POLITECNICO DI MILANO

Facoltà di Ingegneria Industriale e dell'Informazione

Corso di Laurea Magistrale in Ingegneria Elettrica

FEASIBILITY STUDY OF A HYBRID POWER PLANT THAT USES BIOMASS AND SOLAR ENERGY

Location: Ouango, Central African Republic (Africa)

Relatore: Samuele GRILLO

Tesi di Laurea di:

Dania BULFONE

Matr. 800500

Anno Accademico 2013 / 2014

RINGRAZIAMENTI

Desidero ringraziare il mio relatore, l’Ingegner Grillo, per le ore dedicate a questo lavoro ed anche il Professor Tironi che ha ascoltato le mie idee e mi ha permesso di realizzare questa tesi.

Quiero dar las gracias también a los profesores de la UPV que me han seguido durante mi permanencia en Valencia, en particular a aquellos del máster de biomasa: David Alfonso Solar, que ha sido muy paciente y me ha ayudado muchísimo con sus consejos y sus sugerencias, y Ángel Pérez-Navarro Gómez, que me ha permitido de frecuentar esto máster.
Gracias al Profesor Elías José Hurtado Pérez que es lo que me ha puesto en contacto con estos dos profesores y también al Profesor Juan Ángel Saiz Jiménez que me ha aconsejado sobre la planta de energía fotovoltaica.

Credo sia doveroso ringraziare anche le persone che sono state così gentili da chiarire alcuni miei dubbi durante la preparazione dei questa tesi: il Signor Cummings della Community Power Corporation, la Signora Hale del HOMER Enegy support e il Signor Laugero della Pezzolato SpA.

Last but not least, volevo ringraziare tutti quelli che mi sono stati vicini e mi hanno sostenuto economicamente e/o moralmente: la mia famiglia, il mio ragazzo, i miei "suoceri", che mi hanno dato un posto dove stare quando rientravo in Italia durante l'Erasmus, e Liv e Joe che mi hanno accolto in casa loro e dato un posto tranquillo per terminare la tesi.
Un grazie di cuore va anche a tutti i miei amici e conoscenti che hanno fatto il tifo per me: in particolare ad Emanuela, che nonostante la lontananza si è sempre preoccupata di sapere come andava il mio lavoro, a “mis locas compañeras de piso”, Daniela e Maureen, con cui ho passato dei momenti incredibili e a “mis compañeros de curso” Daniel, César, Angel, Antonio y Andrés con cui ho avuto modo di chiacchierare del mio progetto e delle energie alternative.

SUMMARY

FIGURES INDEX

TABLES INDEX

GRAPHS INDEX

ABSTRACT

The aim of this thesis is a feasibility study of a stand-alone hybrid plant that uses biomass and solar energy to produce electricity, in order to contribute to solve the problem of rural electrification. The selected study site is Ouango, a town in the prefecture of Mbomou, Central African Republic.

I started supposing some electrical loads useful for the lifestyle improvement of Ouango, taking inspiration from the World Energy Outlook 2013 definition of energy access.

I searched irradiation data of the site using PVGIS and chose the components of the 12 kWp solar power plant.

Then, I looked for information about biomass available on site and I had to make some hypotheses about waste types and the relating quantities, due to the lack of updated data.

I characterized the residues using Phyllis2 and Feedipedia and selected the most suitable for the biomass plant, considering the ash percentage, the moisture content and the HHV. For converting the biomass to energy I chose a 100 kW BioMax® gasifier and a 30 kW wood chipper.

I used HOMER to model and simulate the hybrid plant, trying different sizes of solar panels, gasfiers and batteries, to individuate the best configuration that minimizes the Cost Of Energy (COE). This configuration is made up of 12 kW of photovoltaic panels, a 100 kW biomass plant, twelve 1500 Ah batteries with diluted sulphuric acid electrolyte and six 6 kW converters. Resulting COE is 0,258 €/kWh.

I also made simulations of a traditional diesel plant, because at present the electricity in rural areas is generated only with diesel generators.

The comparison between the hybrid solution and the traditional solution shows that even if the hybrid plant has larger costs of investment, diesel generators have high cost of fuel and this implies that the COE of the diesel solution is 0,717 €/kWh (about 65% higher than in the case of the hybrid plant).

I tried different models of the hybrid plant, reducing biomass and modifying the working hours of the wood chipper and the results are still in favour of the hybrid installation, so this feasibility study demonstrates that an off-grid hybrid plant could be a good solution for the rural area electrification.

ESTRATTO DELLA TESI

L'intento di questa tesi è realizzare lo studio di fattibilità di un impianto ibrido non connesso alla rete, che utilizza energia solare e biomassa per produrre elettricità in una zona rurale: Ouango, una piccola città della Repubblica Centrafricana.

Traendo ispirazione dalla definizione di accesso all’energia del World Energy Outlook 2013, ho ipotizzato dei carichi elettrici utili per il miglioramento dello stile di vita di Ouango.

Ho ricercato i dati dell’irraggiamento della zona utilizzando PVGIS e scelto i componenti dell’impianto solare da 12 kWp.

Ho cercato poi informazioni riguardo alla biomassa autoctona e formulato alcune ipotesi riguardo i tipi e le quantità di residui, dato che non esistono dati aggiornati.

Ho caratterizzato i residui utilizzando Phyllis2 e Feedipedia e ho selezionato quelli più adatti per l’impianto a biomassa, tenendo in conto la percentuale di ceneri, il contenuto di umidità ed il potere calorifico superiore.

Per convertire la biomassa in energia ho scelto di usare un gassificatore BioMax® da 100 kW e una cippatrice da 30 kW.

Ho utilizzato HOMER per modellizzare e simulare l’impianto ibrido, considerando diverse taglie di pannelli fotovoltaici, gassificatori e batterie per individuare la configurazione che minimizzasse il costo dell’energia. Questa configurazione è composta da 12 kW di pannelli, un gassificatore da 100 kW, dodici batterie da 1500 Ah ad acido solforico diluito e sei convertitori da 6 kW. Il risultante costo dell’energia è 0,258 €/kWh.

Ho anche effettuato delle simulazioni di un impianto diesel tradizionale, che attualmente è l’unica risorsa per generare elettricità nelle aree rurali.

Il confronto tra l’impianto ibrido e quello tradizionale mostra che il costo dell’energia di un impianto a diesel è più alto rispetto a quello ibrido (0,717 €/kWh), anche se l’investimento iniziale di quest’ultimo è maggiore.

Ho anche modellizzato in diversi modi l’impianto ibrido, riducendo la biomassa e modificando le ore di funzionamento della cippatrice, giungendo sempre alla conclusione che l’impianto ibrido off-grid potrebbe essere una buona soluzione all’elettrificazione delle aree rurali.

1 INTRODUCTION

1.1 Energy for all

Modern energy services are essential for human well-being and for a country's economic development. Today billions of people lack access to the most basic energy services: as World Energy Outlook 2013 shows, nearly *1,3 billion people* are *without access to electricity* and more than 2,6 billion people rely on the traditional use of biomass for cooking, which causes dangerous indoor air pollution. These people are mainly in developing Asia or Sub-Saharan Africa and in rural areas.[1]

1.2 Defining energy access

The *World Energy Outlook (WEO)* defines energy access as *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average"*.

This definition of access involves a *minimum level of electricity*, that varies whether the household is in a rural or an urban area. The initial threshold level of electricity consumption for *rural households* is assumed to be *250 kilowatt-hours* (kWh) *per year* and for *urban households* it is *500 kWh per year*. Both are calculated based on an assumption of *five people per household*. In rural areas, this level of consumption could, for example, provide for the use of a fan, a mobile telephone and two light bulbs for about five hours per day. In urban areas, consumption might also include a refrigerator, another mobile phone per household and a small television or a PC.

The definition of energy access also includes provision of cooking services that are more healthy, sustainable and energy efficient than the standard biomass cookstove currently used in developing countries. This definition refers primarily to biogas systems, liquefied petroleum gas (LPG) stoves and advanced biomass cookstoves that have lower emissions and higher efficiencies than traditional fires for cooking.[2]

1.3 The Energy Development Index

The *Energy Development Index* (EDI) is an indicator that *tracks energy development* of eighty countries, distinguishing between developments of households and community.

It focuses on two main features: *access to electricity* and *access to clean cooking facilities*. Regarding community level access, it considers energy use for public services and energy for productive use.

The EDI function is to help better understand the role that energy plays in human development. [3]

In the following image it is possible to see the components of the EDI.

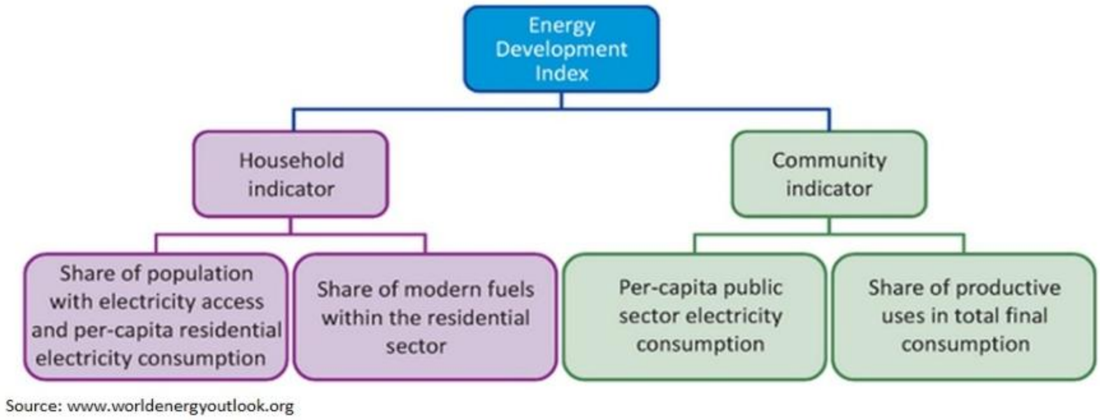


Figure 1. EDI components

2 THE AIM OF THIS THESIS

Starting from the considerations of the WEO about the energy access, I decided to make a feasibility study of a *stand-alone hybrid power plant*, that will use *biomass and solar energy* to produce electricity.

2.1 Steps of the work

The steps that I followed for this purpose are these:

- Research of a suitable site for the power plant
- Definition of loads and generation of the load curve
- Research of the site irradiation data
- Choice of the solar plant components (modules, regulators, inverters, batteries)
- Data research of the biomass available *in situ* and characterization of the residues
- Calculations about monthly biomass distribution and energy provided by the residues
- Choice of the biomass plant components (gasificator, wood chipper)
- Creation of the hybrid power plant model with HOMER and simulations
- Creation of the model of a power plant fed by a diesel generator with HOMER and simulations
- Simulations comparison of the two power plants and possible changes in the hybrid model
- Conclusions

In the following paragraphs, I am going to talk about some working hypotheses, like the location of the plant, the actual situation in the site and the loads definition.

2.2 Working hypotheses

2.2.1 Study site

The study site is a rural location in the Sub Saharan Africa: Ouango, a small town in the prefecture of Mbomou, Central African Republic.

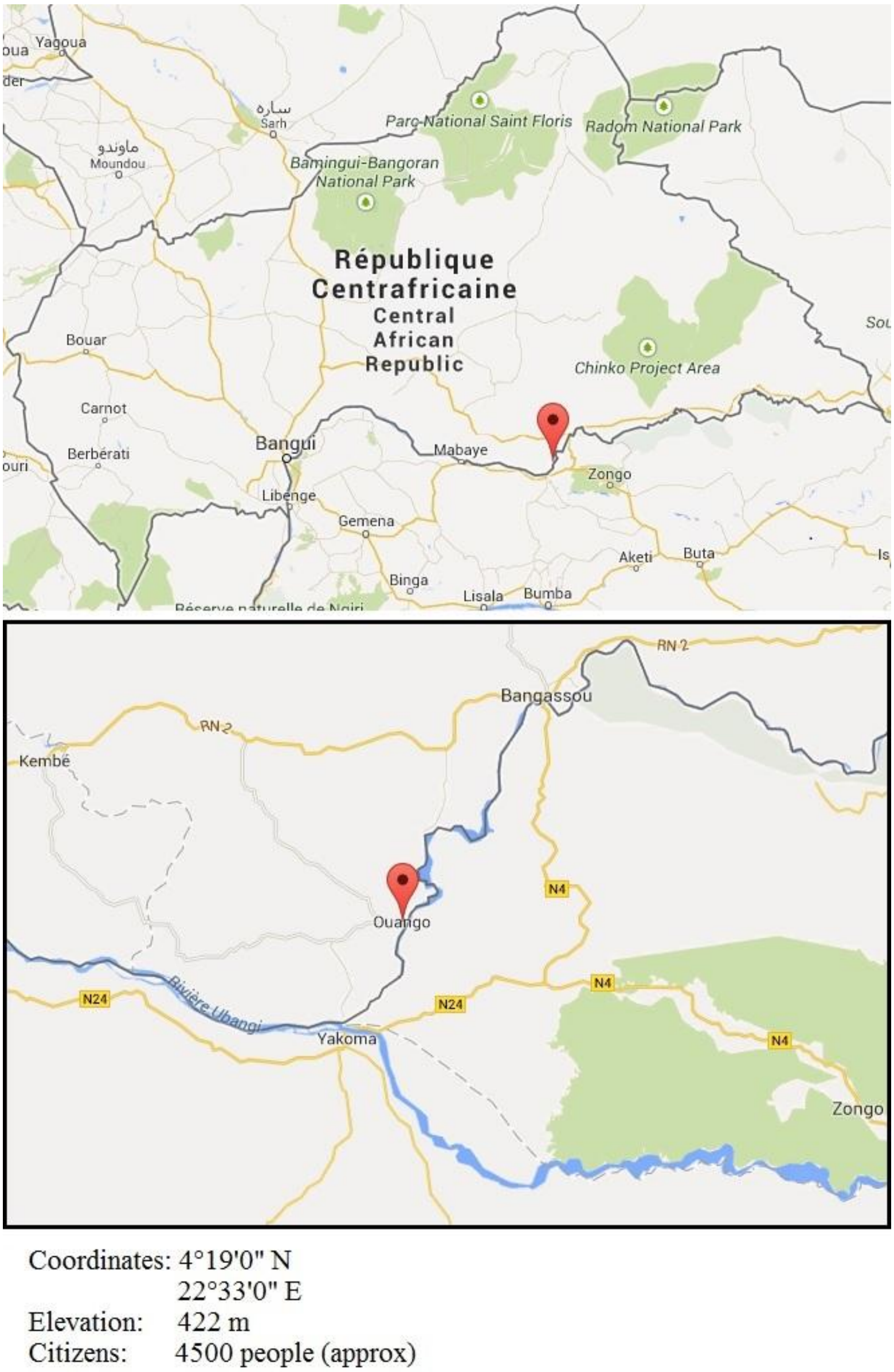


Figure 2. Ouango location

2.2.2 Actual situation in Central African Republic

Central African Republic's (CAR) power sector is managed by a public company, the Energie Centrafricaine (ENERCA), which was established in 1963 and has the monopoly on all electrical power activities.[4]

Renewable energy contributed for the 54,3% (25 MW) to the installed generation capacity in 2008 and the total electricity generation in this year was 162,0 GWh, with a per-capita consumption of 37 kWh.

At present there are three hydro-electric plants in operation: Boali 1 (8,75 MW), Boali 2 (10 MW) and Gamboula (0,2 MW). Their total capacity is nearly 19 MW and the average annual production is 130 GWh, but this capacity is not reliable because of the *lack of maintenance* that comports *frequent power failures*. Boali 3 (10 MW) has recently been commissioned, in addition to a 6 MW thermal power station at Bangui.

ID	1
VOLTAGE	120
FROM	BANGUI
TO	BOALI
STATUS	Existing
SOURCES	WB map archive IBRD #23036, June 1992
ID	2, 3
VOLTAGE	800
FROM	GRAND INGA
TO	CAIRO
STATUS	Under Study
SOURCES	WEC, 2008: How to make the Grand Inga Hydropower Project happen for Africa
PROJECT	Inga Northern Highway

Source: ARCGIS

Figure 3. Electrical lines in CAR

Supply is unable to meet demand: *in 2010*, the rate of *access* of the population *to electricity was 4% at national level*, 15% in Bangui, 1% in secondary centres and *near 0 % in the rural environment*.

The country's grid system is as follows:

- High voltage grid: 110 kV - 84 km;
- Medium voltage grid: 15 kV - 290 km;
- Low voltage grid: 220 V - 433 km.

The town of *Mobaye* (608 kilometres from Bangui) is the only one to have regular electricity supplies because it *imports electricity* generated by a plant in the neighbouring Democratic Republic of the Congo.

Peak demand in 2008 was estimated at 27 MW, but estimated *system losses in 2009 were of 48%*, so there is a large gap between supply and demand. System losses are approximately 15% technical losses and 33% non-technical losses (i.e. theft and inaccurate billing).

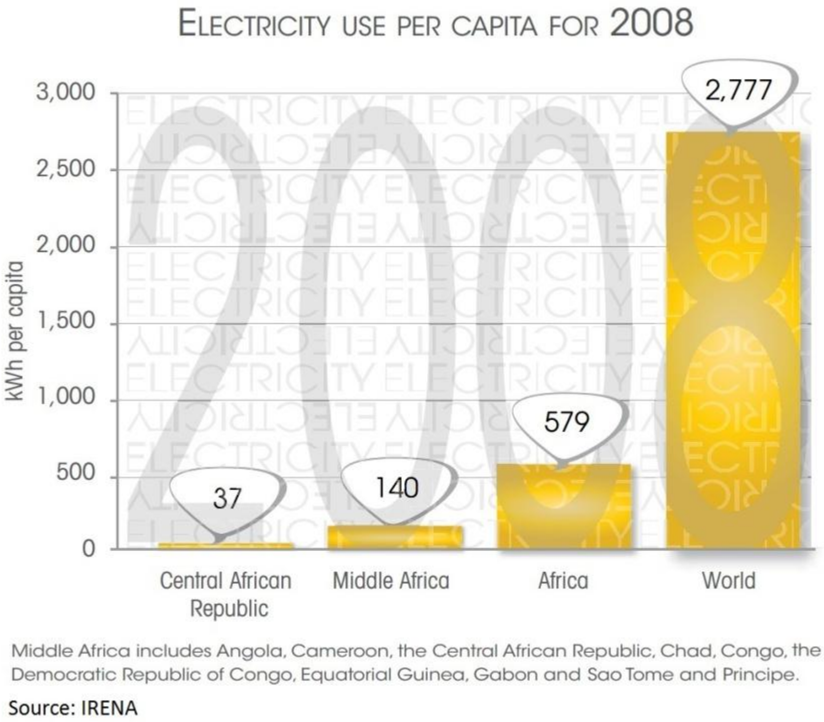
An increasing proportion of people in provincial towns and businesses are using diesel or petrol powered generators to produce their own electricity. In 2008, diesel prices were approximately US$ 1,44 per litre (1,07 €/l). Diesel generators capacity varies from 2 to 650 kVA.[5]

In the following extract of the EDI database[3], it is possible to see that the CAR ranking place it is 63 over 80 countries and the EDI indicator is 0,13 over 1. Both the household level indicator and the community level indicator are very low; in particular the electricity access indicator is 0,02 that is inadequate.

Country	Rank	EDI	Household level energy access					Community level energy access		
			Access to electricity indicator			Access to clean cooking facilities indicator	Household level indicator	Public Services	Productive use	Community level indicator
			Electrification rate	Per-capita residential electricity consumption	Electricity access indicator	Share of modern fuels in residential total final consumption		Per-capita public services electricity consumption	Share of economic energy uses in total final consumption	
Central African Republic	63	0,13	0,05	0,01	0,02	0,07	0,05	0,01	0,42	0,21

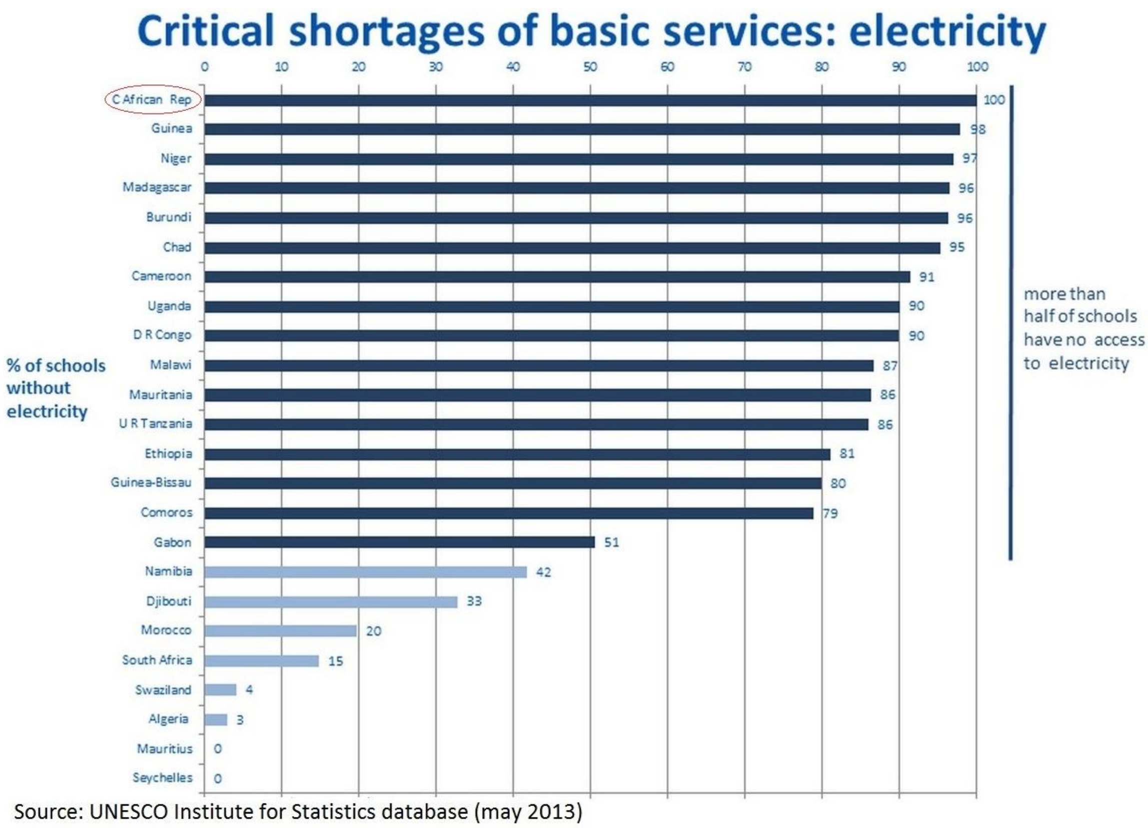
Table 1. EDI indicator for CAR

Electricity use per capita in 2008 was 37 kWh, versus an average African consumption of around 580 kWh per capita.



Graph 1. Electricity use per capita - comparison

One of the major problems in CAR is that actually *the 100% of the schools do not have any electricity access* and it is the only country in the whole Africa to have this unhappy situation.



Graph 2. Electricity in the African schools

In the following figure it is possible to see the African general energy situation; the Central African Republic is one of the countries with the lowest energy access.

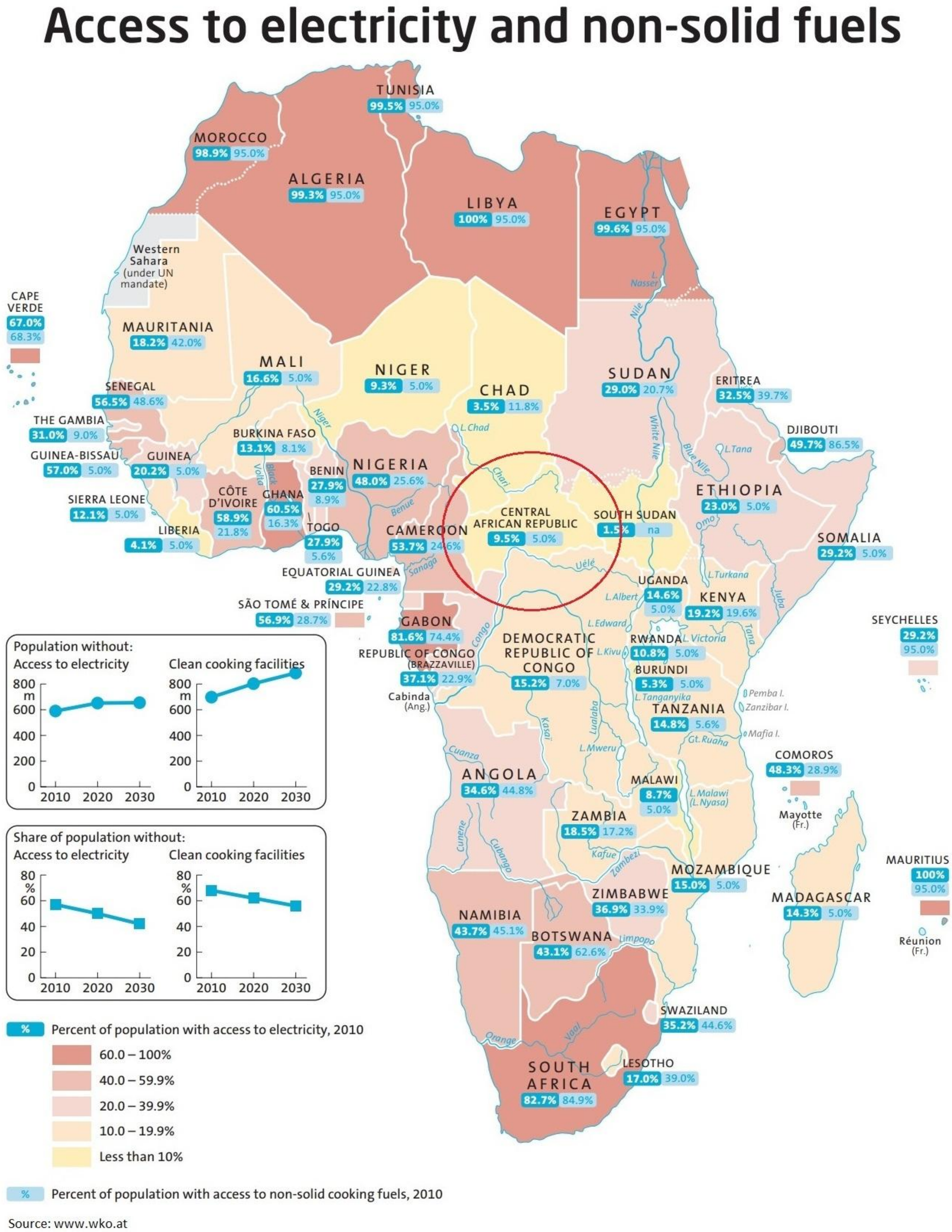


Figure 4. Access to Electricity in Africa

2.2.3 Loads definition

For this feasibility study I made some hypotheses about possible electrical loads that can be useful for the 4500 citizens living in Ouango, divided them in household loads (considering 5 people per household, households are 900) and public loads, that can provide benefits to the whole village.

