
PV Array	Nb. of modules	13222	Pnom total	**3504 kWp**
Battery	Model	RESU 10	Technology	general
battery Pack	Nb. of units	120	Voltage / Capacity	**400 V / 3000 Ah**
User's needs	daily profile	Monthly normalizations	global	18834 MWh/year

Main simulation results				
System Production	**Available Energy**	**5704 MWh/year**	Specific prod.	1628 kWh/kWp/year
	Used Energy	6996 MWh/year	Excess (unused)	4492 MWh/year
	Performance Ratio PR	-18.24 %	Solar Fraction SF	-6.91 %
Back-Up energy from generator	Back-Up energy	8297 MWh/year	Fuel Consumption	2370665/year





Neue Simulationsvariante4
Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E User MWh	E Load MWh	SolFrac
January	147.3	172.7	530.9	418.6	1537	1480	0.578
February	146.4	157.6	484.1	381.5	1381	1376	0.555
March	177.0	169.6	523.3	412.9	1525	1519	0.553
April	178.5	152.9	474.2	373.6	1479	1508	0.537
May	184.0	142.6	443.6	349.6	1613	1630	0.558
June	185.8	136.9	426.3	335.4	1485	1606	0.492
July	198.1	148.5	459.5	361.4	1631	1687	0.540
August	169.7	136.5	422.3	332.9	1627	1684	0.542
September	172.8	159.7	490.2	385.4	1576	1641	0.538
October	152.4	155.8	477.9	375.6	1602	1608	0.523
November	139.2	159.7	489.8	385.6	-9995	1527	-6.983
December	133.5	156.8	481.8	379.6	1535	1568	0.539
Year	1984.7	1849.2	5704.0	4492.0	6996	18834	-0.069

Legends:				
	GlobHor	Horizontal global irradiation	E User	Energy supplied to the user
	GlobEff	Effective Global, corr. for IAM and shadings	E Load	Energy need of the user (Load)
	E Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
	EUnused	Unused energy (full battery) loss		

PVSYST V6.62		15/09/17	Page 6/6

Version 1 Perez

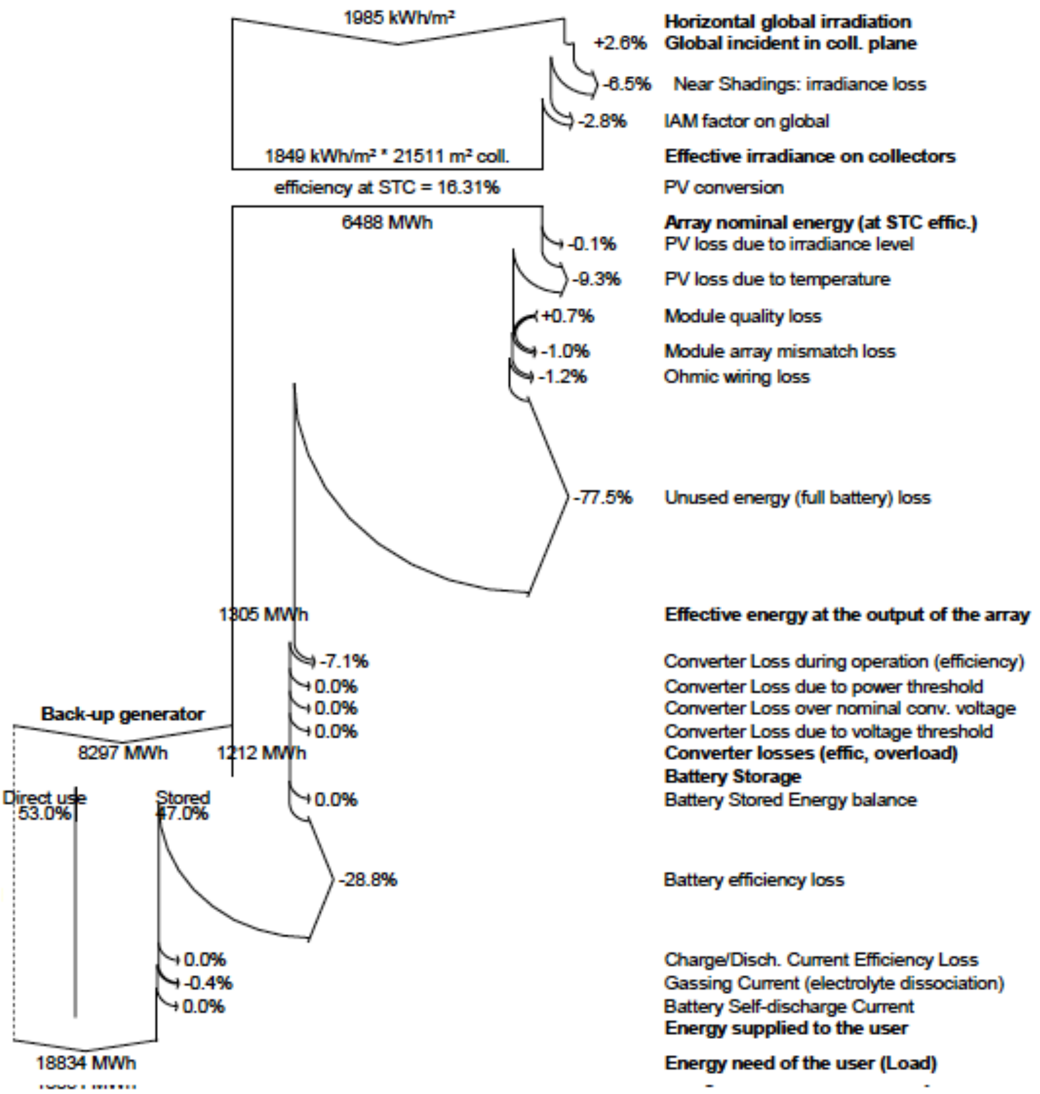
Stand Alone System: Loss diagram

Project : **Pedernales 3.0**

Simulation variant : **Neue Simulationsvariante4**

Main system parameters	System type	**Stand alone with back-up generator**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	STP 265-20/Wem	Pnom	265 Wp
PV Array	Nb. of modules	13222	Pnom total	**3504 kWp**
Battery	Model	RESU 10	Technology	general
battery Pack	Nb. of units	120	Voltage / Capacity	**400 V / 3000 Ah**
User's needs	daily profile	Monthly normalizations	global	18834 MWh/year

Loss diagram over the whole year



8. System in DIGSilent