In the following tables it is possible to see this distribution.

HOUSEHOLD LOADS	NUMBER [-]	SINGLE POWER [W]	TOTAL POWER [W]	HOURS OF USE [h/day]	ENERGY [Wh]	
Lights	2	40,00	80,00	5,00	400,00	
Mobile charger	1	6,00	6,00	1,00	6,00	
Floor fan	1	90,00	90,00	7,00	630,00	
					1,04	kWh/day
					378,14	kWh/year

Table 2. Household Loads Table

PUBLIC LOADS	NUMBER [-]	SINGLE POWER [W]	TOTAL POWER [W]	HOURS OF USE [h/day]	ENERGY [Wh]	
Mobile Phone Antenna	1	25,00	25,00	24,00	600,00	
School Lights	4	40,00	160,00	5,00	800,00	
Lights (various)	2	60,00	120,00	2,00	240,00	
Fridges	2	150,00	300,00	8,00	2.400,00	
Freezers	2	150,00	300,00	8,00	2.400,00	
TV	2	200,00	400,00	2,00	800,00	
Computers	2	100,00	200,00	2,00	400,00	
Field Hospital	1	10.000,00	10.000,00	3,00	30.000,00	
					37,64	kWh/day
					13.738,60	kWh/year

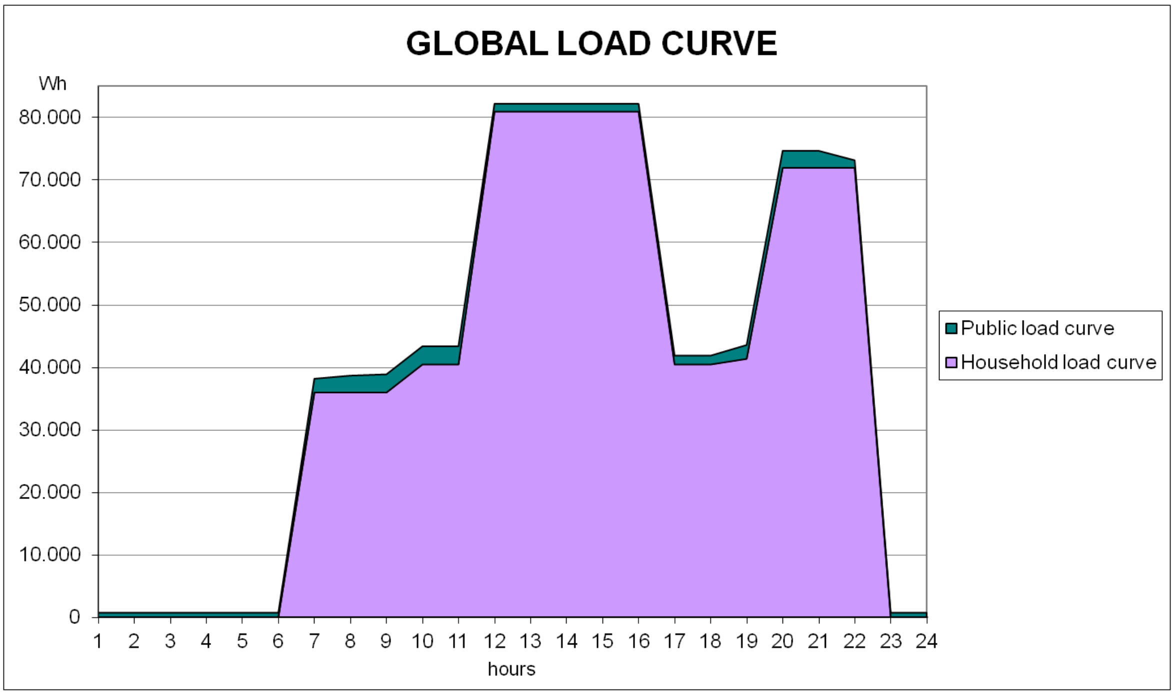
Table 3. Public Loads Table

In every house I decided to place two lights bulbs, a mobile charger and a floor fan, like suggested in the WEO definition of energy access.

I decided to implement also public utilities, assuming to provide energy to a mobile phone antenna for calling and internet services.

I imagined a school illuminated by four light bulbs, with a PC and a TV as supports for education and a common place where people can meet each other, like a recreation room, with lights, a PC, a TV, fridges and freezers where to place some goods for the community. Sanity is something fundamental, so in the calculations I included a field hospital[6] taken reference data from the Annex 8.1.

I generated a load curve for households loads and another one for public loads, creating some tables (see Annex 8.2) where I subdivided consumptions hour by hour, then I summed the two load curves and I obtained the global load curve, that is shown in the Graph 3.



Graph 3. Global Load Curve

3 SOME USEFUL DEFINITIONS

At the beginning of the second paragraph I said that I'm going to do a feasibility study about a hybrid and isolated (no grid connected) power plant that works with biomass and solar energy. Let's have an overview over these terms.

3.1 Isolated and hybrid power plants

Isolated refers to the separation of a facility that runs on its own alternative power source when energy does not come from a grid. This can happen as the result of a power black-out or be set up intentionally.

The process of isolation is realized using a distributed generator, an alternate power source that enables the installation to function independently.

An *isolated system* can be *more effective* when *more than one form of alternative energy is used*, because power sources are often complementary, with one compensating for the weaknesses of the other (e.g. solar panels and wind power, solar panels and biomass, etc…).[7]

A *hybrid power system* is a power plant that incorporates different *electricity generating components*, that allows one major control system and enables the system to supply electricity in the required quality.

Hybrid power systems can have different sizes (from several watts up to several megawatts) and they usually supply isolated networks that are not connected to an integrated grid.

These systems have to cope with much more severe short term variations in power demand, so, different energy management structures have to be applied, that vary with the size of the hybrid power system.

In isolated networks it is crucial to integrate one component that is responsible for frequency and voltage stabilization. In small systems (up to 50 kW) this task is assigned to inverters and battery systems; in lager systems are used synchronous generators with controllable engines. There are also different storage strategies that depend on the dimension of the plant: for megawatt class systems the use of pumped storage plants is more suitable, for medium sizes of several hundred kilowatts is used a compressed air storage plant and for small scale systems the battery storage is the best choice from the economic point of view.

Potential markets for *hybrid power systems* are all areas that have a demand for electrification but without electricity supply from networks. *Large potential* for *rural electrification*, especially with renewable energy sources, can be found in developing countries.[8]

3.2 Solar energy and photovoltaic panels

3.2.1 Energy from the sun

Solar energy is, simply, energy provided by the Sun. This energy is in the form of solar radiation, which makes the production of solar electricity possible.[9]

There are two important parameters to take into account: irradiance and irradiation (or insulation).

Irradiance is the instant value of the solar radiation that reaches the Earth, i.e. the light power per unit area and its measurement unit is Watts/square meter (W/m^2).

$$I = \frac{P_{light}}{A}$$

The *irradiation* is the irradiance quantity received in a certain time and it is measured in Wh/m^2.

In addition to these two parameters, it is necessary to consider that solar modules information is given in standard conditions of 1000 W/m^2, so an additional concept has to be introduced: Peak Solar Hours (PSH). *PSH* is the equivalent solar radiation value collected in a certain time period, considering a constant irradiance of 1000 W/m^2.

In simple terms: a PSH is the *solar radiation received in an hour, with a constant irradiance of 1000 W/m^2*.

3.2.2 Solar panels

Electricity can be produced directly from photovoltaic (PV) cells, that are made from materials which exhibit the “photovoltaic effect”. When sunlight hits the PV cell, the photons of light excite the electrons in the cell and induce them to flow, generating electricity.

During the functioning, solar energy produces no emissions. One megawatt hour of solar electricity offsets about 0,75 to 1 tonne of CO_2.[9]

Individual solar cells are manufactured in different shapes and sizes. Sometimes just one cell is needed to power a device, but usually many cells are connected each other to form solar panels or modules that can be linked to create photovoltaic arrays, used to power small buildings or large complexes. The resulting output of photovoltaic energy depends on the size of the array. The size may vary, depending on the amount of available daylight and the amount of power needed.

Even if the power output of a photovoltaic energy system depends on the global amount of light exposure, it will still generate energy on cloudy days.

To store this energy for later transmission, different storage systems are available, like a combination of rechargeable batteries and energy-storing capacitors, some of which can be designed for AC or DC power.[10]

3.3 Biomass vs. Fossil Fuels

The CEN/TS 14588 normative defines *biomass* as *"all material of biological origin, excluding material embedded in geological formation and transformed to fossil"*.

This means that biomass include both animal and vegetable derived material, not only plant based material as is usually thought of.

Figure 5. Biomass sources

3.3.1 Chemical Composition

Biomass is carbon based and it is composed of a mixture of organic molecules that contain hydrogen, atoms of oxygen, nitrogen and also small quantities of other atoms, like alkali, alkaline earth and heavy metals.[10]

3.3.2 Plant material

The carbon used to build biomass is absorbed from the atmosphere as carbon dioxide by vegetation, using solar energy.

Plants may then be eaten by animals and so converted into animal biomass. However the primary absorption is performed by plants.

If plant material is not eaten, it is generally broken down by micro-organisms or burned:

- If broken down, it releases the carbon back to the atmosphere as carbon dioxide (CO_2) or methane (CH_4).
- If burned, the carbon is returned to the atmosphere as carbon dioxide.

These processes are part of what is known as the carbon cycle.

3.3.3 Fossil fuels

Fossil fuels like coal, oil and gas are also derived from biological material, although that material absorbed CO_2 from the atmosphere many millions of years ago.

Making use of these fuels involves burning them, with the oxidation of the carbon to carbon dioxide and the hydrogen to water (vapour).

If they are not captured and stored, these combustion products are typically released to the atmosphere, returning carbon segregated millions of years ago and contributing to a raise in the atmospheric concentrations of carbon dioxide.

3.3.4 The difference between biomass and fossil fuels

The fundamental *difference* between biomass and fossil fuels is in the *time scale*. Biomass releases carbon in the atmosphere while it is growing and returns it when it is burned. If it is managed on a sustainable basis, biomass is harvested as part of a constantly refilled crop and this maintains a closed carbon cycle with no net increase in atmospheric CO_2 levels.[11]

3.3.5 Biomass generation

The autotrophs (or "producers") are organisms capable of self-nourishment by using inorganic materials (CO_2) as a source of nutrients and using photosynthesis or chemosynthesis as a source of energy.[12]

These organisms turn the solar energy in chemical energy through the biochemical action of the chlorophyll contained in the chloroplast of plants; this energy is stored in the intermolecular bonds of the organic material produced, as we can see in the following reaction:

$$6 * CO_2 + 12 * H_2O + photons \rightarrow C_6H_{12}O_6 + 6 * H_2O + 6 * O_2$$

When bonds between molecules of C, H and O are broken by different types of processes (as digestion, combustion, decomposition), the chemical energy accumulated is released.

3.3.6 Environment impact

The influence of biomass on global warming is determined by the time delay between the CO_2 emission for its use and the absorption of that CO_2 with the photosynthesis process.
To minimize this time, it is necessary to replant and to select species that can improve the absorption and the energy efficiency.
The *ideal cultivation* should have as many features as possible from the followings:

- High yield (dry material production per ha)
- Low energy consumption for the production
- Low economic cost
- Low content of pollutants
- Low nutrient requirements
- Low water demand
- Resistance to drought and plagues

3.3.7 Biomass Classification

There are two big categories of biomass: virgin biomass and waste biomass. Virgin biomass can be terrestrial (forest, grasses, energy crops, cultivated crops) or aquatic (algae, water plants).
Waste biomass can be split up in other four groups, such as municipal waste (solid waste, bio-solids/sewage, landfill gas), agricultural solid waste (livestock and manures), forestry residues (bark, leaves, floor residues) and industrial wastes (demolition wood, sawdust, waste oil, fat).
These residues have different *moisture content*, that *sets the most appropriate form of energy conversion*: biomass with high moisture content is more adequate for biological reactions (e.g. fermentation), instead products with low content are more suitable for combustion, gasification and pyrolysis.

3.3.8 Biomass properties

From the viewpoint of power generation, a particular type of biomass is characterized by the following properties:

1. Moisture content (intrinsic and extrinsic)
2. Calorific value
3. Quantity of fixed carbon and volatiles
4. Content of waste and ash
5. Content of alkali metals
6. Relation cellulose/lignin

For the conversion process of dry biomass, the determining factors are the first five; for wet biomass conversion, the critical factors are the first and the last.

Analysis of biomass can be addressed following the philosophy of fossil fuels by determining the chemical energy stored in two forms: carbon and volatiles.

The *volatile content* (VM) is the portion released by heating (950 °C for 7 minutes), while the *fraction of fixed carbon* (FC) is the mass that remains after the heating process, excluding the ash and moisture content.

These parameters determine how easy biomass can be burnt, gasified or oxidized.

4 SOLAR POWER PLANT

In the following chapters there is an overview on the fundamental parts of a solar plant.

4.1 Energy gathering system

Let's see in a more specific way how the solar energy is converted in electricity.

The *photovoltaic effect* is produced when the solar radiation impacts a type of material called *semiconductor*. When light strikes the cell, a certain portion of it is absorbed inside the semiconductor material and this means that the energy of the absorbed light is transferred to the semiconductor. All photovoltaic (PV) cells have one or more electric field that acts to force electrons to flow in a certain direction.

This flow of electrons is a current and by placing metal contacts on the top and bottom of the PV cell, it is possible to draw that current off for external use.

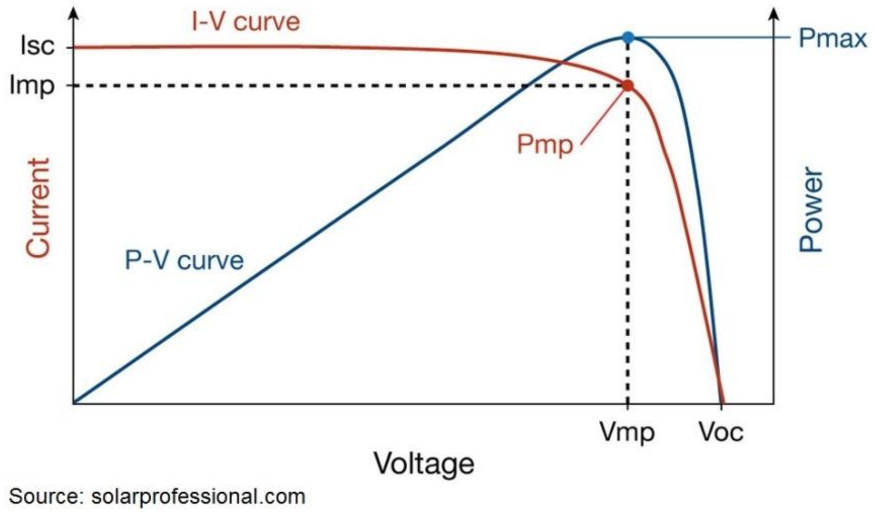
An *individual cell* (with an approximate area of 75 cm^2) sufficiently illuminated can produce a voltage of *0,4 V* and a power of *1 W*.

A solar panel is made of various cells that are connected in series and parallel, so that output voltage and current can be increased at a desired level.

Usually, solar panels are designed for working with 12 V batteries and have between 28 and 40 cells (typically 36). The area of the module can vary from 0,1 to 0,5 m^2, it has two exit contacts (one positive and one negative) and sometimes an intermediate exit where to put a protection diode.

4.1.1 Characteristic I-V curve

The behaviour and the electrical characteristics of a solar module are determined by the voltage-current curve of the panel.



Graph 4. I-V curve

In addition to the peak power of the module, it is necessary to specify other parameters of this characteristic curve, to evaluate the best type of module for every application. These features are defined in some *mean standard conditions*: a incident solar radiation of *1 kW/m^2 and 25 °C* of temperature.

The open circuit voltage V_{OC} is the *maximum voltage* of a solar cell and occurs when the net current through the device is zero. The short circuit current I_{SC} is the *maximum current* that occurs when the voltage across the device is zero.

If a load is connected to the panel, the operating point is determined by a certain current and a certain voltage, that have to be lower than I_{SC} and V_{OC}.

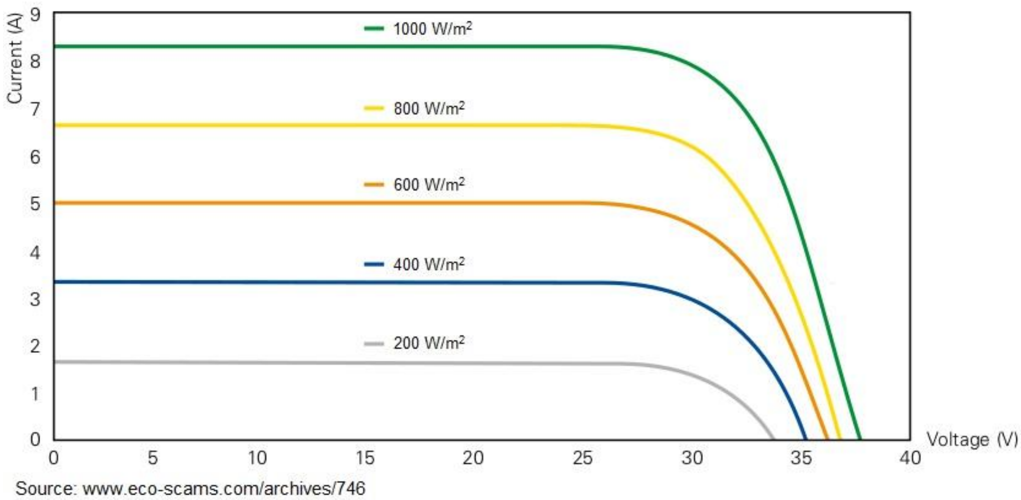
The maximum power point (P_{mp}) of the I-V curve – the product of the maximum power current (I_{mp}) and the maximum power voltage (V_{mp}) – is located at the knee of the curve. At lower voltages, between the knee and the short-circuit current (I_{SC}), the current is less dependent on voltage. At higher voltages, between the knee and open-circuit voltage (V_{OC}), the current drops abruptly with the increasing of the voltage.

The output current of a typical crystalline silicon PV module drops 65% in the upper 10% of its output voltage range.

4.1.2 Parameters that affect solar panels

Once these parameters are known, it is possible to define which parameters affect the solar panels.

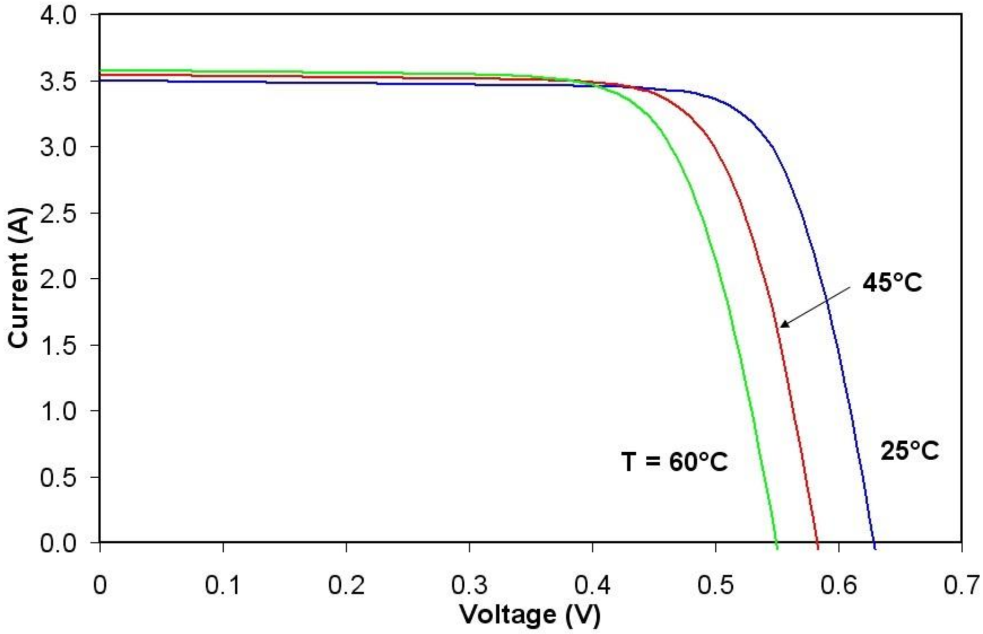
- *Intensity of solar radiation:* as it is possible to see in the Graph 5, the current increases with the radiation, whereas the voltage remains more or less constant. It is very important to know about this effect because radiation values vary during the day as a function of the angle of incidence (the angle at which de Sun's rays strike the Earth's surface) and this affects the position of the solar panels.



Graph 5. I and V variation with solar radiation

The radiation in a sunny day (at the noon) corresponds to 1000 W/m^2, in a cloudy day the radiation can be 200 W/m^2 or less.

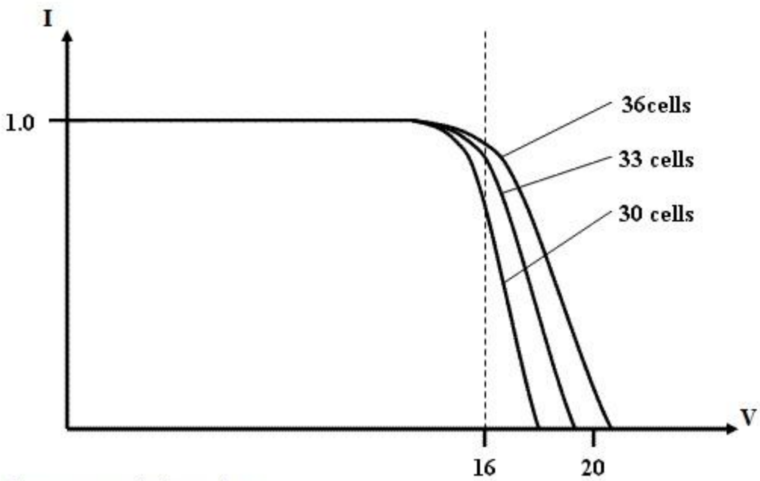
- *Solar cells temperature:* solar exposure heats up cells and this causes variations in the electricity production. A 1000 W/m^2 radiation can heat up the cell at 30 °C above the surrounding air temperature. In the Graph 6 it is possible to see that when temperature rises the voltage decreases, so it is important that panels have a good ventilation or, if it is typical to reach high temperatures, to consider an installation with a greater number of cells.



Source: www.solarpower2day.net/

Graph 6. Solar cell temperature and parameters

- *Number of cells per module:* this number affects mainly the voltage, since every cell produces 0,4 V. The V_{OC} of the module or panel increases in this proportion, as can be seen in the Graph 7.



Source: www.solarfasttrack.com

Graph 7. Influence of the number of cells per module

4.1.3 Typical parameters of the solar panels

A solar panel is designed to work at a nominal voltage V_n, making sure that, at the frequently temperature and light conditions, V_n coincides with V_{mp}.

The main features of the panels that are more often used have the following values:

P_{mp} (peak):	20 – 100 W
Area:	0,1 – 0,5 m^2
I_{SC}:	1,1 – 6 A
V_{OC}:	6,5 – 22,4 V
I_{mp}:	1 – 6 A
V_{mp}:	14,5 – 17 V

Usually manufacturers include other information in the catalogues, such as V-I curves at different levels of radiation, temperature, etc… due to the variation of V_{OC} and I_{SC} with these parameters.

4.2 Energy storage subsystem

In a photovoltaic system it is normal to use a group of batteries to store the electricity generated during solar radiation hours and to use it when the sunshine is low or absent.

It is important to notice that *the reliability of the installation depends greatly on the accumulation system*.

4.2.1 Main features

The main features of this system are:

- *Capacity:* is the quantity of electricity that can be obtained during a total discharge of a full-charge battery. The unit of measurement is the Ampere per hour (Ah) for a certain discharge time, e.g. a 130 Ah-battery can provide 130 A in one hour or 13 A in ten hours. Normally, in the case of batteries for photovoltaic installation, the reference time is 100 hours.
- *Charging voltage:* is the voltage necessary to overcome the resistance of the battery and it is usually 6, 12 or 24 V.
- *Charging efficiency:* is the relation between the energy used for charging the battery and the real energy that is stored. A 100% efficiency means that all the energy used for the charge can be used in the discharge. If charging efficiency is low, it is necessary to use a larger number of panels for the same application.

- *Auto discharge:* is the process in which the accumulator, if not used, tends to discharge itself.
- *Depth of discharge (DOD):* is used to describe how deeply the battery is discharged; e. g. if a 100 Ah-battery is discharged of 20 Ah, its DOD is 20%.

It is possible to have superficial discharges (less than 20%) or deep discharges (till 80%) in daily or annual cycles. The deeper the discharge, the shorter the battery life. It is also important to know that for the majority of battery types, an accumulator that remains completely discharged can be seriously damaged and can lose a large part of its charge capacity.

All these characteristic parameters can vary noticeably with ambient conditions.

4.3 Control subsystem

For a proper functioning of the installation, it is important to put a *control system between panels and batteries*. This system is always required if the panels are not self-controlled.

The controller has to avoid that batteries continue to receive energy from panels when they are fully charged, because if this happens, in the battery will start processes of gasification (hydrolysis of water in hydrogen and oxygen) or heating, that can be very dangerous and, in any case, reduces a lot the battery life.

Some controllers have an alarm with sounds or lights before the disconnection, so the user can adopt appropriate measures, like reducing the consumption.

The latest controllers integrate overcharge and over discharge prevention functions in the same equipment, that also provide battery charging state and battery voltage conditions.

These controllers have to be provided with protection systems like fuses, diodes, etc… to prevent damages at equipments due to excessive punctual charges. Sometimes they can integrate systems that substitute the block diode in avoiding the electricity flow from the battery to the panels, during darkness hours.

Electric features that define a controller are its nominal voltage and its maximum dissipation current.

In the case of self-controlled panels, the controller system it is not required, because they are directly connected to the accumulation subsystem and they automatically adapt their own generated energy when batteries reach a certain charging value.

These systems are suitable for small and remote installations, where the maintenance is difficult and the installation design avoids overcharges.

4.4 Energy conversion subsystem

It is formed by *converters and inverters*, that *adapt the characteristics of generated current to applications demand.*

In some DC applications is not possible to match battery voltage with loads voltage request, so in these cases the best solution is a DC-DC converter.

In other applications, some loads can work with an AC supply, so it is necessary to have an inverter to convert the DC current provided by panels and batteries.

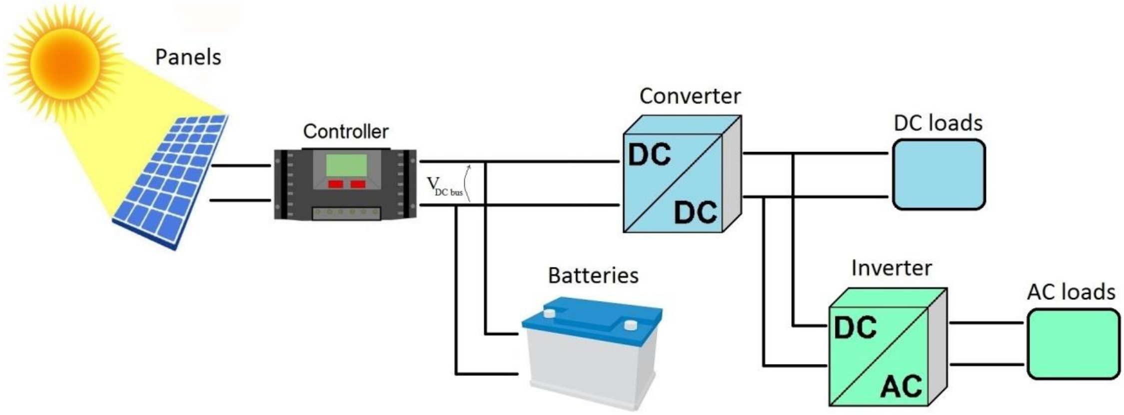


Figure 6. A typical solar installation

4.4.1 Inverter

The main features of an inverter are the inlet voltage, that has to adapt itself at the generator voltage, the maximum power and the efficiency (relation between outlet and inlet inverter power).

Inverter efficiency varies as a function of load power consumption. It is important to know this variation in particular with variable AC loads, to fit the operating point at a specific average value. If the inverter has a inlet voltage of *24 V*, the *efficiency* has to be greater than *70%*, if the inlet voltage is *110 V*, the efficiency has to be larger than *85%*.

Other important aspects about inverters are the followings:

- They must have a high efficiency, if not, the number of panels has to be unnecessary incremented. Not all the inverters meets this characteristic. However, every time is more simple to find equipments that are specifically designed to cover these applications.
- They have to be protected against short-circuits and overloads.
- They have to incorporate automatic re-armament and disconnection when there are no AC loads in use.
- They have to admit instant power requests higher than 200% of their maximum power.

4.5 Project of the photovoltaic power plant

To project a photovoltaic power plant, first of all it is important to look at the radiation of the site where we would like to place the installation. To do this we can use the SolarGIS maps to have an overall view of the site, as it is possible to see in the Figure 7, or the PVGIS (Photovoltaic Geographical Information System) database to know the solar irradiation in a certain city.

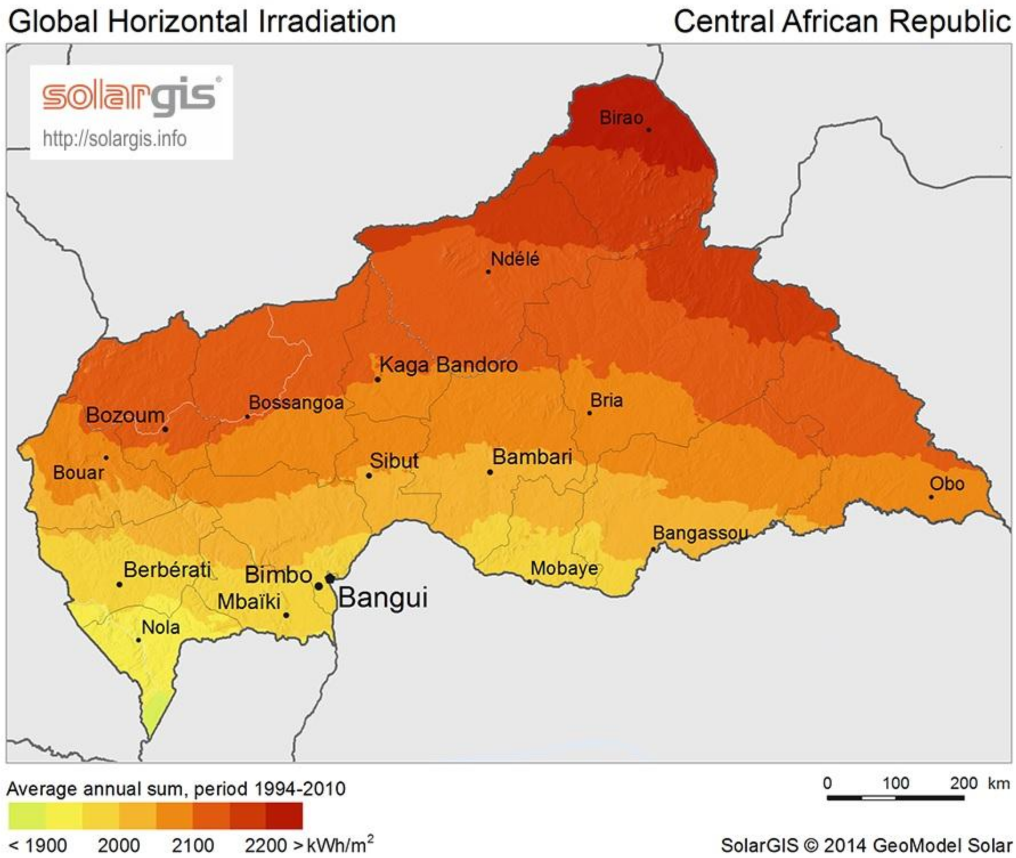


Figure 7. Irradiation in the Central African Republic

4.5.1 PVGIS

The PVGIS is a free online tool that provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. It is a part of the SOLAREC action that contributes to the implementation of renewable energy in the European Union as a sustainable and long-term energy supply by undertaking new S&T developments in fields where harmonization is required and requested by customers.[14]

In the PVGIS homepage let's select the “Interactive access to solar resource and photovoltaic potential”, then click on the Africa icon (for example, as I am going to use this map), as it is shown in the Figure 8.

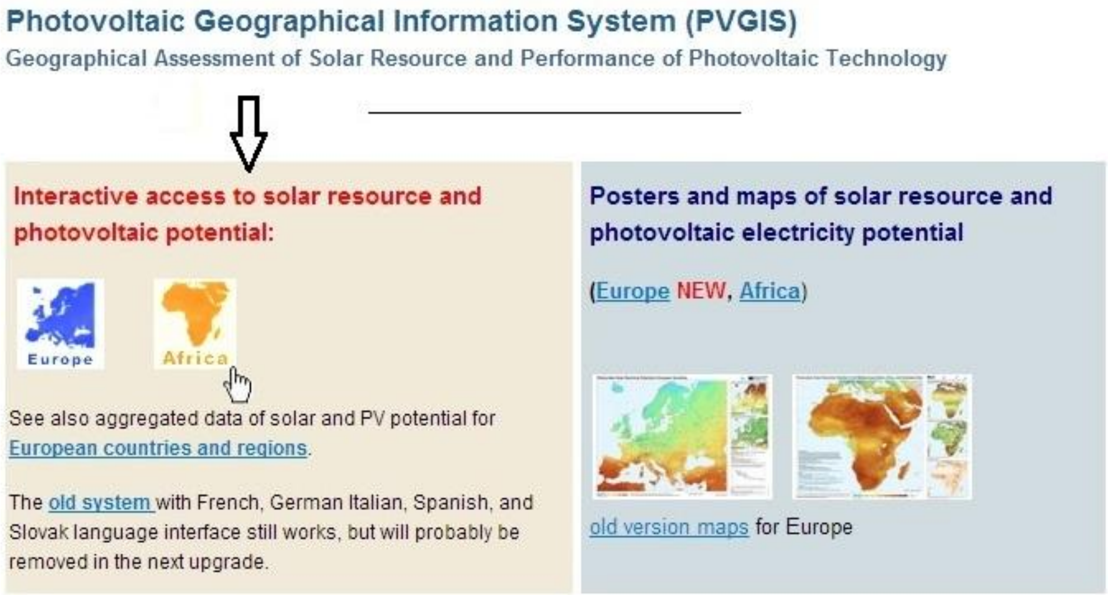


Figure 8. PVGIS homepage

A page will open, with a map and a search bar where it is possible to search the city which one is interested in, by name or coordinates.

There are four tabs, that permit to do different calculations:

- *PV Estimation* allows to estimate the performances of a grid-connected photovoltaic plant
- *Monthly radiation* gives the monthly global irradiation data for the selected position
- *Daily radiation* provides the average solar irradiance
- *Stand-alone PV* estimates the performances of an isolated installation.

In the first three tabs, it is possible to choose between two radiation databases: the PVGIS-Helioclim and the Climate-SAF PVGIS. The first one is the oldest, and for Africa the database is from satellite-based calculations at MINES ParisTech, France, using data from the first generation of the Meteosat series of satellites (data cover the period 1985-2004).

The second one is the newest and data are based on calculations from satellite images performed by CM-SAF. The database represents a total of 12 years of data.

From the first generation of Meteosat satellites (Meteosat 5-7), known as MFG, there are data from 1998 to 2005 and from the second-generation Meteosat satellites (known as MSG) there are data from June 2006 to December 2011.[15]

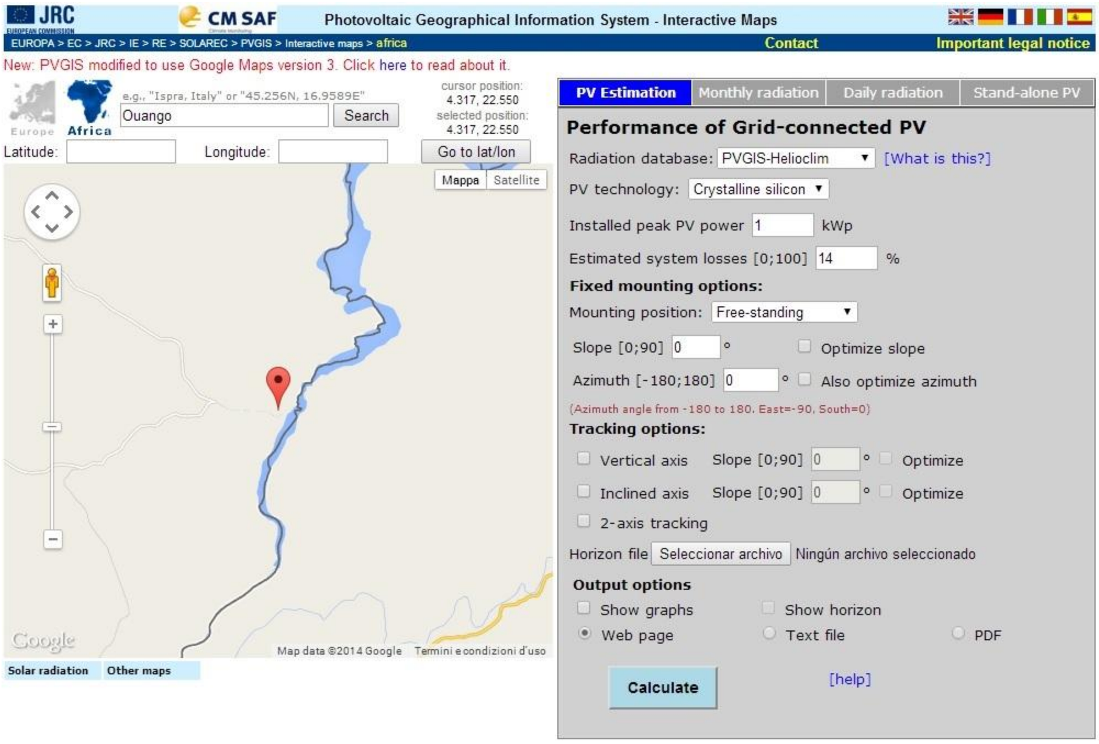


Figure 9. PVGIS search

4.5.2 Monthly radiation in Ouango

For this project I used the Monthly radiation tab, selecting the newest database.

I chose to display data of horizontal irradiation, the irradiation at the optimized angle and the optimal inclination angle for every month.

It is possible to decide the type of output needed (web page, text file or PDF) and whether to show graphs and/or the horizon.

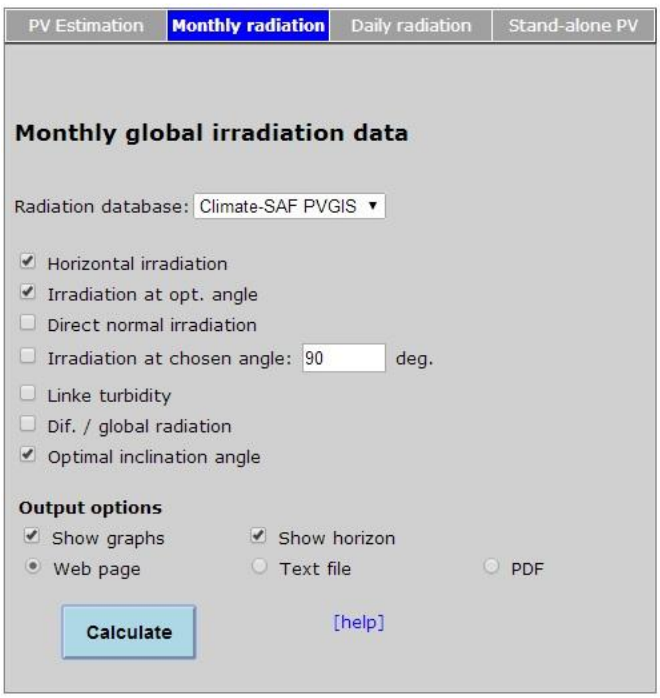


Figure 10. Monthly irradiation calculation

In the output page are shown location information (coordinates and elevation), the optimal inclination angle calculated by the tool, the shadowing and a table with the info we selected to display:

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 4°19'0'' North, 22°33'0'' East, Elevation: 420 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Optimal inclination angle is: 6 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.0 %

Month	H_h	H_{opt}	I_{opt}
Jan	6140	6420	33
Feb	6280	6460	23
Mar	6190	6220	7
Apr	5860	5770	-10
May	5610	5420	-24
Jun	5340	5120	-29
Jul	5280	5090	-27
Aug	5410	5290	-16
Sep	5560	5550	1
Oct	5280	5370	17
Nov	5500	5710	29
Dec	6480	6800	35
Year	5740	5770	6

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

I_{opt}: Optimal inclination (deg.)

Table 4. Monthly radiation in Ouango

The corresponding graphs are in the Annex 8.3.

4.5.3 Solar cells required

As it is possible to see in the Table 4, the irradiation varies every month.

It is necessary to identify the worst month of the year, doing a balance between energy received and consumption, to calculate the number of solar cells needed.

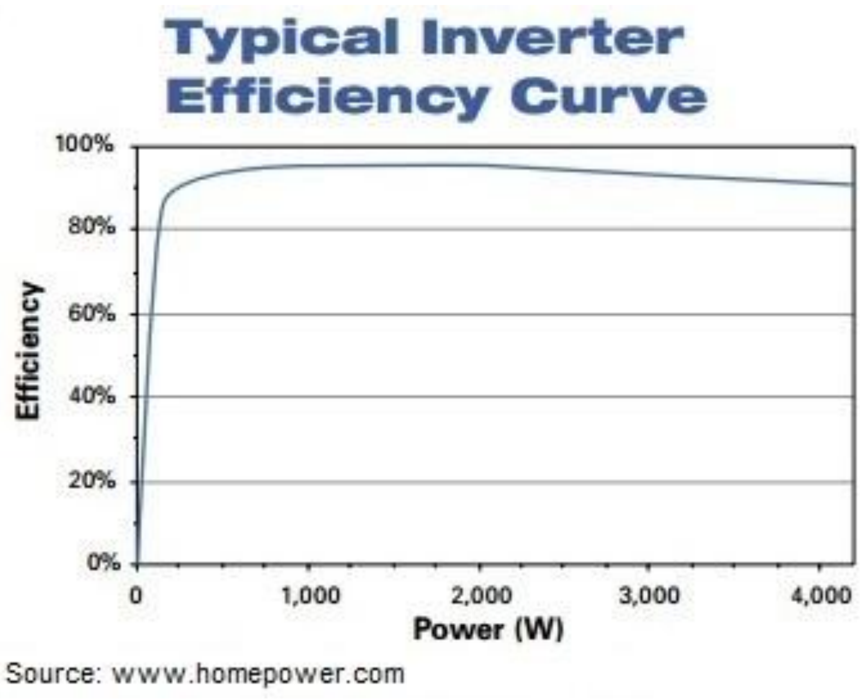
First of all, I calculated the monthly consumptions multiplying the daily total consumption (see Annex 8.2) for the days that has every month. Then I divided the result by the voltage of the DC bus – trying different voltages (12, 24, 48 V) – and the inverter efficiency, since I have only AC loads. In this way I obtained the monthly consumption in Ah/month.

$$Monthly\ consumption\ in\ DC = \frac{\sum[(P_n * h_d) * n_{dm}]}{V_{DC\ bus} * \eta_{inv}}$$

Where:

- P_n is the nominal power of every load of the installation
- h_d is the number of hours of utilization
- n_{dm} is the number of the days in the month studied
- $V_{DC\ bus}$ is the DC voltage of the batteries
- η_{inv} is the inverter efficiency

I supposed the inverter efficiency equal to 0,9 because this is a typical value.



Graph 8. Inverter efficiency curve

I created a table with monthly consumptions and irradiation values (in kWh/m^2).

The ratio between these two quantities is a coefficient that relates energy needs with the available solar irradiation. The value increases in those months with high energy request and low irradiation.

$$C_{md} = \frac{Monthly\ consumption\ in\ DC}{Monthly\ irradiation}$$

The table that follows is an extract of the table in the Annex 8.4, where the highlighted month, July, is the worst of the year.

	J	F	M	A	M	J	J
Irradiation	199,02	180,88	192,82	173,10	168,02	153,60	157,79
Cons 12 V	3.093.596	2.794.216	3.093.596	2.993.802	3.093.596	2.993.802	3.093.596
Cons 24 V	1.546.798	1.397.108	1.546.798	1.496.901	1.546.798	1.496.901	1.546.798
Cons 48 V	773.399	698.554	773.399	748.451	773.399	748.451	773.399
Coef 12 V	15.544,15	15.447,90	16.043,96	17.295,22	18.412,07	19.490,90	19.605,78
Coef 24 V	7.772,07	7.723,95	8.021,98	8.647,61	9.206,03	9.745,45	9.802,89
Coef 48 V	3.886,04	3.861,97	4.010,99	4.323,80	4.603,02	4.872,73	4.901,44

Table 5. Extract of the table in Annex 8.4

The value of this coefficient, divided by I_{mp}, that is the peak current of a module at 1000 W/m^2, is used to calculate the number of parallel lines needed N_{pl}.

$$N_{pl} = \frac{C_{md}}{I_{mp}}$$

The number of modules in series is calculated divided the input voltage of the controller by the open circuit voltage of the module:

$$N_{ms} = \frac{V_{in\ DC}}{V_{OC}}$$

For this project I decided to use the Panasonic VBHN240SE10 module and the Schneider Electric Xantrex XW MPPT 80 600 solar charge controller, whose fact sheets are in the Annex 8.5 and 8.6 respectively. In the following figures there are the extracts of the module and controller main parameters.

Electrical data (at STC)	VBHN240SE10	VBHN235SE10
Max. power (Pmax) [W]	240	235
Max. power voltage (Vmp) [V]	43.7	43.0
Max. power current (Imp) [A]	5.51	5.48
Open circuit voltage (Voc) [V]	52.4	51.8
Short circuit current (Isc) [A]	5.85	5.84
Max. over current rating [A]	15	
Production tolerance power [%]	+10/-5*	
Max. system voltage [V]	1000	

Note: Standard Test Conditions: Air mass 1.5; Irradiance = 1000W/m^2; cell temp. 25°C
* All modules measured by Panasonic facility have output with positive tolerance.

Figure 11. Panasonic module fact sheet extract

Device short name	MPPT 80 600
Electrical specifications	
Nominal battery voltage	24 and 48 V (Default is 48 V)
Max. PV array voltage (operating)	195 to 550 V
Max. PV array open circuit voltage	600 V including temperature correction factor
Battery voltage operating range	16 to 67 VDC
Array short-circuit current	35 A (28 A @ STC)
Max. charge current	80 A
Max. and min. wire size in conduit	#6 AWG to #14 AWG (13.5 to 2.5 mm^2)
Max. output power	2560 W (nominal 24 V), 4800 W (nominal 48 V)

Figure 12. Xantrex controller datasheet extract

In this case the number of modules in series is:

$$N_{ms} = \frac{V_{in\,DC}}{V_{OC}} = \frac{550}{52{,}4} = 10{,}5 \rightarrow 10\ modules\ in\ series$$

So, the input voltage of the controller will be at most 524 V.

The controller has a nominal output power of 48 V, thus, in the calculation of the parallel lines I used the coefficient calculated at 48 V.

$$N_{pl} = \frac{C_{md}}{I_{mp}} = \frac{4901{,}44}{5{,}51} = 889{,}55 \rightarrow 890\ parallel\ lines$$

This number has to be reduced due to the hybrid nature of the installation, so as a first assumption I decided to use only 50 modules. Therefore, the peak power of the photovoltaic plant is 12 kWp.

4.5.4 Controllers

Every controller has a maximum output power of 4800 W with 48 V-batteries, so the optimal set is two strings in parallel, with ten panels each one.

In this way I respect power, voltage and current thresholds (see Figure 12):

- $P_{regulator} = P_{module} * N_{ms} * N_{strings} = 240 * 10 * 2 = 4800\ W\ \leq 4800\ W$
- $V_{regulator} = V_{OC} * N_{ms} = 52{,}4 * 10 = 524\ V\ \leq 550\ V$
- $I_{SC_{string}} = I_{SC_{module}} = 5{,}85\ A\ \leq 35\ A$
- $I_{regulator} = I_{SC} * N_{strigs} = 5{,}85 * 2 = 11{,}7\ A\ \leq 80\ A$

To obtain the desired peak power I need three controllers, so the last one will have a maximum output power of 2400 W and the current of the controller will be equal to the string one.

4.5.5 Inverters

I decided to use the inverter Conext XW X6048 (see Annex 8.7) that has 6 kVA of power. Creating a tree-phase distribution line requires two inverters per phase and this means that I need to use six inverters. The total useful power is 36 kVA, so in the future it is possible to expand the system.

4.5.6 Batteries

Inverters support batteries with capacities from 100 Ah to 2000 Ah and this has to take into account during the choice of batteries dimensions. The number of accumulators has to be decided after the project of the biomass plant.

4.5.7 Maintenance

The photovoltaic plant needs some simple and periodic maintenance for keeping its best performances, that basically consist in the following tips.

Period	**Panels**	**Batteries**	**Cables**
Daily		– checking that the charging indicator is alight in sunny weather – verifying system status of battery charge; corrective actions in case of having for two weeks less than 50% of charge	
Monthly	– cleaning the front side of the modules – checking that there is no shade over the panels		
Every six months		– checking the electrolyte level and eventually fill it – charging till full capacity reserve batteries that are not connected to the grid	
Annually			– checking the state of the cables and tightening of all the contacts

5 BIOMASS POWER PLANT

5.1 Area of study

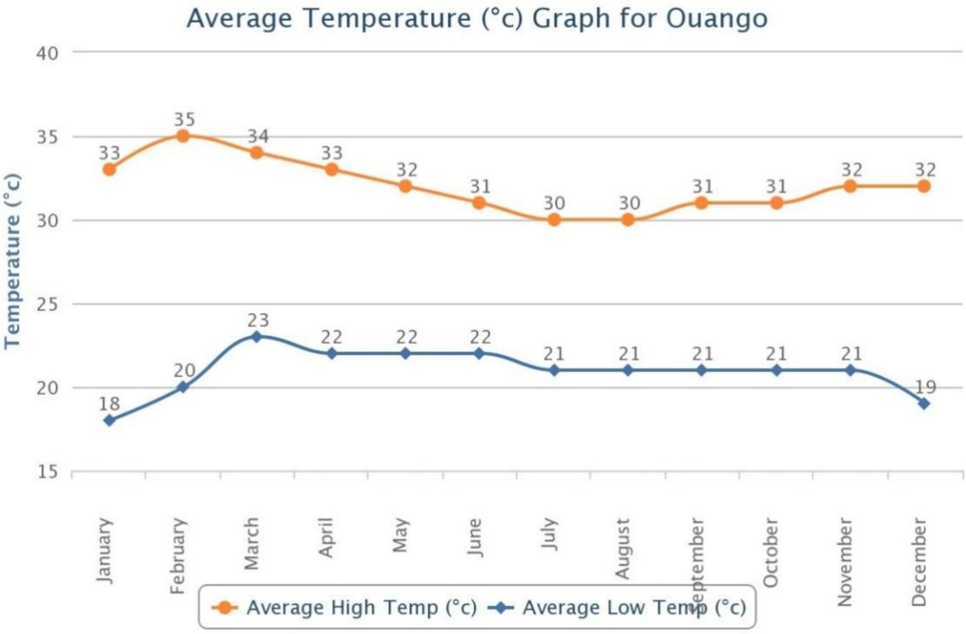
I identified and area useful for the biomass production useful for the power plant, that it is about 1100 ha wide.

Source: Google Earth

Figure 13. Biomass area

Excluding the urban area (approximately 66 ha), and the area covered by water (about 70 ha), the green area is more or less 964 ha.

The climate of this zone is tropical, with a rainfall that is at least 1600 mm and a forest-type vegetation, with more than six rainy months[16]; temperatures stay between 18 °C and 35 °C.



Source: www.worldweatheronline.com

Graph 9. Temperatures Ouango

5.2 Residues

I considered two types of residues in my research: those proceeding from agriculture and the ones from pruning and logging. It was quite difficult to identify the types of the residues, due to the lack of information in this region, but using various scientific papers and different websites I could make some hypotheses.

5.2.1 FAO Crop Calendar

The FAO Crop Calendar was very useful to spot typical cultivations, to determine planting and harvesting periods and to know the availability of the residues during the year.

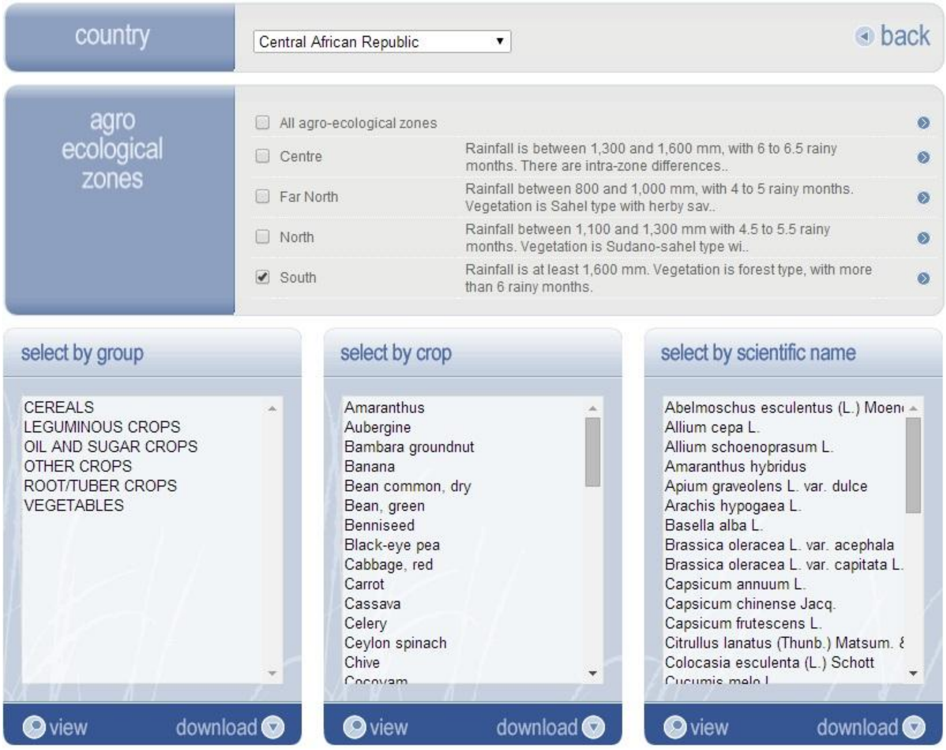
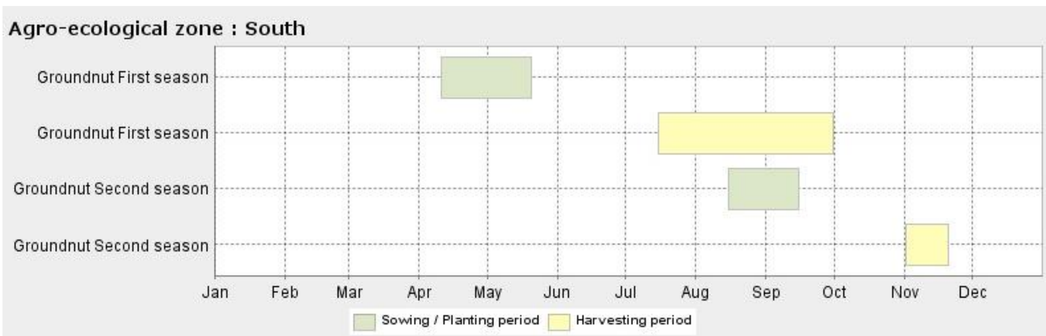


Figure 14. FAO Crop Calendar

Once selected the type of cultivation by group, crop or scientific name, it appears a visual calendar, like the following one:



Graph 10. Example of a planting and harvesting calendar

Considering all the available crops in this zone, I created a global harvesting calendar (see Annex 8.8).

5.2.2 Phyllis2

To characterize the biomass I used mainly Phyllis2, a database for biomass and waste, that allows to obtain analysis data of individual biomass or waste materials, searching materials by name or browsing them by category.

Source: www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#

Figure 15. Homepage Phyllis2 database

The more interesting parameters to consider are moisture and ash content and also the gross energy value or higher heating value (HHV).

In the following table it is possible to see an extract of data provided by Phyllis2.

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▾ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		5.93							
Volatile matter	wt%		75.30	80.05						
Fixed carbon	wt%		18.77	19.95					Calculated	
▾ Calorific Values										
Net calorific value (LHV)	MJ/kg		16.24	17.26						
Gross calorific value (HHV)	MJ/kg		17.46	18.56						
HHV_{Milne}	MJ/kg		16.47	17.50					Calculated	

Table 6. Phyllis2 data extract (example)

Values are given in three ways:

- ar, as received (the material is in its original form, including ash and moisture)
- dry, dry material (including ash)
- daf, dry and ash free material

For my calculations I used the second column.

5.2.3 Feedipedia

When the Phyllis2 information was incomplete or absent, I used Feedipedia, that is an online encyclopaedia of animal feeds. It provides information on nature, occurrence, chemical composition, nutritional value and safe use of nearly 1400 worldwide livestock feeds.[17]

5.2.4 Quantity coefficients

For quantifying the biomass it is helpful the use of some coefficients:

- CR_S **(**coefficient of surface generation) expressed in t_{waste}/ha
- CR_P (coefficient of generation as a function of the production) expressed in t_{waste}/t_{plant}

5.2.5 Choice of the most important residues

After the research of the various types of residues, I had to choose those that can be useful for the biomass plant.

Decisions were made considering some aspects:

- The ash percentage has to be less than 5-10%, to avoid some problems like the “slag” formation in the hottest zone of the combustion and the dirt in the gas produced
- The moisture content has to be more or less 30 or 40%, for reducing dry-times (usually the feedstock must have a moisture content of about 15%)
- The HHV has to stay around 16-19 MJ/kg
- The residues have to be available during the year in a good quantity.

Comparing the crop calendar and the characteristics of the resources using Phyllis2 or Feedipedia, I identified the right resources for the power plant and I resumed the results in two tables, one for agricultural residues and the other one for wood residues (see tables 7 and 8).

Agricultural residues	moisture	ash	HHV	yield	waste	area	total
	%	%	MJ/kg	t/ha	t/ha	ha	t
bean straw	12,00	8,90	17,90	6,0	9,00	1,34	12,06
cassava residues	11,70	5,05	17,85	6,0	1,80	50,01	90,02
corn stalks	8,02	7,02	16,94	3,0	6,00	19,68	118,08
groundnut shells	8,20	3,90	18,30	1,6	0,40	18,97	7,59
agricultural (avg)	9,98	6,22	17,75	4,2	4,30	90,00	227,75

Table 7. Agricultural residues

Forestry residues	moisture	ash	HHV	yield	waste	area	total
	%	%	MJ/kg	t/ha	t/ha	ha	t
african oak wood	5,30	0,32	18,16		0,75		
bamboo wood	15,00	3,91	18,49		0,75		
casuarina wood	46,00	1,83	18,77		0,75		
cedar bark	37,50	5,10	20,03		0,75		
leucaena wood	30,00	1,53	19,07		0,75		
mango wood	42,86	2,98	19,17		0,75		
wood (average)	29,44	2,61	18,95	60,0	4,50	870,00	3.915,00

Table 8. Forestry residues

5.2.6 Considerations about the research

The following ones are the hypotheses that I made for every type of waste (in brackets the reference Annex):

- Agricultural residues
  - *Bean straw* (Annex 8.9.1): I took moisture content (that is the hundred's complement of the dry matter), ash content and HHV from the Feedipedia site; the yield is an average value of the likely yields and the CR_P of the straw is taken as a mean value of the coefficient from some cereals.
  - *Cassava residues* (Annex 8.9.2): I decided to consider two types of residues (peels and pomace) and I took the mean of the values of moisture, ash and HHV from the Feedipedia site; the yield can be found in the FAO crop calendar and the CR_P coefficient is calculated as an average value between the weight percentage of the peels and the one of the pomace.
  - *Corn stalks* (Annex 8.9.3): I took moisture content, ash content and HHV_{dry} from the Phyillis2 database, the yield from the FAO Crop Calendar and the CR_P from the table of the waste generation coefficients.
  - *Groundnut shells* (Annex 8.9.4): I took moisture content, ash content and HHV from the Feedipedia site; the yield is taken from the FAOSTAT site and the CR_P from an article of a project.

Regarding areas, I made a proportion between an area at Ouango that can be used for agriculture (I suppose that area equal to 90 ha) and data about harvesting areas in the whole country, from the FAO site.

In the Annex 8.10 it is possible to see the harvesting areas of the crops (for beans I used data from the Republic of Congo, that has a similar weather).

I create a table to obtain for every crop a proportional area.

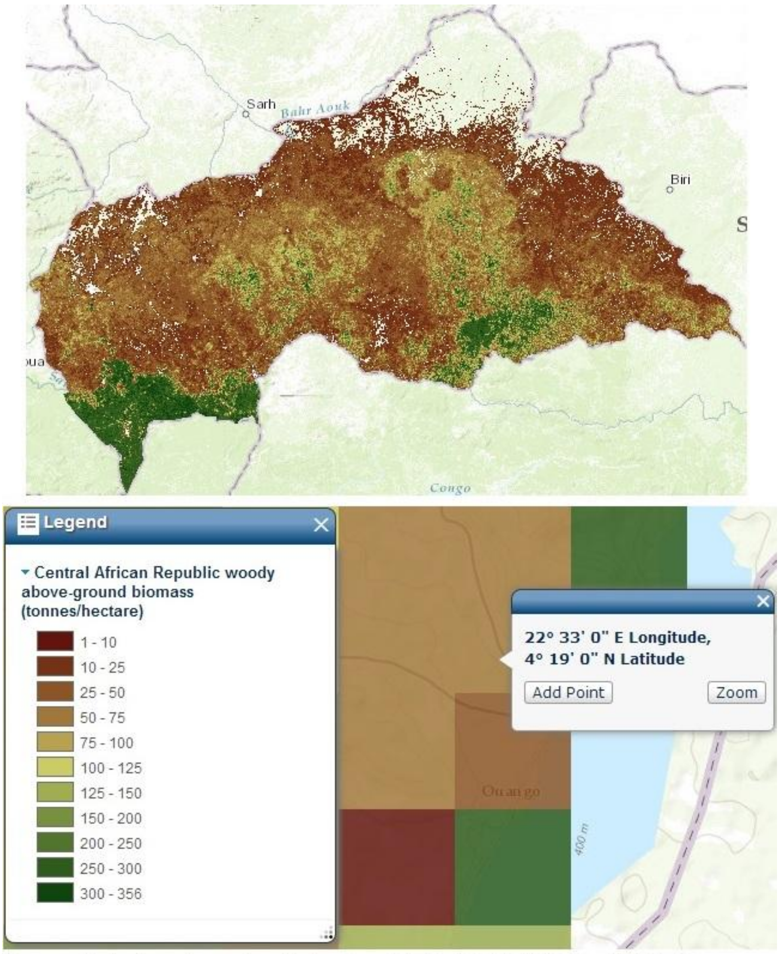
What	ha harvesting CAR	percentage	ha Ouango
Bean	6.500,00	1%	1,34
Cassava	243.219,00	56%	50,01
Groundnuts	95.715,00	22%	19,68
Maize	92.261,00	21%	18,97
	437.695,00	100,00%	90,00

Table 9. Crops area calculation

- Wood residues
  - *African oak wood* (Annex 8.11.1): I took moisture content, ash content and HHV_{dry} from the Phyillis2 database
  - *Bamboo wood* (Annex 8.11.2): I took ash content and HHV_{dry} from the Phyillis2 database and the moisture content from a scientific article
  - *Casuarina wood* (Annex 8.11.3): I took ash content and HHV_{dry} from the Phyillis2 database and the moisture content from a botanical article
  - *Cedar bark* (Annex 8.11.4): I took ash content and HHV_{dry} from the Phyillis2 database and the moisture content from a scientific article
  - *Leucaena wood* (Annex 8.11.5): I took ash content and HHV_{dry} from the Phyillis2 database ad the moisture content from a botanical article
  - *Mango wood* (Annex 8.11.6): I took ash content and HHV_{dry} from the Phyillis2 database and the moisture content from a scientific article

For the forestry residues I could not find the information for every species, so I had to use a dataset for the woody above-ground biomass.

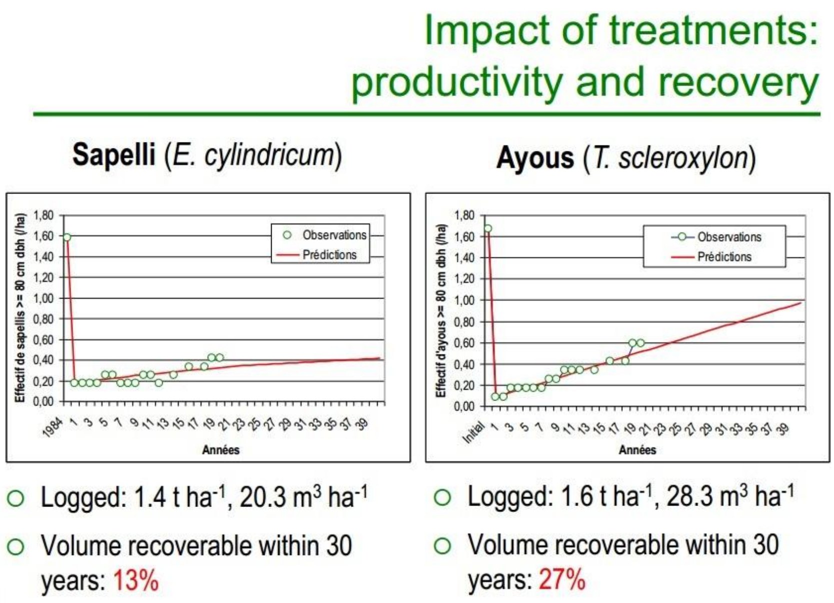
As it is possible to observe in the Figure 16, in Ouango the rate of biomass is between 50 an 75 t/ha; in my study I assumed a value equal to 60 t/ha (see Table 8).



Source: databasin.org/maps/new#datasets=cdc9a36a1ef440efbf2ab3ae01038a53

Figure 16. Biomass rate in Central African Republic and Ouango

To calculate the residues I referred to a research about the impact of logging in Central African Republic, taking the values as a starting point. In the following graph it is possible to see an extract.



Source: www.cifor.org/forenet/publications/pdf_files/SGFleury-LoggingImpact.pdf

Figure 17. Logging impact

As it is possible to see, these logging rates cause some problems in the volume recovery time, so I decided to use for every tree a reduced CR_P that is half of the mean value (0,75 t/ha). In this way I can preserve the environment and avoid deforestation problems.

5.3 Project of the plant

5.3.1 Biomass distribution during the year

After defining the biomass type useful for the power plant, it is necessary to do some calculations about the monthly availability of the resources.

I took the harvesting calendar (see Annex 8.8) of the crops that I selected, for every crop I calculated the length of the harvesting period and the percentage of the crop harvesting per day; for wood I considered a constant harvesting rate during the year.

I assumed to dry all residues till obtaining a maximum moisture value of the 10% and I calculated the tons after the drying, then I multiplied the percentage for the tonnes of each residue and I put all the results in a table, that it is possible to see in the Annex 8.12.1.

In the following table it is possible to see the biomass quantity before and after the drying.

	$moisture_{before}$	$moisture_{after}$	t_{before}	t_{after}
	%	%		
bean straw	12,00	10,00	12,06	11,79
cassava peel	11,70	10,00	90,02	88,32
corn stalks	8,02	8,02	118,08	118,08
groundnut shells	8,20	8,20	7,59	7,59
WOOD	29,44	10,00	3.915,00	3.069,36
			4.142,75	3.295,14

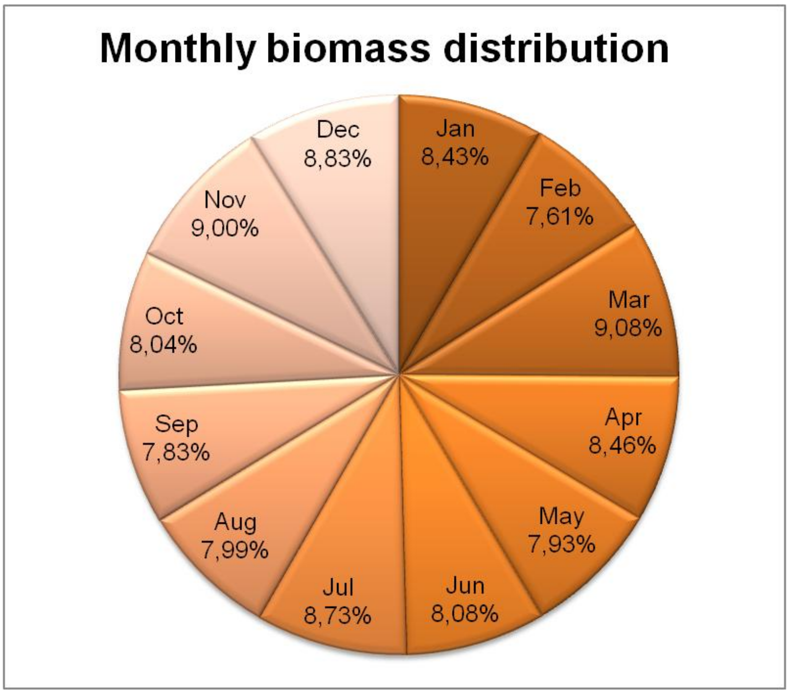
Table 10. Tonnes before and after drying

The calculation of the final weight of the residues is made using a dry matter balance:

$$t_{before}\left(1-\%moisture_{before}\right)=t_{after}(1-\%moisture_{after})$$

I also made some graphs to show the monthly distribution of crops and wood and the biomass availability subdivided between crops and wood. These graphs are shown in the Annexes 8.12.2, 8.12.3 and 8.12.4.

The Graph 11 shows the percentage distribution of the biomass during the year, that is almost constant.



Graph 11. Monthly biomass percentage distribution

5.3.2 Energy provided by biomass

The values of the HHV in the tables 7 and 8 do not take into account the moisture, so they have to be converted in the HHV on wet basis:

$$HHV_{wet} = HHV_{dry}(1 - \frac{m}{100})$$

where "m" is the moisture percentage.

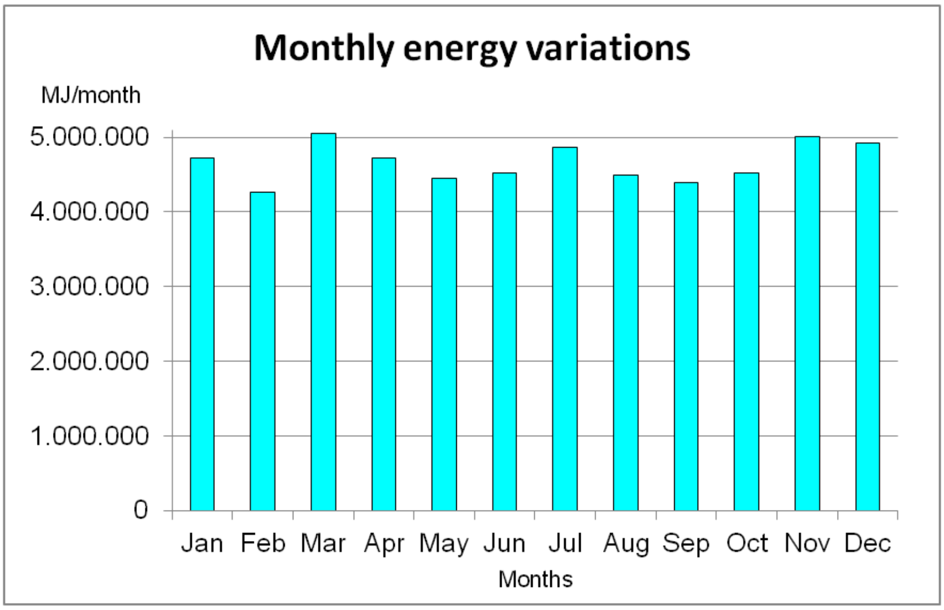
In the following table it is possible to see the conversion from dry basis, in MJ/kg, to wet basis, in MJ/t.

	$moisture_{before}$	$moisture_{after}$	HHV_{dry}	HHV_{wet}
	%	%	MJ/kg	MJ/t
bean straw	12,00	10,00	17,90	16.110,00
cassava peel	11,70	10,00	17,85	16.065,00
corn stalks	8,02	8,02	16,94	15.581,41
groundnut shells	8,20	8,20	18,30	16.799,40
WOOD	29,44	10,00	18,95	17.055,00

Table 11. HHV on wet basis

I multiplied these values for the corresponding tonnes values of the Table 10 (t_{after}), then I made a sum for every month and I obtained the MJ/month and the average tonnes/day of every month. This table is reported in the Annex 8.13.

The following graph displays the results of the table.



Graph 12. Monthly energy variations

5.3.3 Average values

I resume some average values in a table to have an overview on the biomass resources. Moisture percentages and HHV are weighted average values, in this way the values are closest to the reality.

	average values
t/month	274,59
t/day	9,03
% $moisture_{before}$	28,35
% $moisturea_{after}$	9,92
HHV_{dry} (MJ/t)	18.864,56
HHV_{wet} (MJ/t)	16.971,69
MJ/month	4.660.340,64

Table 12. Average values

5.4 Gasification

5.4.1 Definition

The gasification of a solid is a thermochemical process that involves the thermal decomposition of organic matter and the action of a gas, which reacts mainly with the carbonaceous residue from the thermal decomposition.

In commercial gasifiers the leavening agent is usually air and the heating value of the gas obtained is 4000-5500 kJ/Nm^3.

The gas obtained is far from meeting the specifications required by the turbines or engines, both the alkali metal content, particles and tars can damage machinery, so it is necessary cleaning and gas conditioning.

5.4.2 Thermochemical process

The gasification process is composed by the following stages:

- *Drying:* if needed, the feedstock is dried before the gasification process and the moisture extracted is used in following chemical reactions (T <200 °C).
- *Pyrolysis:* next, organic materials are thermo-chemically decomposed at elevated temperatures, in the absence of oxygen, releasing volatiles and producing char.
  This prepares the chemically changed feedstock for combustion. (T = 200-500 °C).
- *Combustion:* a controlled burn, using small amounts of air, allows the volatiles and the char to react with the oxygen to form mainly carbon dioxide, water and trace amounts of carbon monoxide. The heat created in this process is used in the gasification process. The main difference between gasification and combustion is the concentration of O_2.
- *Gasification:* in this step, the char reacts with the carbon dioxide and the steam produced in previous steps to form carbon monoxide and hydrogen.
- *Equilibrium:* a chemical reaction known as the “water gas shift reaction” ($CO+H_2O=CO_2+H_2$) helps to balance carbon monoxide, steam, carbon dioxide and hydrogen in the gasifier, creating a chemical equilibrium during the final step of the process.[18]

5.4.3 Types of gasifiers

There are basically four different types of gasifiers:

- *“Up Draft” fixed bed* (see Annex 8.14.1). It is a tested, simple and low cost technology; it is able to support biomass with high moisture and high ash content.
  It requires a biomass supply of 500-2000 kg/h and the output syngas has a temperature of 100-300 °C.
- *“Down Draft” fixed bed* (see Annex 8.14.2). It is a tested, simple and low cost technology; unlike the “Up Draft”, needs a biomass supply with a low moisture (less than 20%) and the syngas exits at high temperature, so it requires a heat exchanger. It requires a biomass supply of 10-800 kg/h and the output syngas has a temperature of 600-800 °C.

- *Bubbling Fluidized Bed* (see Annex 8.14.3). It is an innovative technology with high cost and high capacity (kg solid/m^3 reactor) and complexity. The temperature is uniform throughout the reactor and the produced syngas; it accepts particles of many sizes, including fines, with a moisture up to 50%. The biomass supply has to be higher than 600 kg/h.
- *Circulating Fluidized Bed* (see Annex 8.14.4). It is an innovative technology with high cost and high capacity (kg solid/m^3 reactor) and very high complexity (more than BFB). In this gasifier syngas and particle drag have an high speed, there are also temperature gradients. The CFB accepts particles of various sizes, including fines, with a moisture up to 50%. It requires a biomass supply of more than 5000 kg/h.

5.4.4 Syngas

Syngas is an abbreviation for synthesis gas, which is a mixture of carbon monoxide, carbon dioxide, and hydrogen. The syngas is produced by gasification of a fuel that contains carbon, to a gaseous product that has some heating value.

It is a gas that can be used to synthesize other chemicals, hence the name synthesis gas. Syngas is an intermediate in generating synthetic natural gas and to create ammonia or methanol and is also an intermediate in creating synthetic petroleum to use as a lubricant or fuel. Another use of this syngas is as a fuel to manufacture steam or electricity.

This gas has 50% of the energy density of natural gas, it cannot be burnt directly, but is used as a fuel source. In gasification reactions, carbon combines with water or oxygen to give rise to carbon dioxide, carbon monoxide and hydrogen.

The general raw materials used for gasification are coal, petroleum based materials or other materials that would be rejected as waste. The feedstock of these material is prepared and then is inserted into the gasifier in dry or slurry form, where reacts in an oxygen starved environment with steam at elevated pressure and temperature. The resultant syngas is composed of 85% carbon monoxide and hydrogen and small amounts of methane and carbon dioxide.

If the syngas is employed to generate electricity, it is generally used as a fuel in an IGCC (integrated gasification combine cycle) power generation configuration.

There are commercially available technologies to process syngas to generate industrial gases, fertilizers, chemicals, fuels and other products.[19]

5.5 The BioMax® Modular Bioenergy System

For the conversion of biomass in energy I decided to use the BioMax® Modular Bioenergy System produced by Community Power corporation (see Annex 8.15) that has a peak power of 100 kW.

5.5.1 Biomass to energy

The BioMax® is a modular and fully automated renewable energy system that converts biomass to syngas; the core of the system is the gas production module.

The primary function of this system is to convert the energy stored in biomass material into syngas (~17% hydrogen, 20% carbon monoxide, 8% carbon dioxide, 2% methane and the balance nitrogen).

The photosynthetic energy stored in the biomass feedstock is converted to other forms of energy with a thermochemical reaction in a downdraft gasifier.

The system uses a shell and tube heat exchanger to cool the gas stream in the gas production module. Waste heat from the gas cooling is used to dry feedstock.

The char/ash particles are removed by self-cleaning filters and automatically stored in collection bags and can be used as a soil amendment (depending on the feedstock).

The following figure represents the core processes of the system.

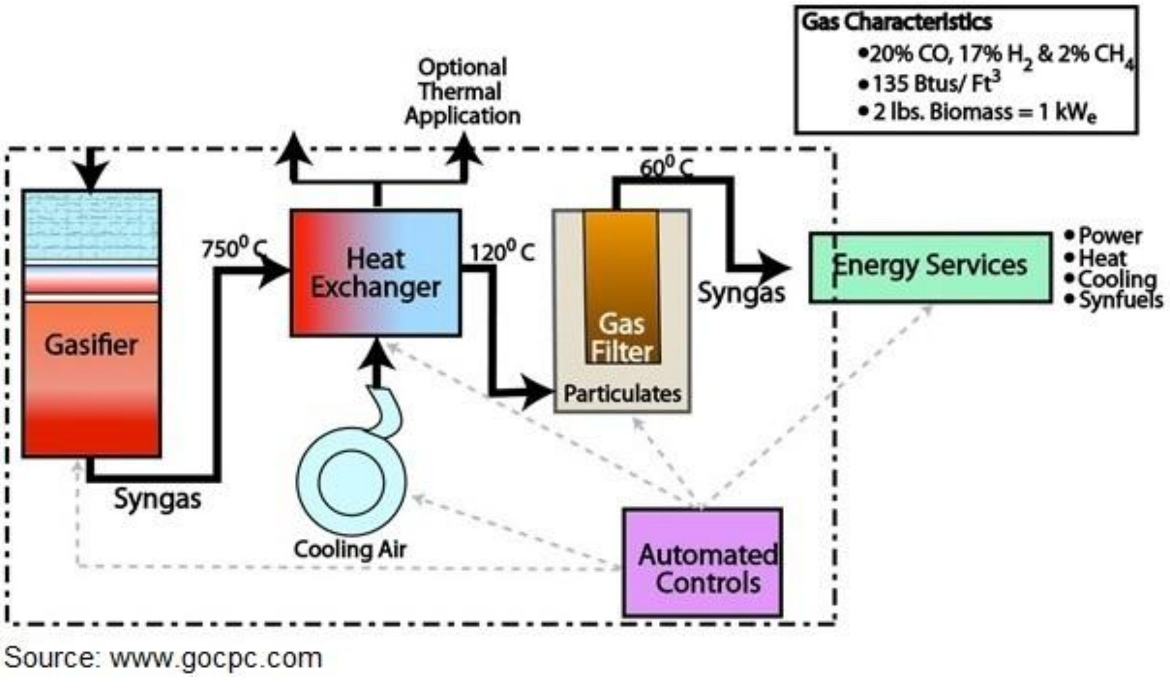


Figure 18. Gasification Module schematic

5.5.2 Electricity generation

The syngas is converted to electricity as follows:

- *Internal combustion engine:* gas is ignited in the cylinders and the crankshaft spins an electrical generator.
- *Stirling engine:* gas is combusted in a radiant burner that heats the head and transfers heat to an internal working fluid for conversion to electricity via a linear alternator.
- *Fuel cell:* gas constituents are chemically combined in the fuel cell to create electricity.

5.5.3 Waste products and emissions

The BioMax® uses a dry system to cool and remove particulates from the syngas; wet scrubbers are not used in the process, eliminating the need to dispose of large quantities of contaminated water.

Solids are automatically collected and are processed as follows:

- Ash and char are automatically extracted and stored in drums for easy handling and typically can be dispersed in the soil as a fertilizer.
- Expended dry fabric filters are stored and periodically combusted

The char/ash effluent has been independently tested and found to be non-hazardous.

5.5.4 Operating efficiency

Electrical conversion efficiencies vary by the choice of prime mover:

- Internal combustion engines: up to 40% (diesels will achieve higher efficiency than spark ignited engines)
- Stirling engine: up to 25%
- Fuel cells: up to 45%

When the systems' heat can be used in a combined heat and power mode, the overall system efficiency can be up to 80 %.

5.5.5 Maintenance requirements

The BioMax® is designed to operate 24x7, with a daily maintenance of about half an hour per day. Other routine maintenance for the BioMax® is the standard engine maintenance (filters, oil changes, etc.) performed monthly on the engine-generators.

For the gasifier, the char/ash is automatically removed from the system to one or more drums. Removal of this non-toxic char/ash is part of the daily maintenance activities.

The gasifier is also periodically inspected and cleaned. Occasionally, a bag filter has to be replaced.[20]

5.5.6 Other equipment

For the correct feeding of the biomass plant is required a wood chipper with chips dimension between 9,525 and 41,275 mm. I chose an electrical one (see Annex 8.16) that allows material with a maximum diameter of 200 m and has production rates from 10 up to 15 m^3 chips per hour.

6 HYBRID POWER PLANT VS. DIESEL GENERATOR POWER PLANT

Combining solar and biomass power, the result is a hybrid power plant, that has to be modelled, analyzed and compared with a traditional diesel generator power plant.

To do this, a very useful tool is HOMER.

In the following paragraphs I am going to develop the following points:

- Brief description of the tool
- Configuration of the hybrid power plant using HOMER and simulations
- Configuration of the diesel generator power plant and simulations
- Comparison of these two power plants

6.1 HOMER description

HOMER is a micropower optimization model used to design both off-grid and grid-connected power systems for a variety of applications. Its optimization and sensitivity analysis algorithms allow to evaluate the economic and technical feasibility of lots of technology options and to account for variations in technology costs and energy resource availability. Originally designed at the National Renewable Energy Laboratory for the village power program, HOMER is now licensed to HOMER Energy.

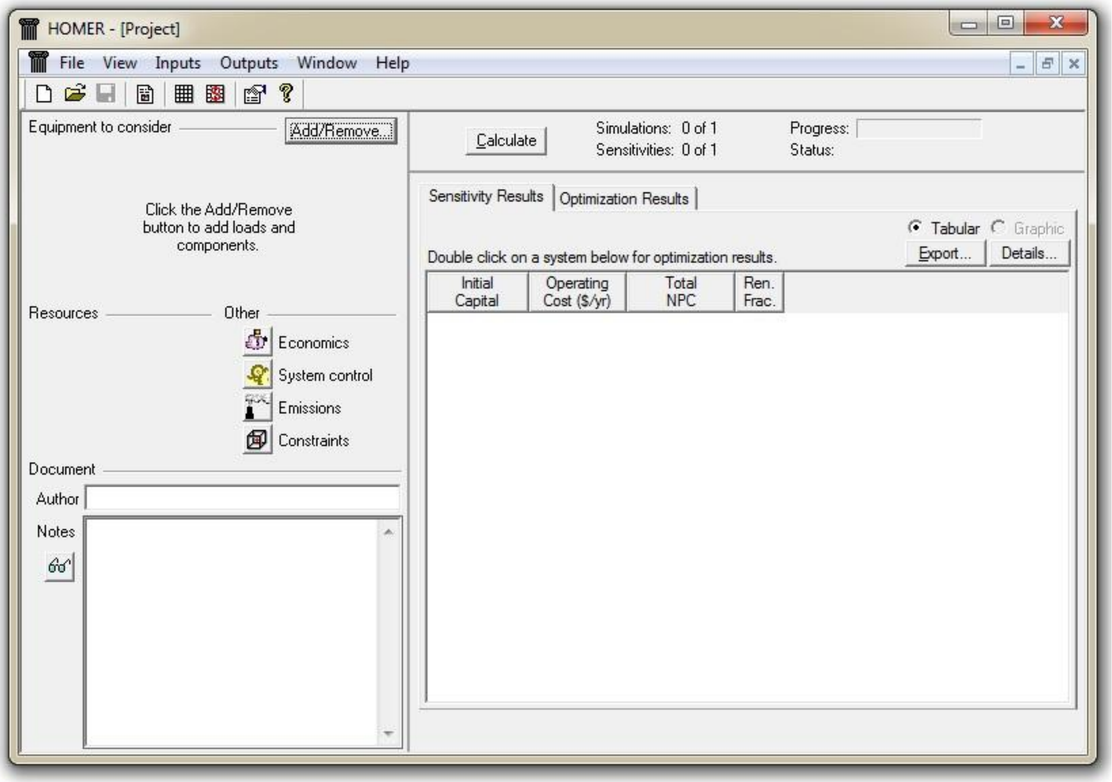


Figure 19. HOMER starting page

HOMER simulates the operation of a system by making energy balance calculations for the 8760 hours of a year. For each hour, it compares the electric and thermal demand in the hour to the energy that the system can supply in that hour and calculates the flows of energy to and from each component of the system. If systems include batteries or fuel-powered generators, it also decides how to operate the generators and if charging or discharging the batteries.

This tool performs energy balance calculations for each system configuration considered, determines whether a configuration is viable (i.e. whether it can meet the electric demand under the conditions that are specified) and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations include costs such as capital, replacement, operation and maintenance, fuel and interest.

It is necessary to provide the model with inputs that describe technology options, component costs and resource availability.

After simulating all of the possible system configurations, HOMER displays a list of configurations, sorted by net present cost, that is useful to compare system design options.

It also displays simulation results in tables and graphs that help to compare configurations and evaluate them on their economic and technical merits.

When sensitivity variables are defined as inputs, HOMER repeats the optimization process for each sensitivity variable that is specified. If a sensitivity analysis is performed, it is possible to identify the factors that have the greatest impact on the design and operation of a power system.[21]

Note: prices are in euro, although in the tables there is the dollar symbol.

6.2 Configuration of the hybrid plant

In the starting page of the software, selecting the Add/Remove button, I added the equipment that compose the power plant and I chose to not model the grid because of the isolated nature of the installation.

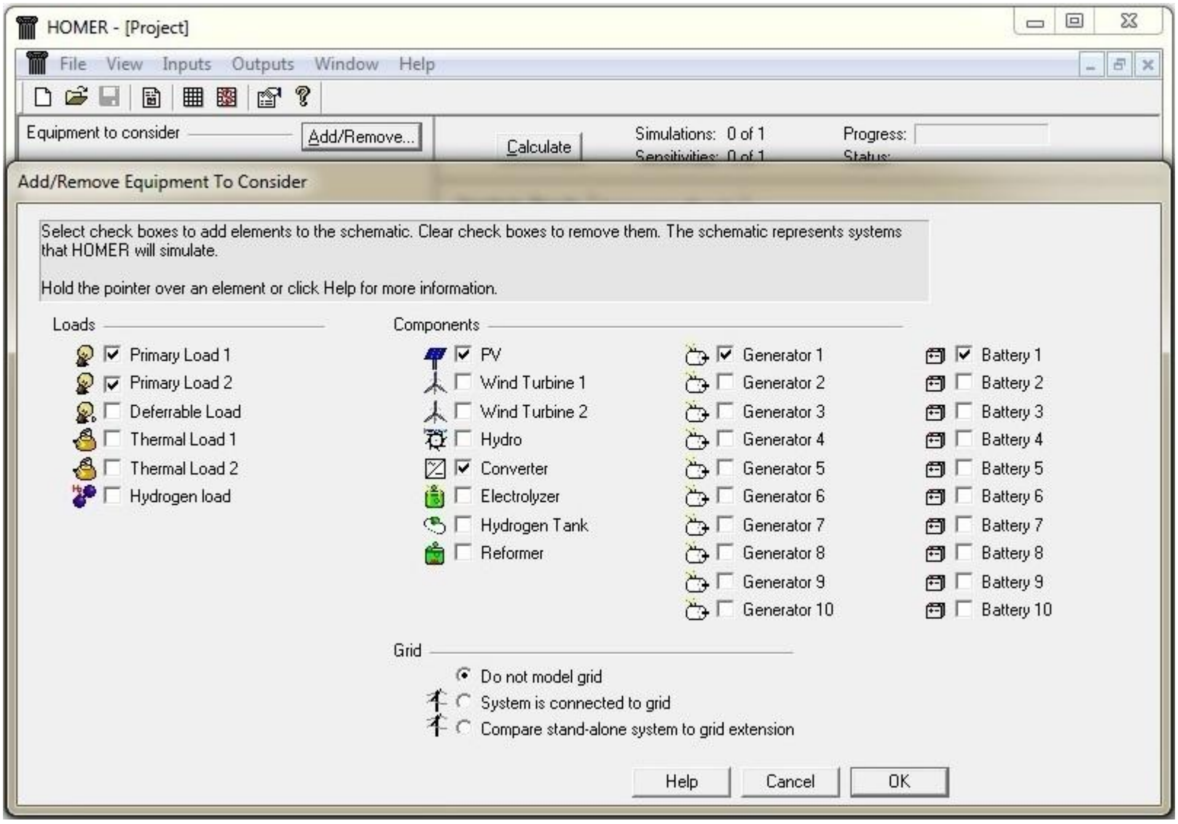


Figure 20. Power plant components

After that, I renamed the loads and the components and defined the single properties.

6.2.1 Loads properties

Primary load is the electrical load that must be met immediately. Each hour of the year, HOMER dispatches the power-producing components of the system to serve the total primary load.

For the loads it is necessary to define the type of load (AC or DC) and to enter a baseline data choosing between inserting a daily profile or importing a time series data file. It is possible to decide a random variability day-to-day or time-step-to-time-step for taking into account potential variations from the starting profile.

For the Primary Load (electricity requested by the village) I decided to enter a daily profile using data from the Annex 8.2 and I selected both day-to-day and time-step-to-time-step random variability, while for the wood chipper I only inserted a daily profile, splitting the power of the machine in three hours.

In the Annexes 8.17.1 and 8.17.2 are shown data of these two loads.

6.2.2 Solar plant properties

Regarding the solar source, the required inputs are the monthly solar radiation, the costs and properties of the panels and the characteristics of converter and batteries.

The average daily radiation is shown in the following figure and the values are those of the Table 4.

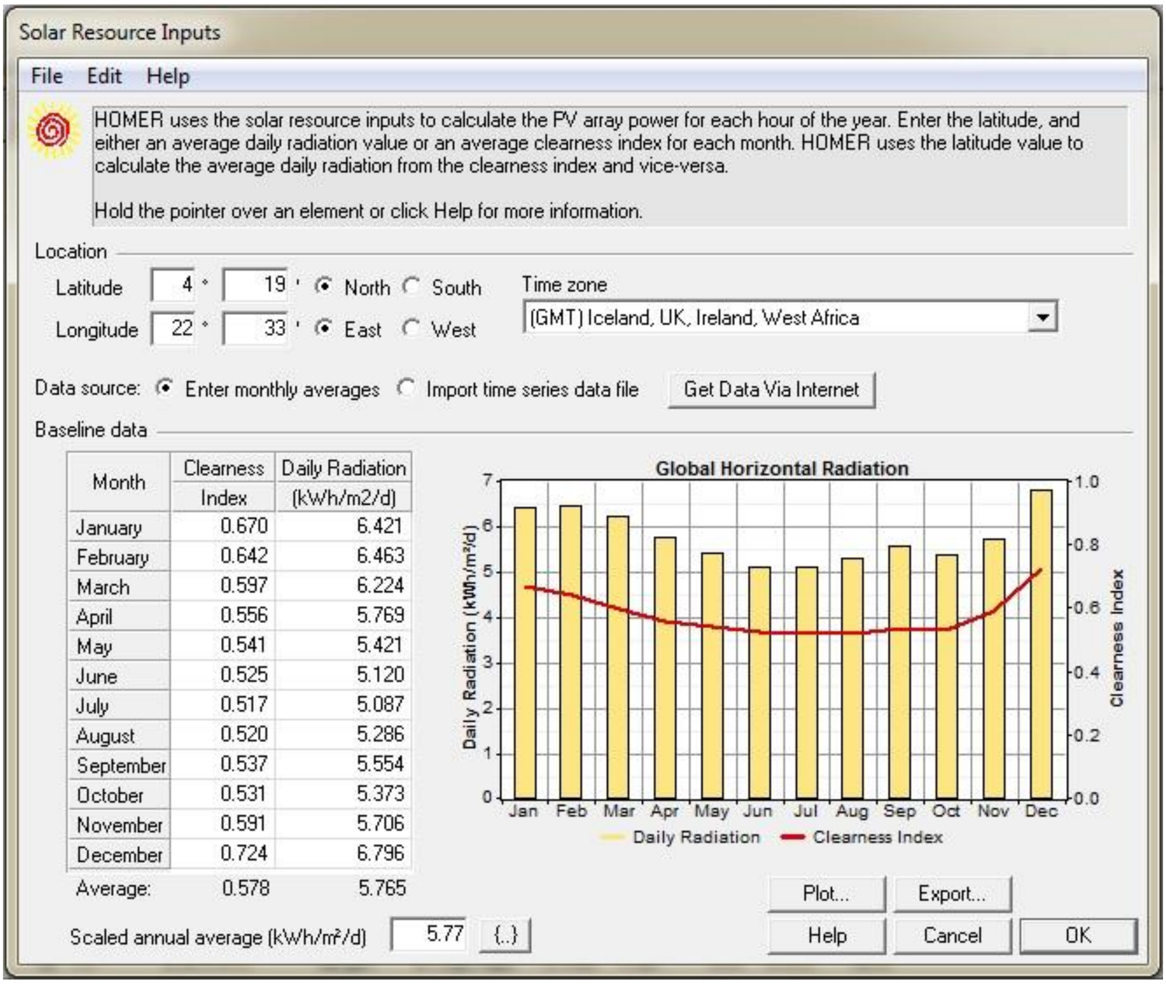


Figure 21. Solar resource HOMER

In the cost of the panels I considered the cost of the modules that is about 0,7 €/W_p and the cost of the controllers, that depends on the power of the panels. I decided to try different sizes of panels, letting HOMER test different configurations.

The price of the controllers is taken from the Schneider Electric price list (see Annex 8.18) and in the following table there are the prices for every size of the plant.

P	Panel price	Controllers	Controllers Price	Capital
kW	€	-	€	€
12,00	8.400,00	3	5.217,00	13.617,00
24,00	16.800,00	5	8.695,00	25.495,00
36,00	25.200,00	8	13.912,00	39.112,00
48,00	33.600,00	10	17.390,00	50.990,00
60,00	42.000,00	13	22.607,00	64.607,00
72,00	50.400,00	15	26.085,00	76.485,00

Table 13. Capital of the solar plant

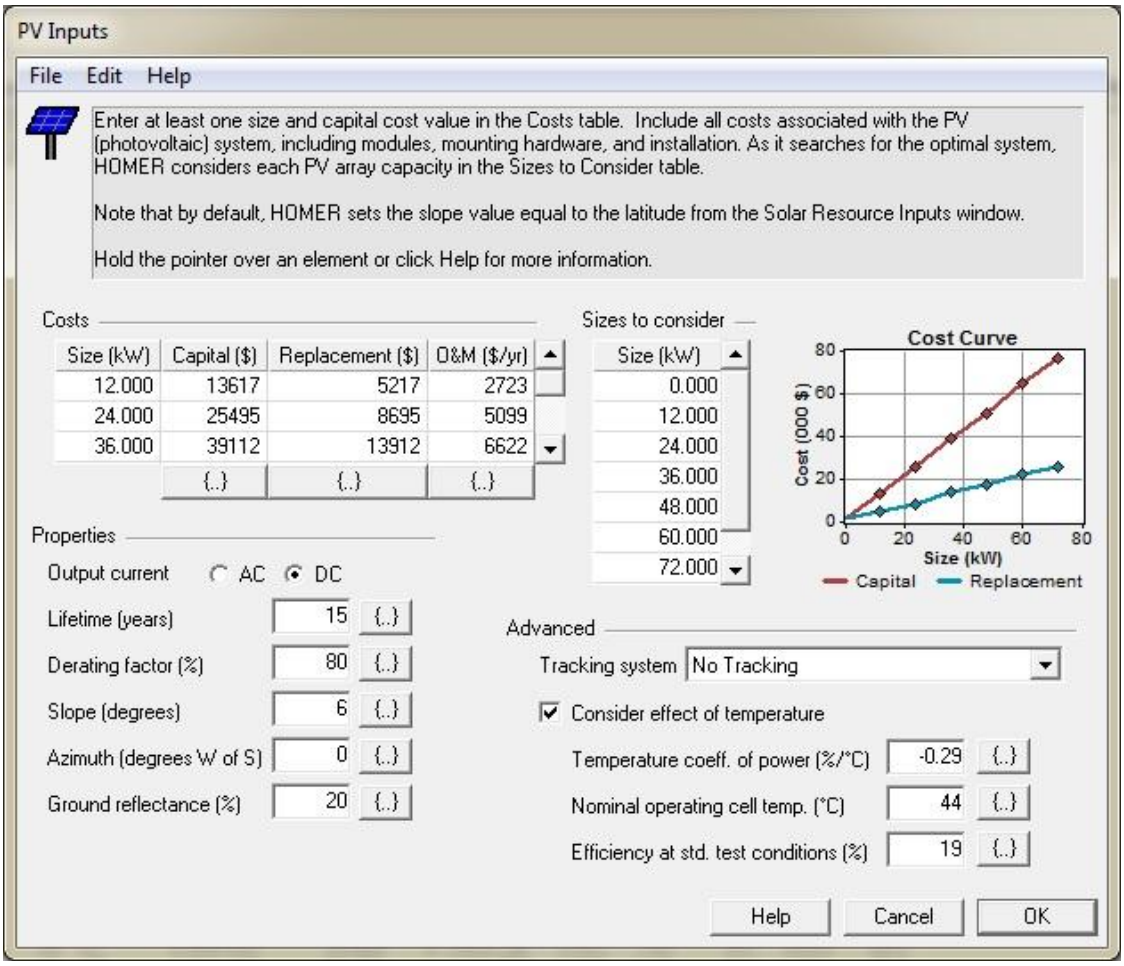


Figure 22. Solar plant costs

The replacement cost is the only cost of the controllers, that have a lifetime of about fifteen years. The O&M costs are the 20% of the capital, that is a typical value.

For the converter I supposed different sizes with different prices.

The replacement cost is the one of the hybrid inverters/chargers (see Annex 8.18) and the O&M costs are the 20% of this price.

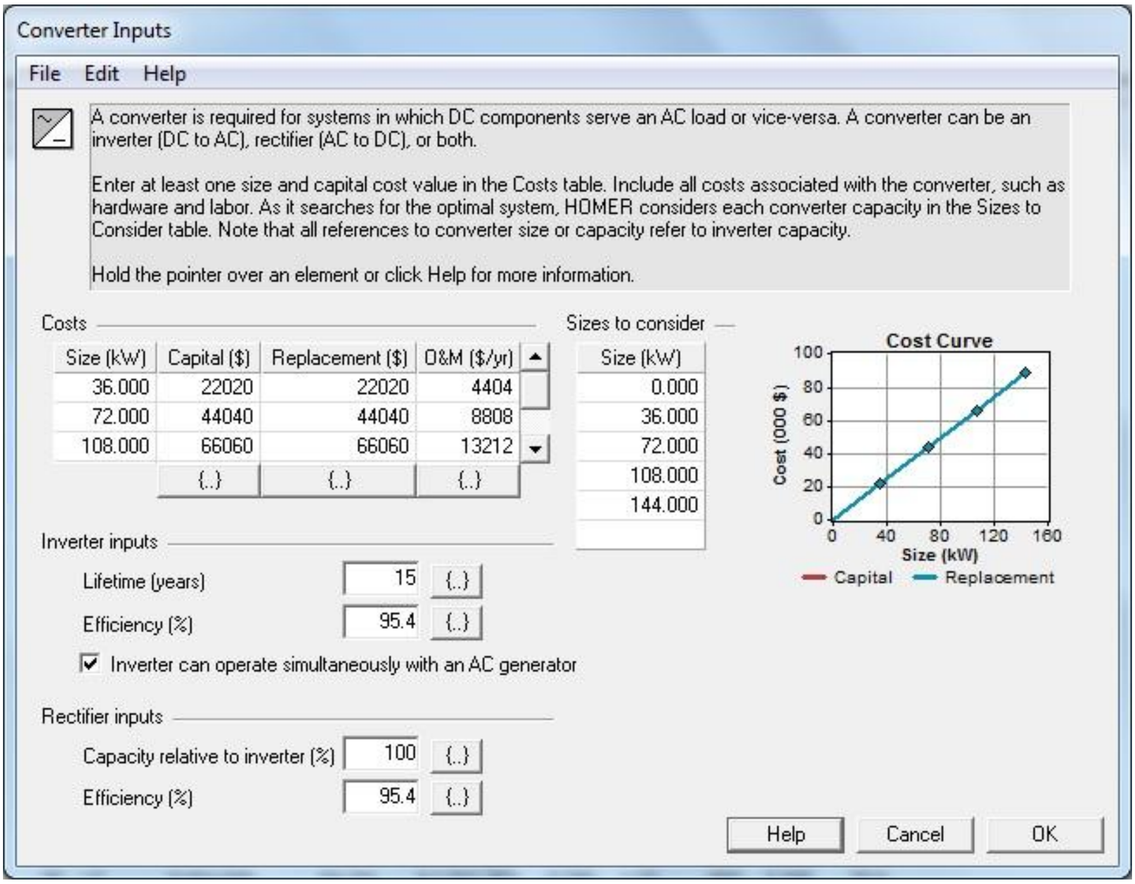


Figure 23. Converters costs

6.2.3 Biomass plant properties

For the biomass, the required inputs are data about resources during the year, costs, fuel characteristics, schedule of the plant and emissions.

Data of yearly resources are shown in the Figure 24 and refer to the Annex 8.12.1, the average price is taken from a slide of the biomass curse at the UPV (see OP2 Annex 8.19). The gasification ratio is the default value of HOMER and due to the low moisture content of the biomass, instead of the LHV, I put the HHV_{wet} average value of Table 12.

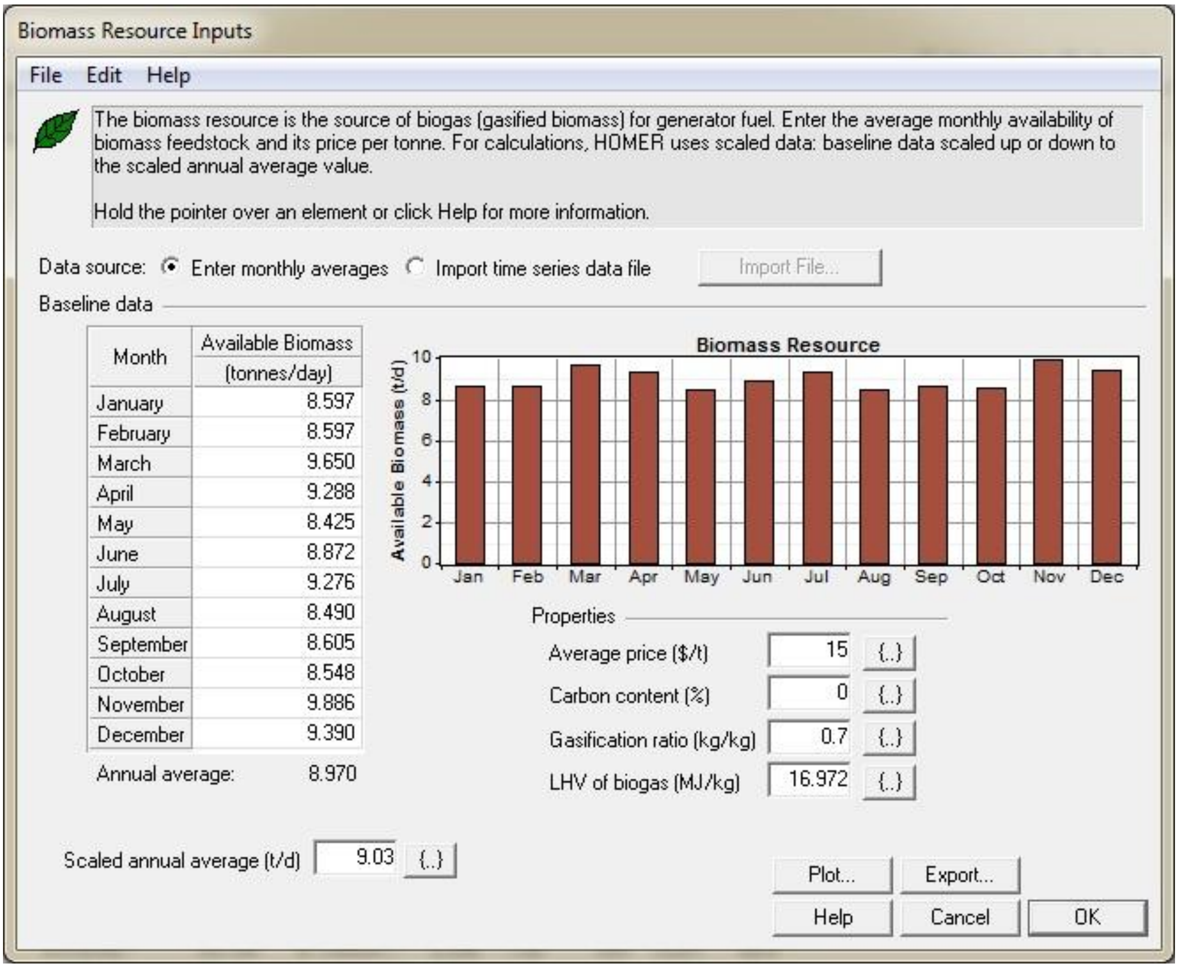
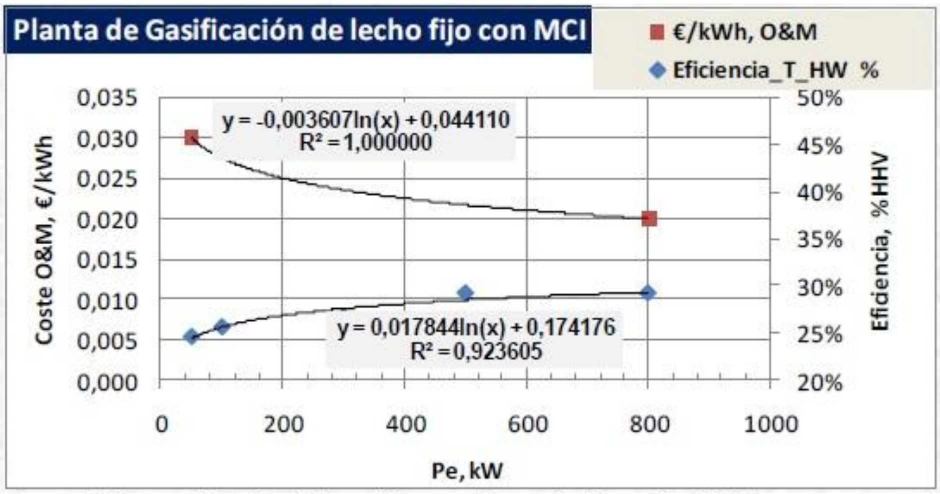


Figure 24. Biomass resource HOMER

The cost of the biomass plant is 830.000 €, including the cost of the gasifier that is about 808.000 € and the wood chipper that costs 22.000 €.

I suppose a gasifier lifetime of 60.000 hours and the replacement cost a quarter of the gasifier costs, to take into account the need of replacing the motor or other pieces.

I decide to try two different sizes of the gasifier: 100 kW and 200 kW, so the O&M are 3 € and 5 € respectively, as it is possible to deduce from the following graph.



Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

Figure 25. O&M biomass costs

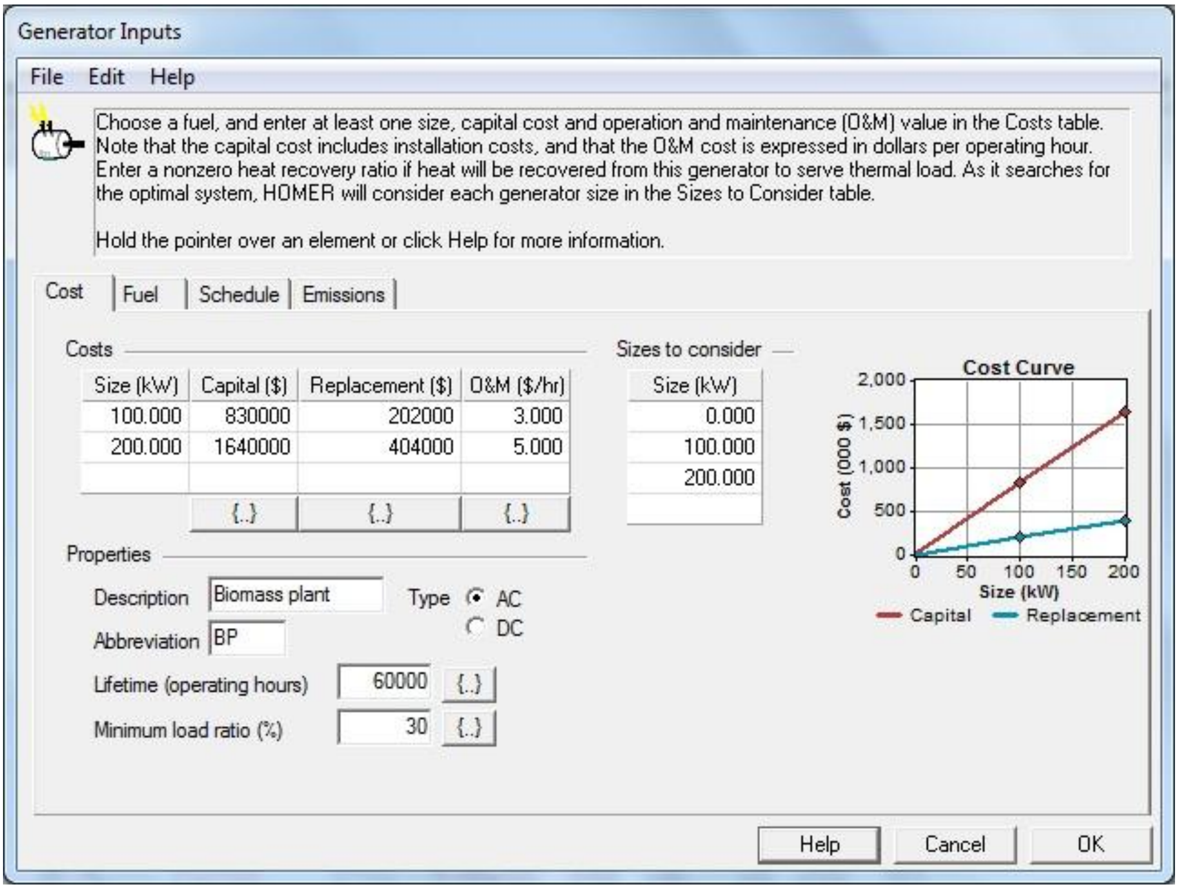


Figure 26. Biomass costs

I took the biogas fuel that is defined by default in HOMER and modified the curve.

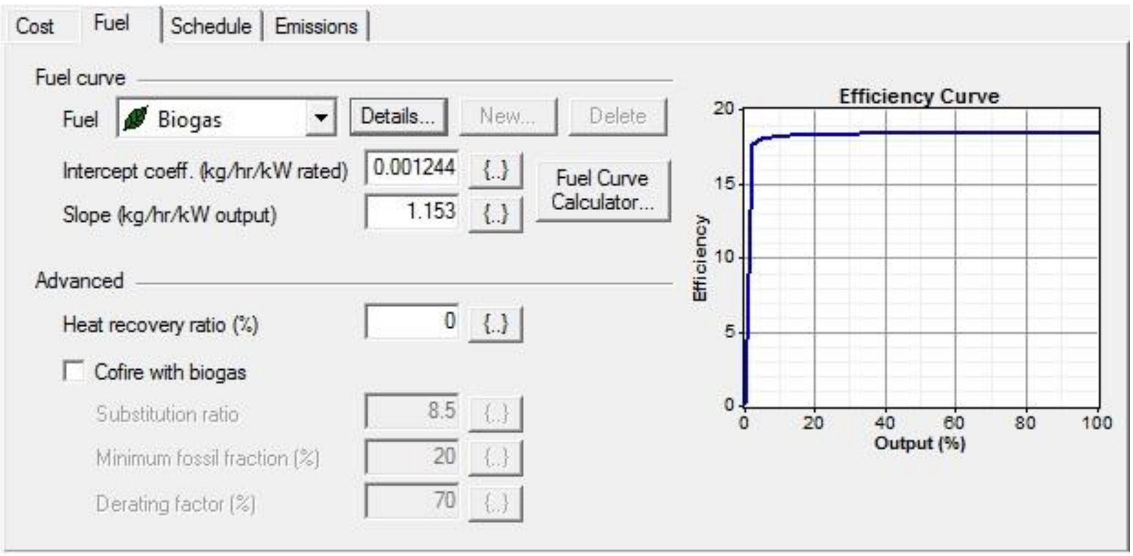


Figure 27. Biomass fuel

Data for the definition of the fuel curve originate from a private conversation with the company: for the production of 110 kW are necessary about 280 lb/hour (127,010 kg/hour) of biomass, so this means that for producing 1 kW are required 2,5454 lb/hour (1,1546 kg/hour) of feedstock. In the Figure 18 is written that with 2 lb it is possible to produce 1 kW_e, so 0,5454 lb/hour (0,247 kg/hour) go to parasitic loads.

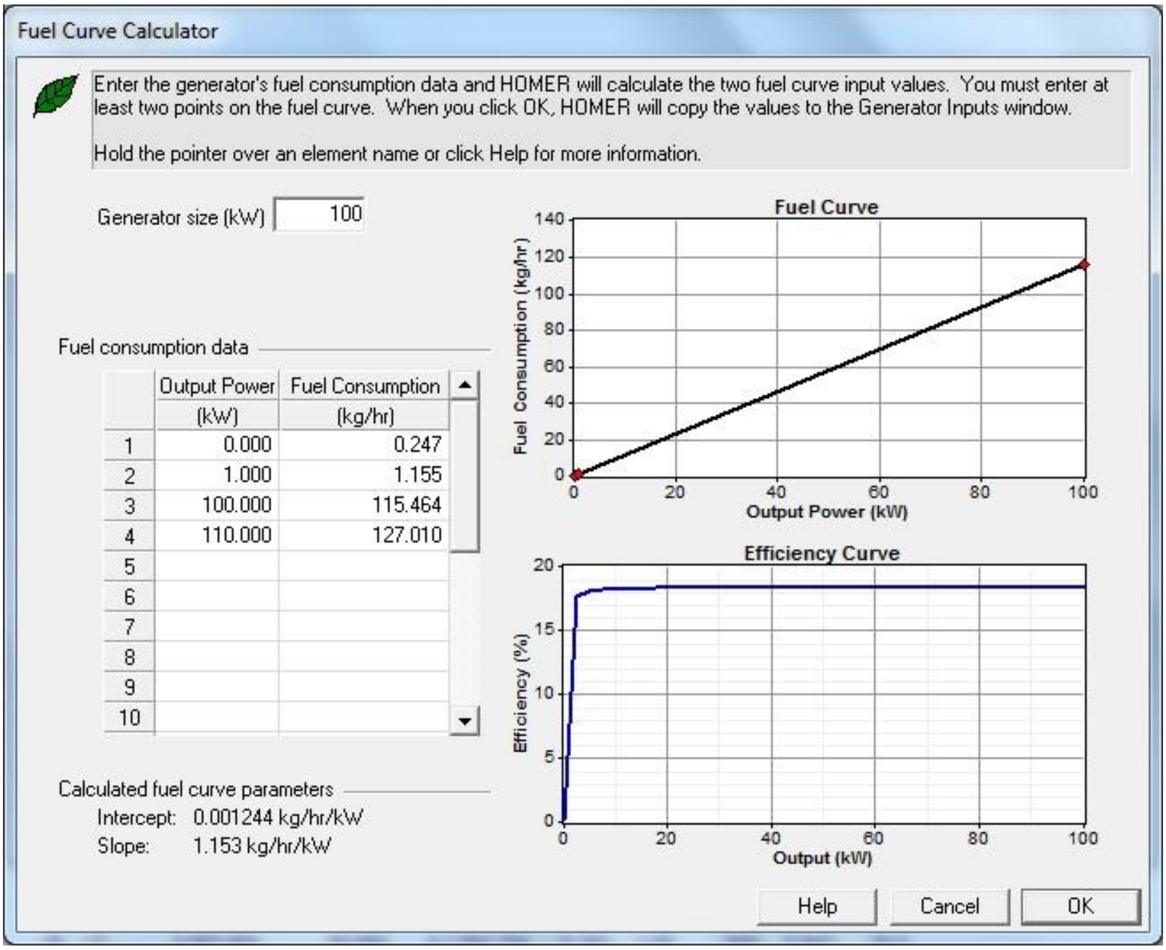


Figure 28. Fuel curve definition

The scheduling of the power plant is shown in the Figure 29. I decided to switch off the plant every day from 11 p.m. to 4 a.m. and to optimize the operating mode from 4 a.m. to 11 a.m. and from 7 p.m. to 11 p.m..

From 11 a.m. to 7 p.m. the plant is switched on during the week and has an optimized operating mode during the weekends, when probably energy demand can drop.

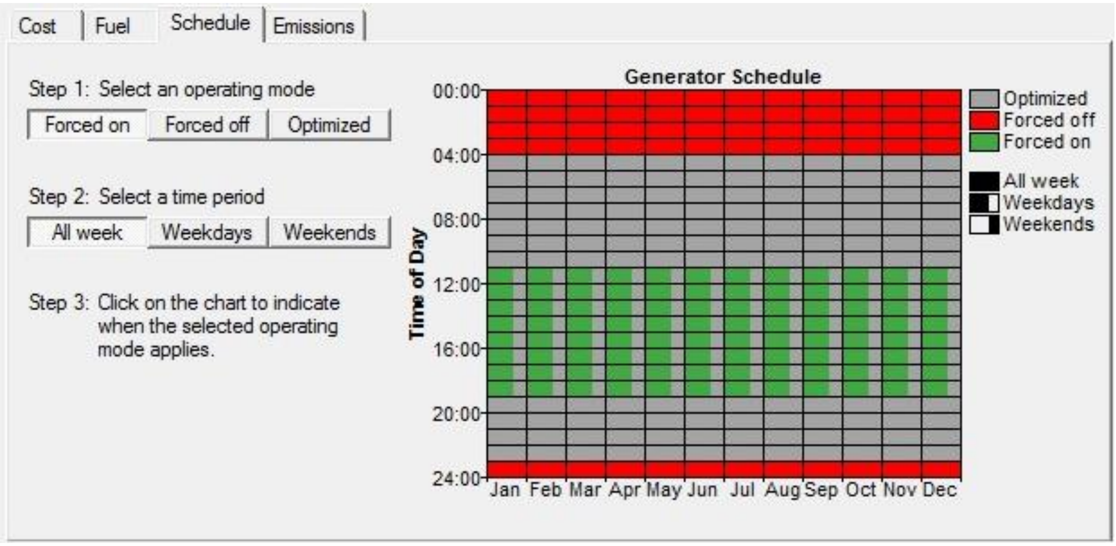


Figure 29. Biomass plant schedule

In the parameters requested by HOMER there are also the emissions of the plant, where I decided to leave the default values.

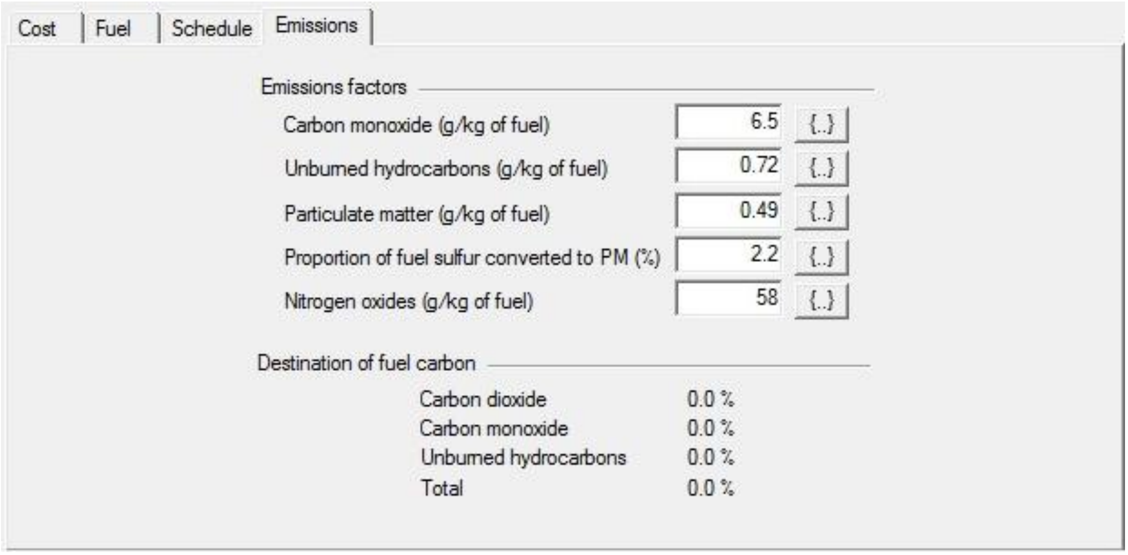


Figure 30. Biomass emissions

6.2.4 Batteries

As said in the paragraph 4.5.6, the inverters support batteries with capacities from 100 Ah to 2000 Ah. I decided to use the Hoppecke 12 OPzS 1500 battery with diluted sulphuric acid electrolyte, that has a nominal capacity of 1500 Ah.

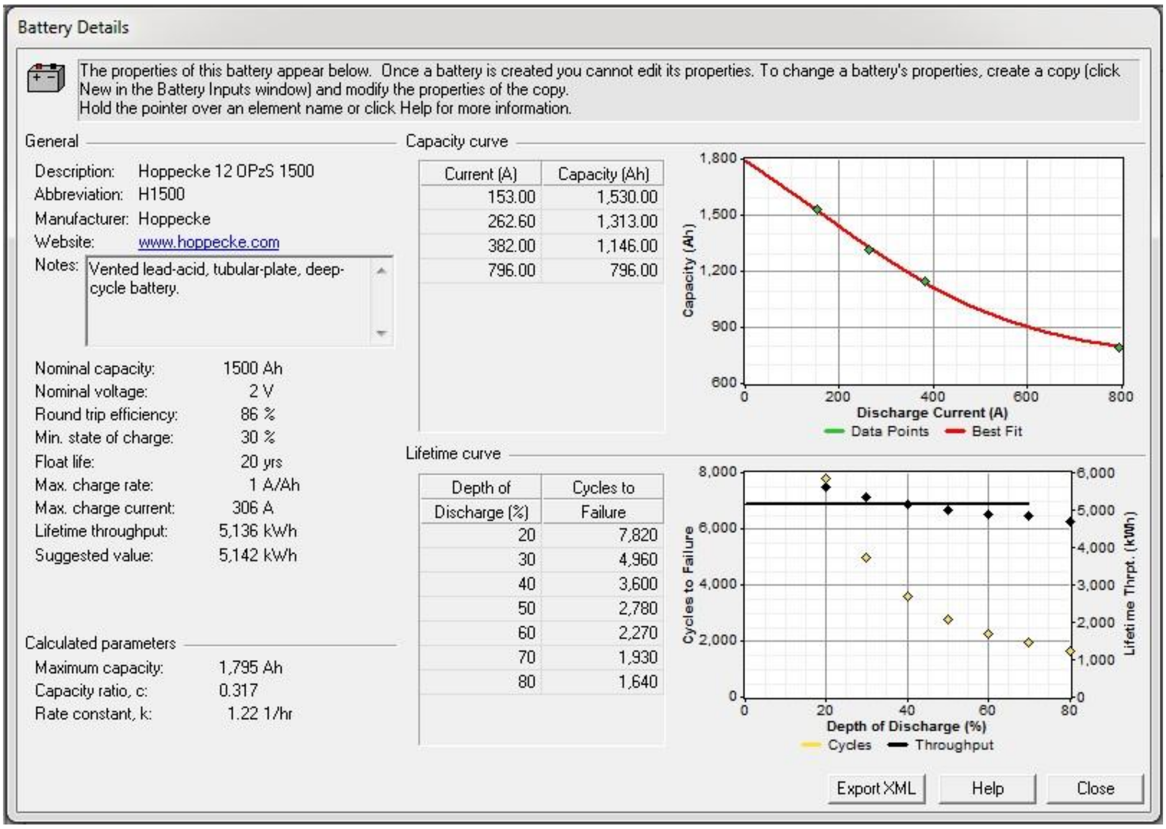


Figure 31. Batteries details

The nominal voltage of these batteries is 2 V, so I have to put 24 batteries per string to reach 48 V, that is the voltage of the DC bus.

I supposed that batteries have a lifetime of fifteen years and a O&M cost that is the 20% of a battery price (see Annex 8.20).

I chose to try different number of strings and let HOMER decide the best configuration.

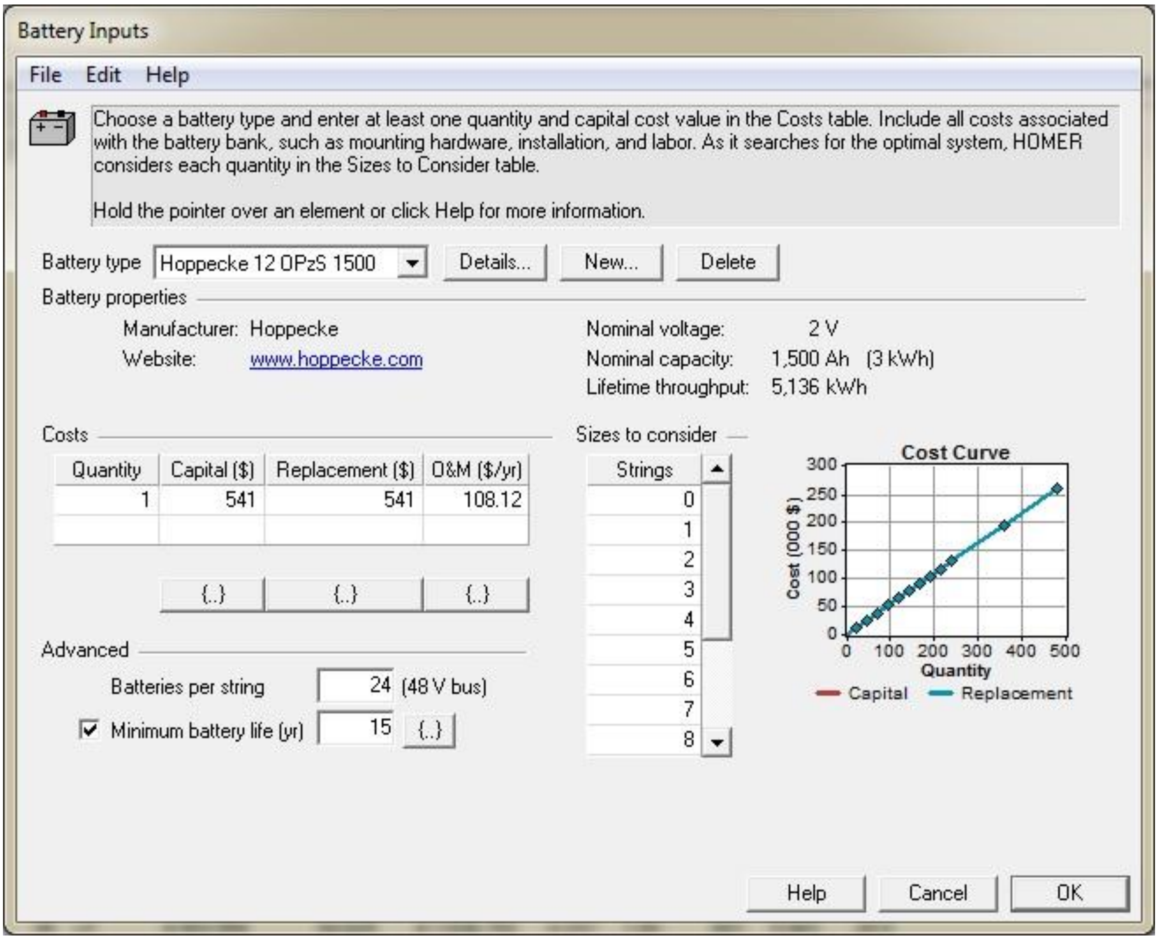


Figure 32. Battery inputs

6.2.5 Hybrid plant schematic

In the Figure 33 there is the schematic of the Hybrid power plant by HOMER.

As it is possible to see, there are also other parameters to detail, i.e. economics, system control, temperature, emissions and constraints.

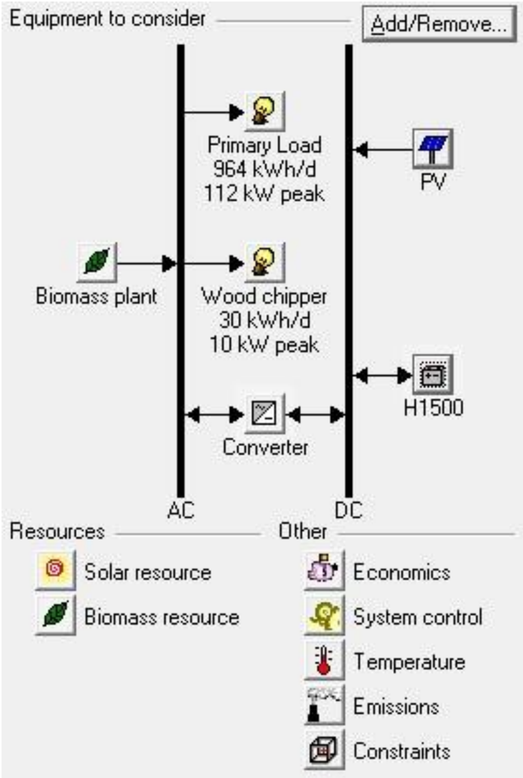


Figure 33. Hybrid power plant schematic

6.2.6 Economics

In the economic inputs I specified only the European annual 25-years EURIRS interest rate (see Annex 8.21) and the project life.

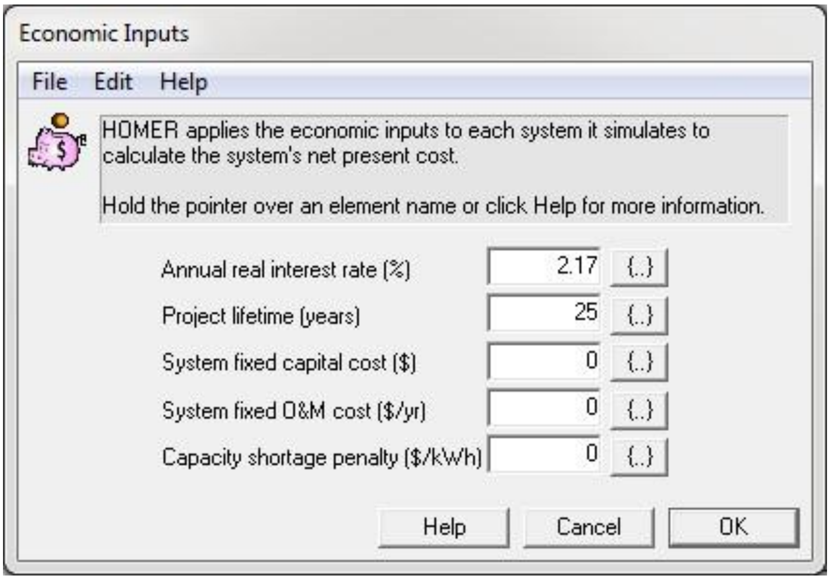


Figure 34. Economic inputs

6.2.7 System control

In the system control inputs, I set the simulation time step a 60 minutes and I decided to compare two different dispatch strategies: load following (LF) and cycle charging (CC).

In the load following strategy the generator produces only the power to met the load consumption, in the cycle charging the generator runs at full power and charges the batteries. I left other settings at their default value.

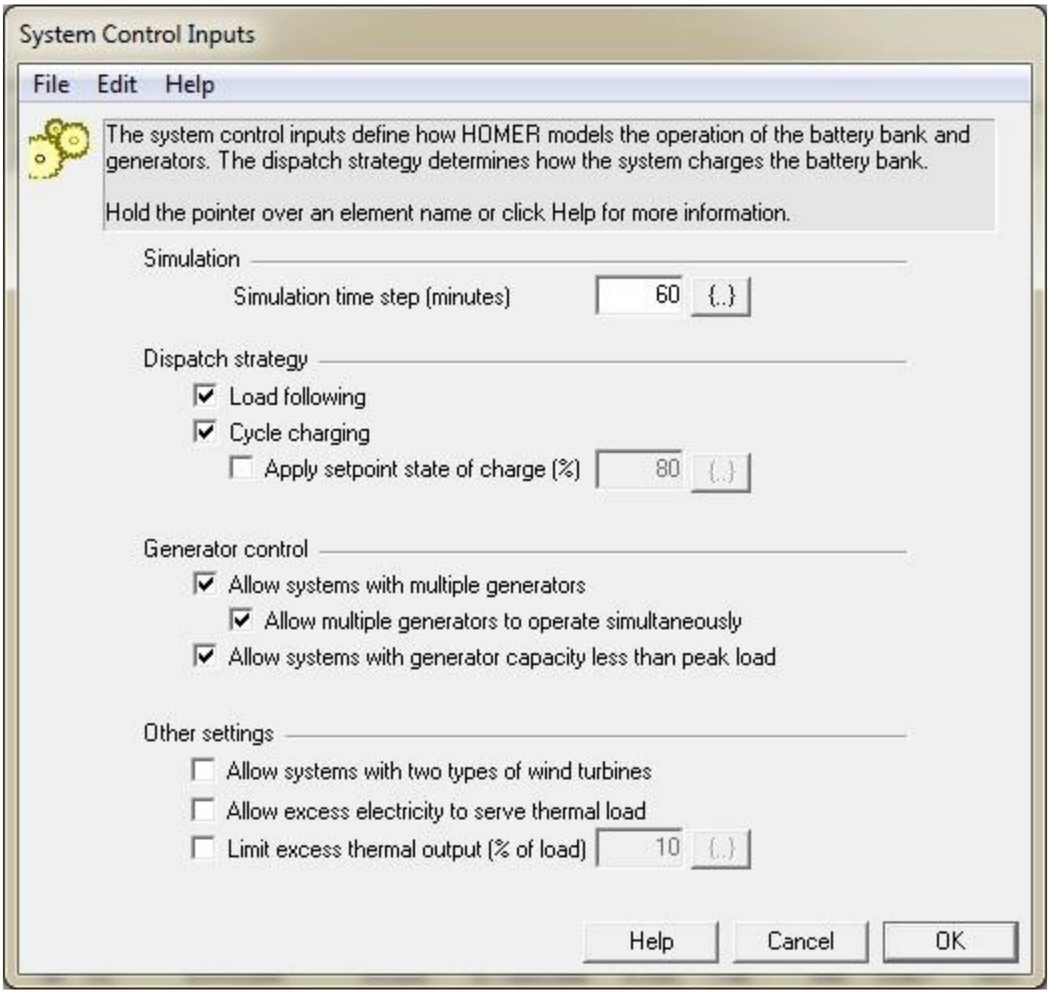


Figure 35. System control inputs

6.2.8 Temperature

In the temperature data I copied down data from the Graph 9.

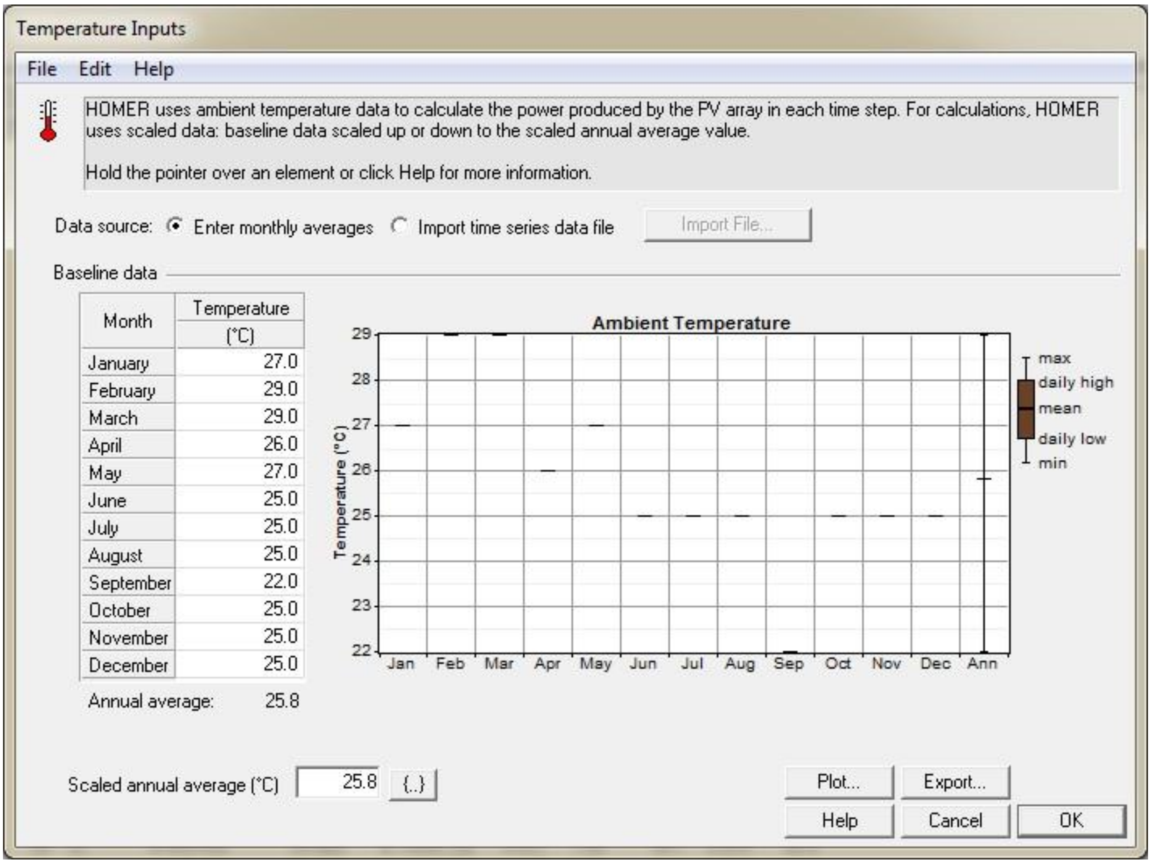


Figure 36. Temperature inputs

6.2.9 Emissions

I did not consider emission penalties for the plant.

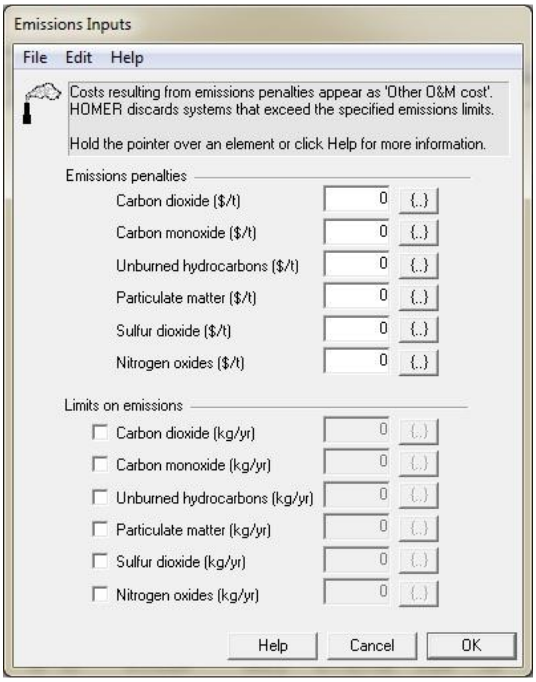


Figure 37. Emission inputs

6.2.10 Constraints

In the constraints I put the shortage capacity at 0%, to met all the load request and I decided to keep an operating reserve that is the 1% of the hourly load.

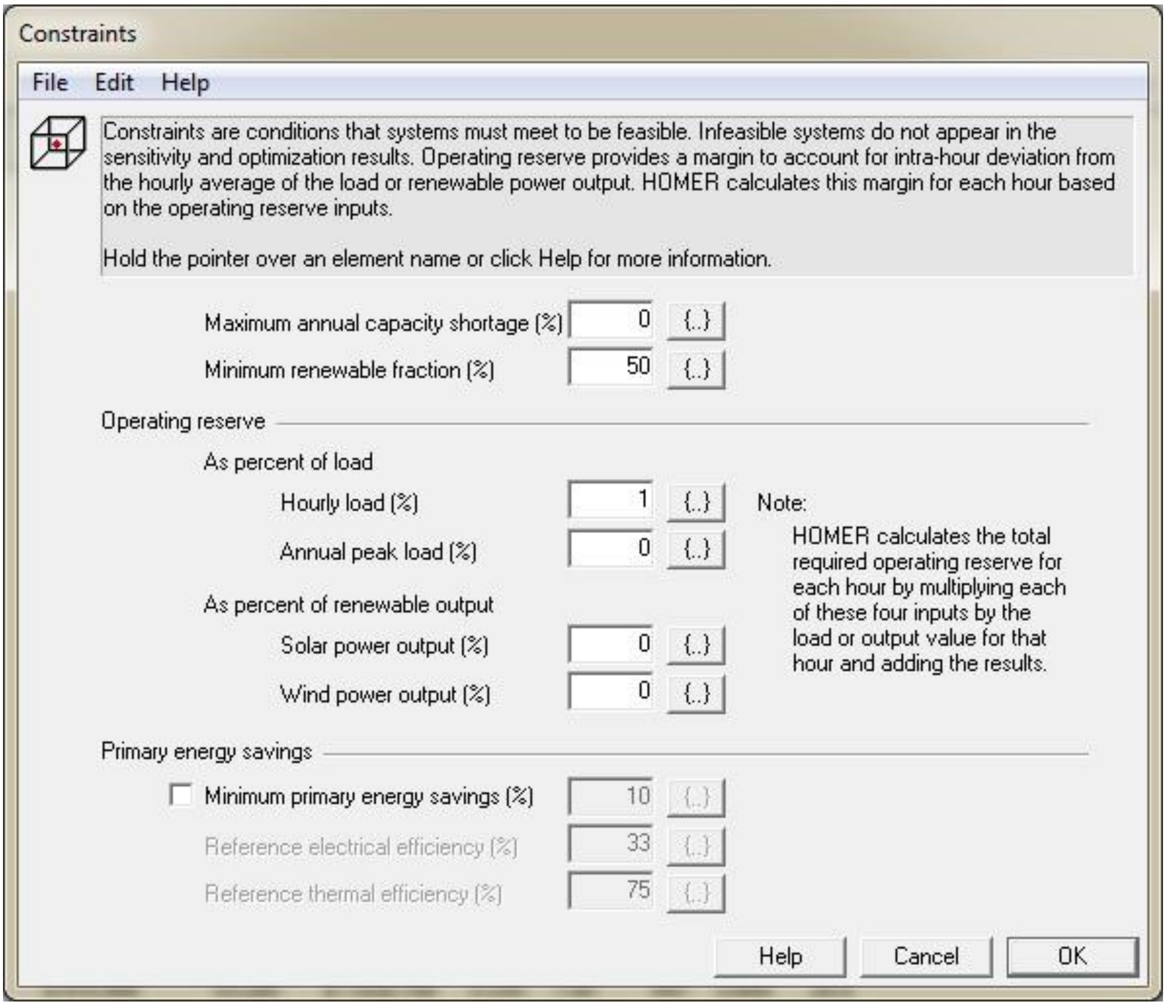


Figure 38. Constraints

6.3 Simulations of the hybrid power plant

After defining all the parameters useful for the simulation, I made HOMER calculate the optimization results.

The results are ordered by net present cost (NPC), from the lowest to the highest, and there are subdivided in two dispatch categories: LF (load following) and CC (cycle charging).

The best combination of the hybrid power plant it is shown in the following table and it is possible to see the full outcomes in the Annex 8.22.

PV (kW)	BP (kW)	H1500	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	BP (hrs)	Batt. Lf. (yr)
	100	24	36	CC	$ 865,004	45,631	$ 1,738,343	0.250	1.00	601	5,776	20.0
	100	48	36	CC	$ 877,988	47,162	$ 1,780,634	0.256	1.00	604	5,573	19.2
12	100	24	36	CC	$ 878,621	47,580	$ 1,789,274	0.258	1.00	570	5,690	17.5
12	100	24	36	LF	$ 878,621	48,991	$ 1,816,275	0.262	1.00	570	5,924	20.0
	100	48	36	LF	$ 877,988	49,372	$ 1,822,942	0.263	1.00	599	5,936	20.0
12	100	48	36	CC	$ 891,605	49,259	$ 1,834,383	0.264	1.00	572	5,536	20.0

Table 14. Extract of the optimization results for the hybrid power plant (best combination highlighted)

The configuration is the following one:

- 12 kW of photovoltaic panels
- 100 kW of biomass plant
- 24 batteries OPzS 1500
- 6 x 6 kW converters
- cycle charging dispatch strategy

Even if this is not the cheapest solution, it is the first admissible solution, because I need some energy for running the wood chipper that has to come from an energy source different from the biomass power plant.

Double-clicking on the solution it is possible to see the detailed simulation results.

There are nine tabs with different specifics: cost summary, cash flow, electrical, photovoltaic plant (PV), biomass plant (BP), battery, converter, emissions and hourly data.

The more interesting tabs are the electrical one that is shown in the Figure 39 and displays production and consumption of electricity, excess of electricity, unmet electric load, capacity shortage and renewable fraction (that is 1, because the hybrid plant produces electricity only with renewable energies) and the hourly plot of the hourly data shown in the Figure 40.

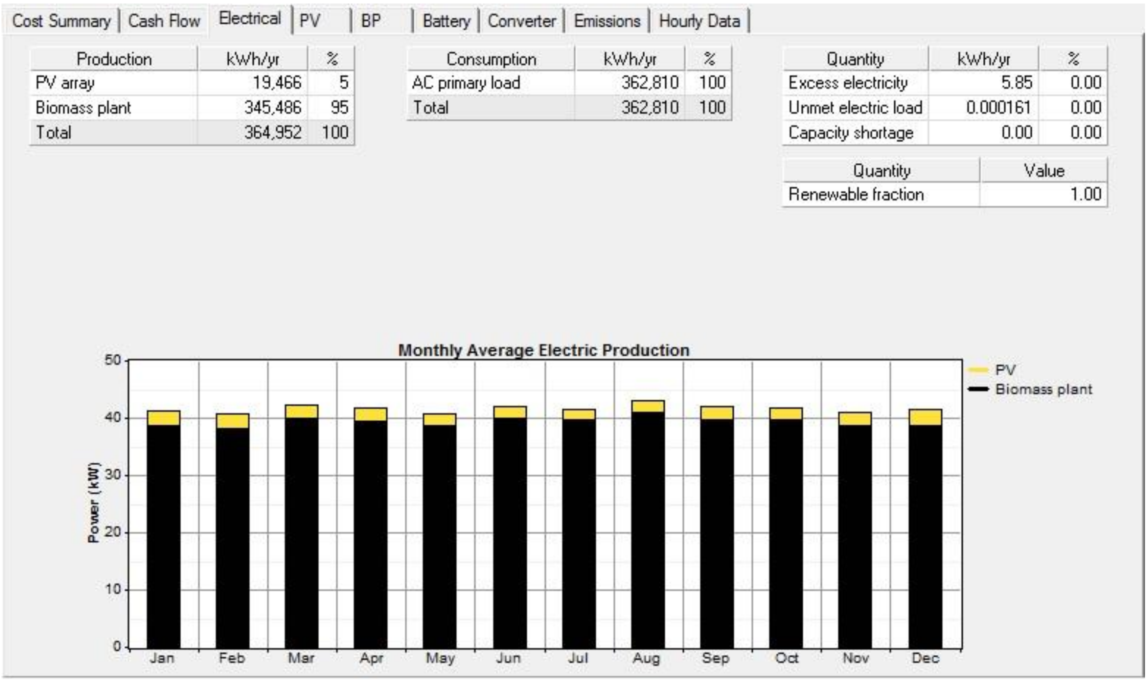


Figure 39. Electrical results hybrid plant

In the previous figure is possible to see that biomass contributes for the 95% to the production of the hybrid plant and the solar plant only for the 5%.

The electricity excess is only 5,85 kWh/year, the unmet electric load and the capacity shortage are zero, due to the settings in the constraints tab (see Figure 38).

In the following figure there is an example of the contribution of biomass and solar sources in producing energy to cover the load curve.

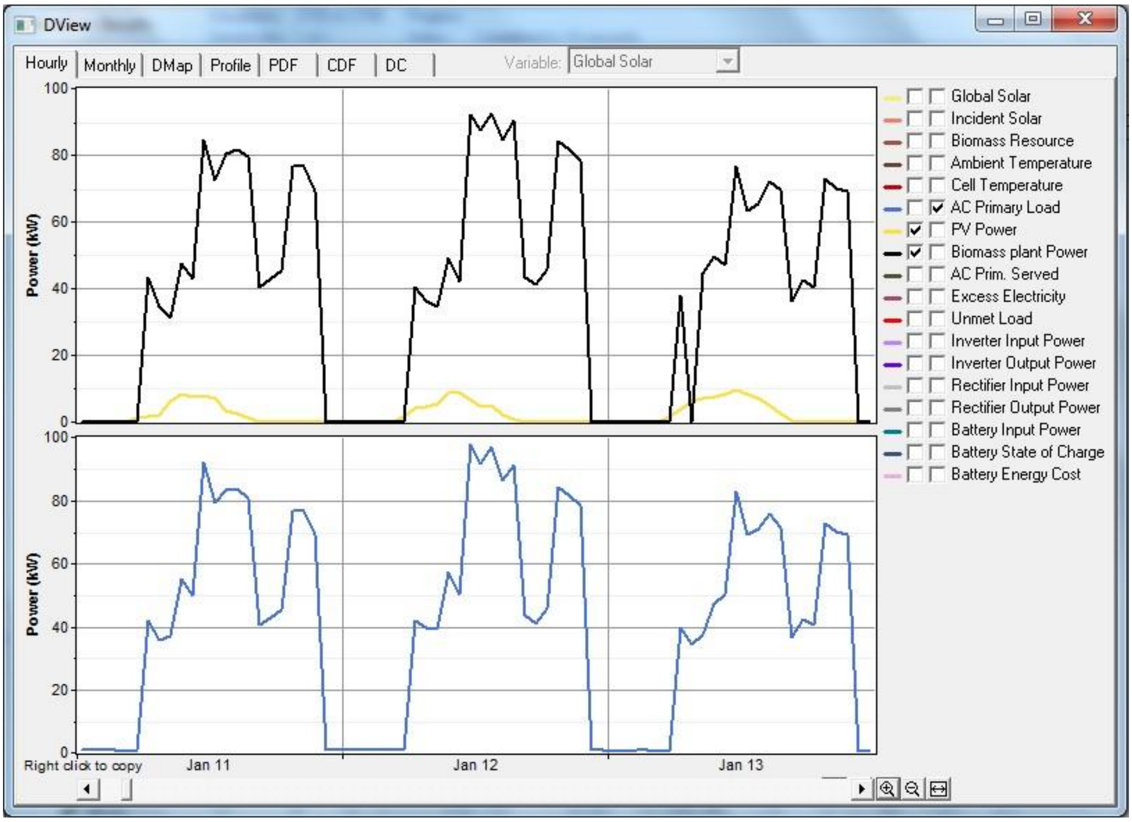


Figure 40. Hybrid plant hourly plot

6.4 Diesel generator power plant

I wanted to compare the renewable solution with the traditional solution, so I modelled also a diesel power plant with HOMER.

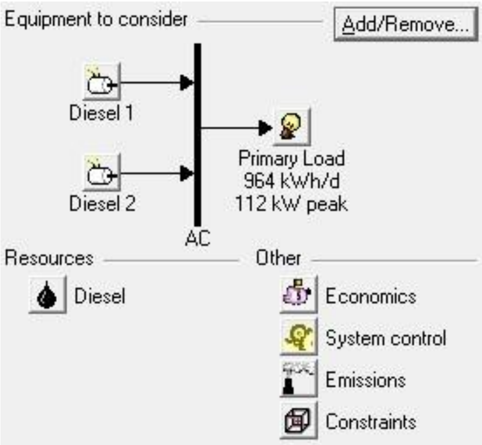


Figure 41. Diesel generator power plant schematic

The characteristics of the primary load are the same as before (see Annex 8.17.1).

Both diesel generators one and two can have two sizes: 47,25 kW and 93,75 kW; the first generator is a commercial 63kW generator and the second one is a 125kW generator, both used at 75% of the load (for sizes and costs see Annex 8.23).

I took these sizes after doing a sensitivity analysis with HOMER, trying different dimensions of generators. The result of this sensitivity analysis was that the combination of generators that produced enough energy for the needs of the plant, without a large excess of energy, was one generator with an approximately size of 45 kW and another one of about 90 kW.

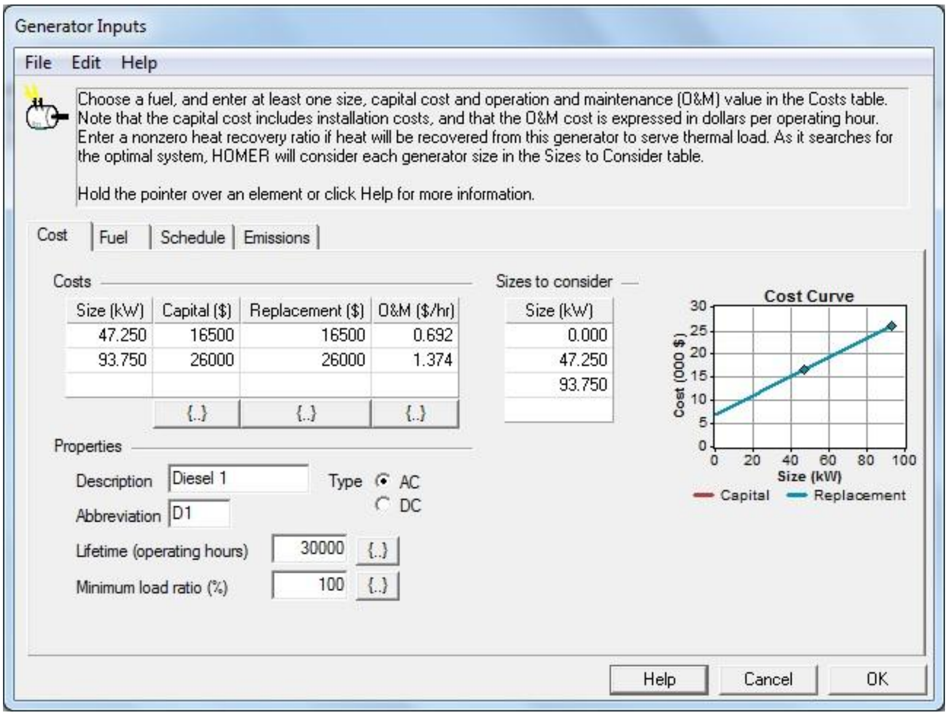


Figure 42. Diesel generator sizes

The O&M costs are taken from the following HOMER support page.

> Knowledgebase
>
> ## 10066 - Diesel O&M costs in HOMER
>
> Posted by on 02 December 2010 03:56 PM
>
> The diesel O&M cost is a critical factor in HOMER analyses, and we know frustratingly little about it. For diesel generators, I typically assume an O&M cost of about 2 US cents per kWh at rated output. That would be $1/hr for a 50 kW diesel. HOMER assumes that the O&M cost per hour is independent of the power output, so that 50 kW diesel would cost $1 per hour of operation whether idling or running full blast.
>
> HOMER calculates the annual O&M cost of the diesel by multiplying the hourly O&M cost by the operating hours per year. In a diesel-only system, that 50 kW generator would run full time and the O&M cost would be $8,760/yr. In a wind-diesel-battery system if it ran only 3,000 hours per year, its O&M cost would drop to $3,000/yr.

Source: support.homerenergy.com/

Figure 43. Diesel O&M costs

Lifetime hours are taken form an informative site about diesel generators.

> **Advantages of a Diesel Engine**
>
> The diesel engine is much more efficient and preferable as compared with gasoline engine due to the following reasons:
>
> - Modern diesel engines have overcome disadvantages of earlier models of higher noise and maintenance costs. They are now quiet and require less maintenance as compared with gas engines of similar size.
> - They are more rugged and reliable.
> - There is no sparking as the fuel auto-ignites. The absence of spark plugs or spark wires lowers maintenance costs.
> - Fuel cost per KiloWatt produced is thirty to fifty percent lower than that of gas engines.
> - An 1800 rpm water cooled diesel unit operates for 12,000 to 30,000 hours before any major maintenance is necessary. An 1800 rpm water cooled gas unit usually operates for 6000-10,000 hours before it needs servicing.
> - Gas units burn hotter than diesel units, and hence they have a significantly shorter life compared with diesel units.

Source: www.dieselserviceandsupply.com/why_use_diesel.aspx

Figure 44. Diesel lifetime

Diesel properties are the default set by HOMER and the price is taken from the World Bank (see Annex 8.24).

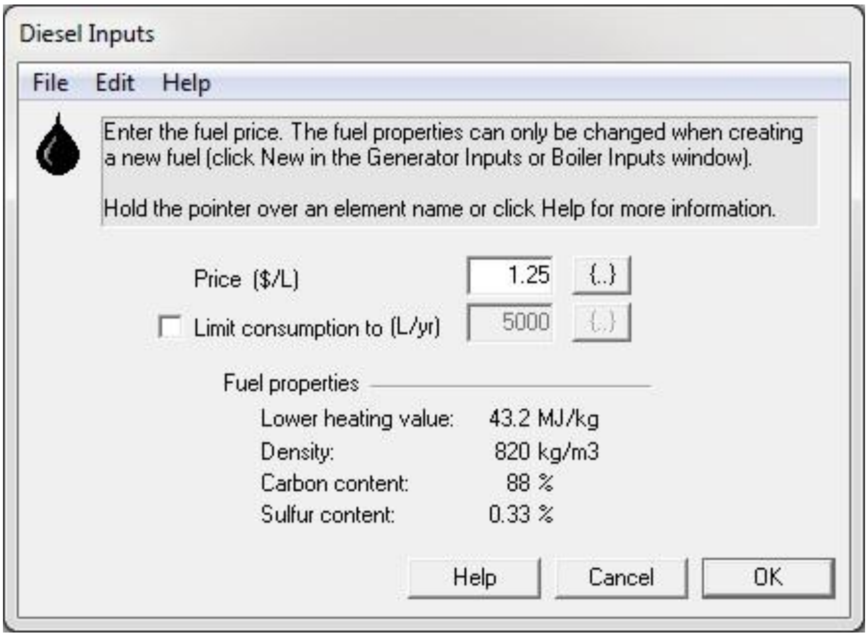


Figure 45. Diesel properties

The operating mode of both diesel generators is optimized all day long and the emissions values are the default set by HOMER (see Figure 30).

In the system control tab I considered only the load following dispatch strategy, since I did not put batteries; all other parameters (Economics, Emissions and Constraints) are the same as before.

6.5 Simulations of the diesel power plant

In the following figure are shown the optimization results for the diesel power plant; as it is possible to see, the first and the second configuration are equal.

		D1 (kW)	D2 (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	D1 (hrs)	D2 (hrs)
		93.75	47.25	$ 42,500	250,133	$ 4,829,882	0.717	0.00	189,920	3,279	5,674
		47.25	93.75	$ 42,500	250,133	$ 4,829,882	0.717	0.00	189,920	5,674	3,279
		93.75	93.75	$ 52,000	364,471	$ 7,027,751	1.044	0.00	276,983	8,760	193

Table 15. Optimization results for the diesel power plant

Like before, double-clicking on the solution it is possible to see the detailed results.

Let's consider the first configuration, where the generator D1 contributes for the 53% at the total energy production and the generator D2 contributes for the remaining 47 %.

There is no unmet electric load and the capacity shortage is 0. The excess of electricity is almost the 39%, this means that this percentage of electricity will be wasted since there are not batteries to store energy.

Figure 46. Electrical results diesel plant

In the following figure are shown the variations of the two diesel power generators. It is possible to note that generators has a different shape with respect to the load due to the lack of an accumulation system.

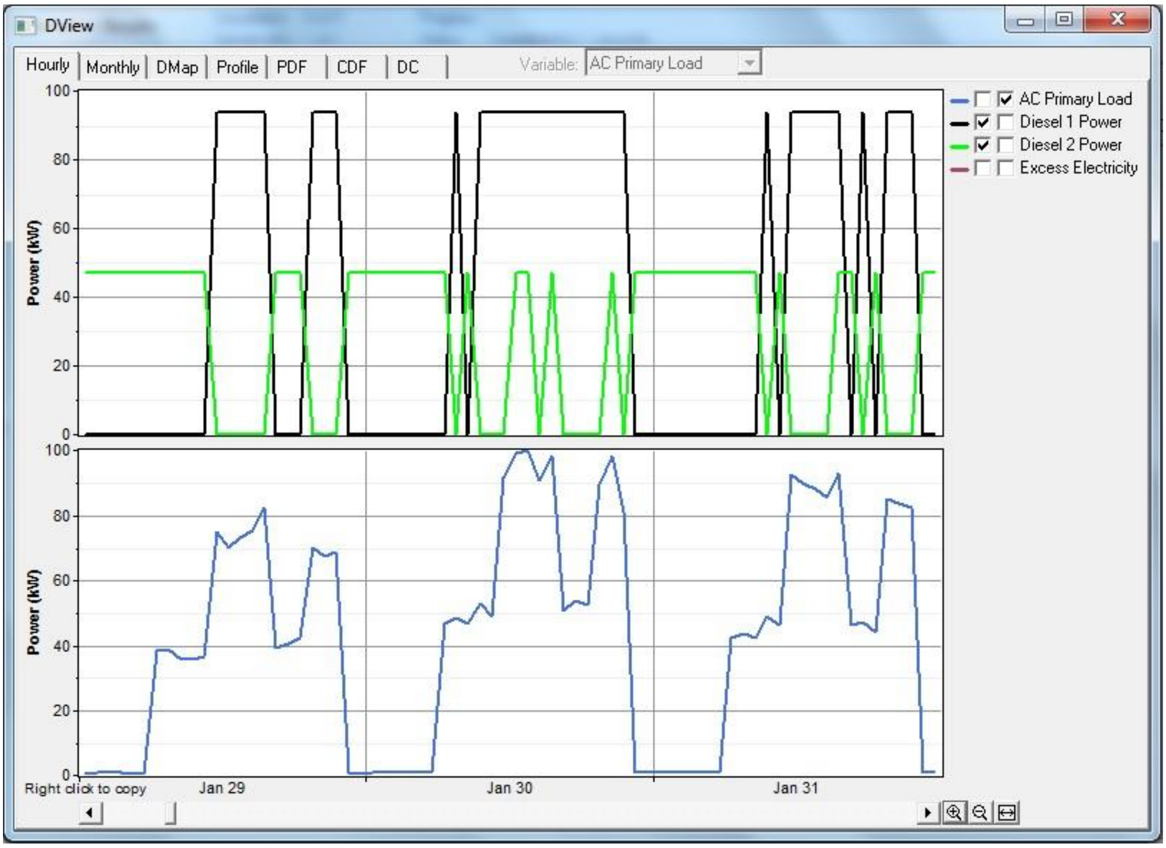


Figure 47. Diesel hourly plot

6.6 Comparison

The simplest comparison of these two power plants is the economic one.

In the following figures it is possible to see the cash flow comparison between the hybrid plant and the diesel plant.

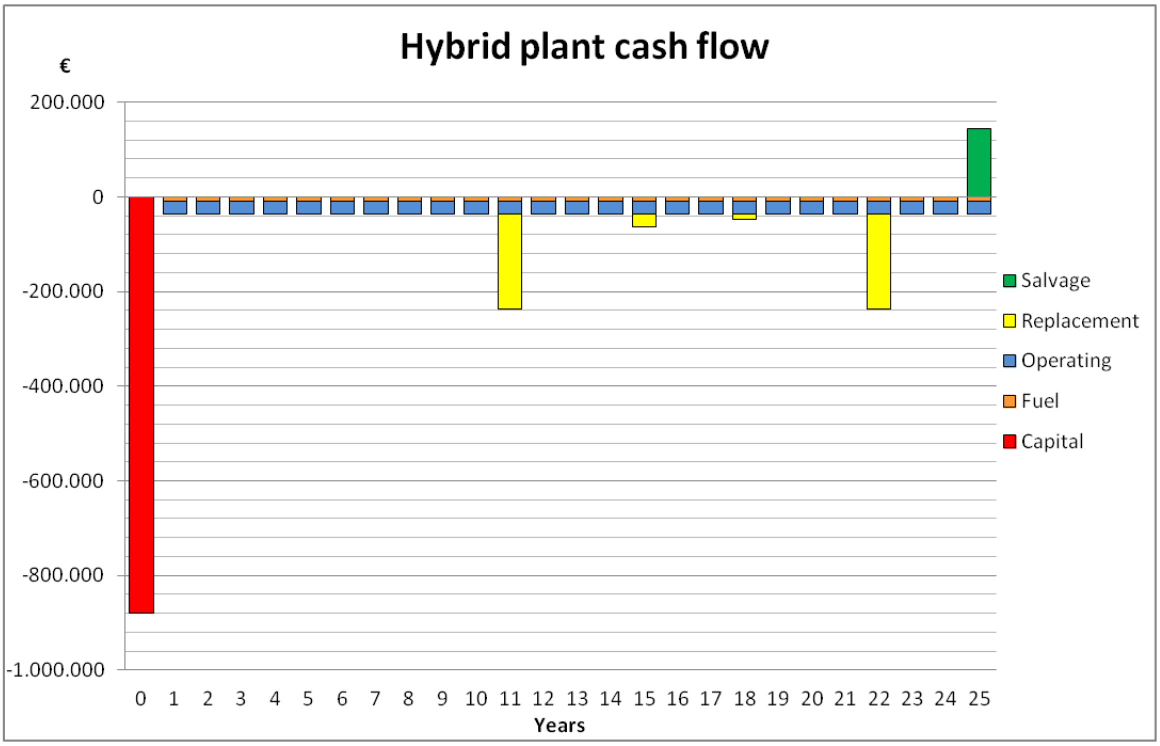


Figure 48. Hybrid plan cash flow

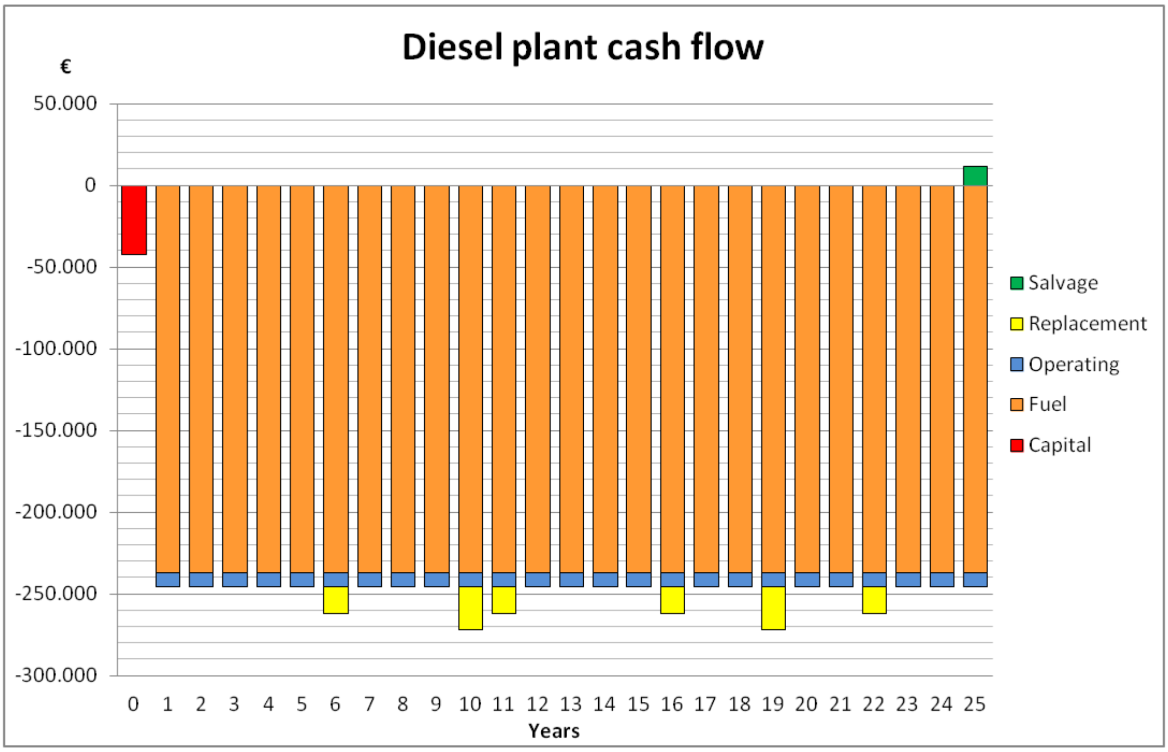


Figure 49. Diesel plant cash flow

As it is possible to notice, the greatest differences are in the initial capital, that is higher in the case of the hybrid power plant, and in the fuel costs, that are higher in the case of the diesel power plant.

The different system architectures are recapped in the Table 16 and the most relevant costs are summarized in the Table 17.

Diesel power plant	
Diesel 1	93,75 kW
Diesel 2	47,25 kW

Hybrid power plant	
Photovoltaic panels	12 kW
Converter	36 kW
Biomass plant	100 kW
Batteries OPzS 1500	24

Table 16. Power plants architecture

	Capital	Fuel	NPC	COE	Operating cost	Salvage cost
	€	€	€	€/kWh	€/year	€
Hybrid plant	878.621,00	163.664,00	1.789.274,00	0,258	47.580,00	83.968,00
Diesel plant	42.500,00	4.543.677,00	4.829.880,00	0,717	250.133,00	6.687,00

Table 17. Costs comparison

Even if the capital of the hybrid power plant is higher than the capital of the diesel plant, the fuel costs of the hybrid plant are much lower than those of the diesel plant.

The Net Present Cost (NPC) and the Cost Of Energy (COE) are lower in the hybrid plant, so this means that this plant is the best choice from the economic point of view.

If the plants will be sold after 25 years, gains are higher in the case of the hybrid power plant.

In the Table 18 are shown the percent variations of the values in Table 17.

Hybrid plant vs. Diesel plant	
Capital	**+95,16%**
Fuel	**-96,40%**
NPC	**-62,95%**
COE	**-64,02%**
Operating cost	**-80,98%**
Salvage cost	**+92,04%**

Table 18. Hybrid plant vs. Diesel plant percent variations

It is clearly deducible that the only disadvantage of the hybrid power plant is the initial capital cost.

6.7 Possible changes in the hybrid plant model

6.7.1 Reduction of the biomass availability

One of the changes that is possible to do in the hybrid plant model is reducing the biomass resource, because with and area of about 960 ha (see Figure 13) and average waste generation rates of 4,3 t/ha for agricultural biomass and 4,5 t/ha for wood biomass, there is a surplus of waste: the plant needs only 570 tonnes and the total production is over 4000 tonnes.

After some attempts with HOMER, I found that it is possible to reduce the area of about the 50% and the waste generation rate of the wood from 4,5 to 3 t/ha.

In the following figure there is an example of the new area, that now is about 430 ha.

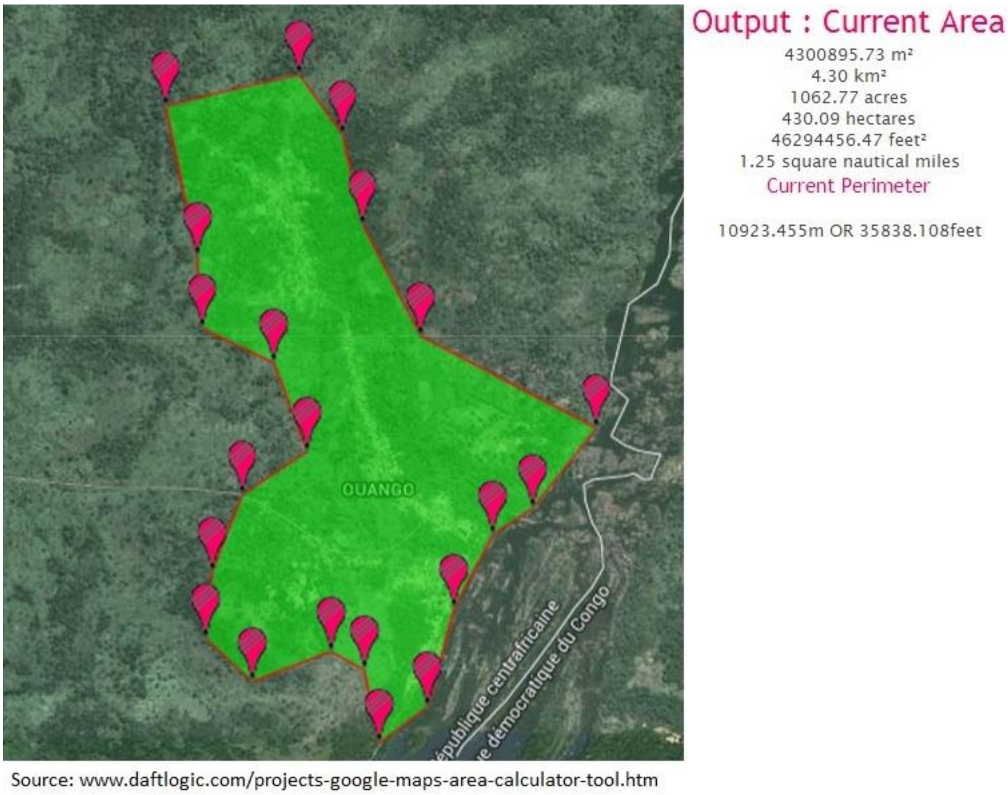


Figure 50. Biomass area reduced

In the tables 19 and 20, highlighted in pink, there are the new values of agricultural and wood residues.

Agricultural residues	area	$area_{reduced}$	total	$total_{reduced}$
	ha	ha	t	t
bean straw	1,34	0,45	12,06	4,01
cassava residues	50,01	16,67	90,02	30,01
corn stalks	19,68	6,32	118,08	2,53
groundnut shells	18,97	6,56	7,59	39,36
mean values	90,00	30,00	227,75	75,91

Table 19. Agricultural residues reduced

Forestry residues	waste	area	total
	t/ha	ha	t
wood	4,50	870,00	3.915,00
$wood_{reduced}$	3,00	400,00	1.200,00

Table 20. Wood residues reduced

As it is possible to notice, there is a high reduction in the biomass quantity.

With these new values I created a table like the one in the Annex 8.12.1, that is possible to see in the Annex 8.25.1.

Then I created a table of the energy provided by the new quantity of waste, that is reported in the Annex 8.25.2, and is like the one in the Annex 8.13.

For a comparison between the previous situation and the present one, it can be useful the following table, with the parallel of the average values.

	average values	$\text{average values}_{reduced}$
t/month	274,59	76,55
t/day	9,03	2,52
$\%\ moisture_{before}$	28,35	28,27
$\%\ moisturea_{after}$	9,92	9,91
HHV_{dry} (MJ/t)	18.864,56	18.857,53
HHV_{wet} (MJ/t)	16.971,69	16.958,97
MJ/month	4.660.340,64	1.298.260,50

Table 21. Comparison of the average values

The highest variations are in the monthly and daily tonnes and in the monthly energy production. The other values are more or less the same.

6.7.2 Simulations of the new hybrid plant

The new configuration of the hybrid plant is shown in the Figure 51.

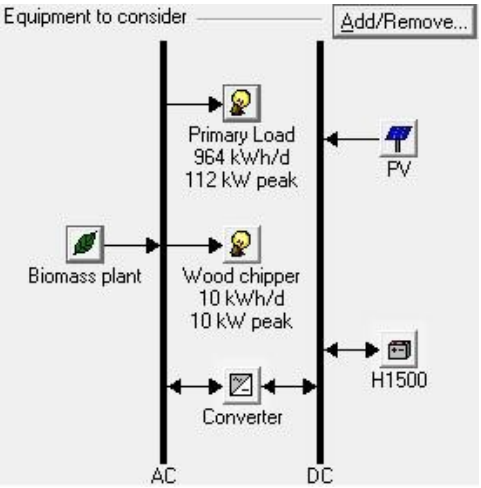


Figure 51. New configuration of the hybrid plant

In the new configuration there are variations only in the biomass resource data, that are those in the Annex 8.25.1 and in the power of the wood chipper.

The reduction of the biomass implies a reduction in the utilization hours of the wood chipper, so this load will only work for one hour (not three), from 10 to 11 a.m..

Some results of the HOMER simulations are shown in the following figure, where there is highlighted the same solution as before the reduction of the biomass.

PV (kW)	BP (kW)	H1500	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	BP (hrs)	Batt. Lf. (yr)
	100	24	36	CC	$ 865,004	45,442	$ 1,734,732	0.255	1.00	589	5,775	20.0
	100	24	36	LF	$ 865,004	46,845	$ 1,761,594	0.259	1.00	590	5,990	20.0
	100	48	36	CC	$ 877,988	46,926	$ 1,776,127	0.261	1.00	592	5,566	19.4
12	100	24	36	CC	$ 878,621	47,377	$ 1,785,379	0.262	1.00	558	5,686	17.5
12	100	24	36	LF	$ 878,621	48,757	$ 1,811,798	0.266	1.00	558	5,916	20.0
	100	48	36	LF	$ 877,988	49,121	$ 1,818,138	0.267	1.00	587	5,925	20.0
12	100	48	36	CC	$ 891,605	49,034	$ 1,830,080	0.269	1.00	560	5,529	20.0
24	100	24	36	CC	$ 890,499	49,162	$ 1,831,423	0.269	1.00	529	5,637	16.0
	100	72	36	CC	$ 890,972	49,308	$ 1,834,694	0.270	1.00	592	5,516	20.0

Table 22. HOMER simulations with reduced biomass

The comparison of the costs of the "old" hybrid plant and the "new" one is shown in the Table 23, where it is possible to see that the costs are very similar.

	Capital	Fuel	NPC	COE	Operating cost	Salvage cost
	€	€	€	€/kWh	€/year	€
"Old" plant	878.621,00	163.664,00	1.789.274,00	0,258	47.580,00	83.968,00
"New" plant	878.621,00	160.241,00	1.785.379,00	0,262	47.377,00	84.128,00

Table 23. Cost comparison of the two hybrid plants

The Cost Of Energy (COE) in this case is a bit higher, because the formula for the calculation of this indicator is the following:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC}}$$

where

- $C_{ann,tot}$ is the total annualized cost of the system (€/year)
- $E_{prim,AC}$ is the AC primary load served (kWh/year)

Total annualized costs are quite similar: for the "old" hybrid plant this cost is 93.487 €/year and for the "new" hybrid plant is 93.283 €/year, but in the second case the load served is smaller (355.510 versus 362.810 kWh/year).

Even if the reduction of the biomass increases a bit the COE, the cost of the energy is still convenient with respect to the diesel power plant.

6.7.3 Different distribution of the wood chipper functioning

Another possible change is setting the wood chipper for working for two hours (from 12 p.m. to 2 p.m.) and not for three hours.

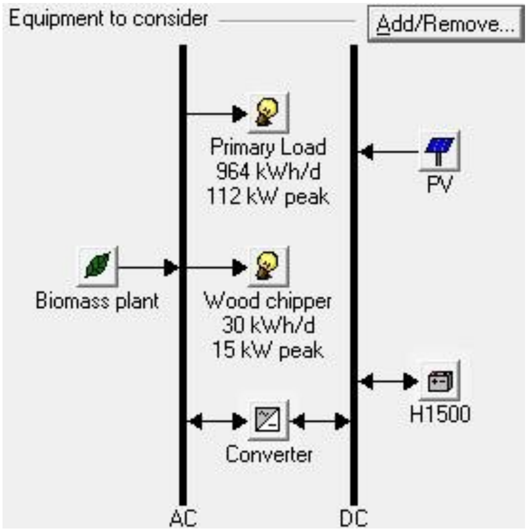


Figure 52. Hybrid plant with the wood chipper working for two hours

The result is that the COE is the same as before and there are only small variations in the operating costs and, consequently, in the NPC (see Table 14 for the comparison).

PV (kW)	BP (kW)	H1500	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	BP (hrs)	Batt. Lf. (yr)
	100	24	36	CC	$ 865,004	45,659	$ 1,738,895	0.250	1.00	601	5,775	19.2
	100	48	36	CC	$ 877,988	47,253	$ 1,782,372	0.257	1.00	605	5,547	16.3
12	100	24	36	CC	$ 878,621	47,586	$ 1,789,394	0.258	1.00	570	5,673	15.2
12	100	48	36	CC	$ 891,605	49,233	$ 1,833,888	0.264	1.00	572	5,511	18.3

Table 24. HOMER simulations with the wood chipper working for two hours

6.7.4 Different models of the wood chipper

The last change that is possible to make in the model of the hybrid plant, is modelling the wood chipper as a deferrable load.

A deferrable load is a load that has to be served in a period, but the exact time is not relevant. This load is served after the primary load, but it has a priority over batteries charging.

If the dispatch strategy is load following (LF), HOMER serves the deferrable load when the system is producing electricity in excess; if the strategy is cycle charging (CC), it will also serve the load when the generator is producing more electricity that the one that needs the primary load.[21]

I modelled both the hybrid plants without and with the reduction of the biomass.

In the Figure 53 and 54 are shown the architectures of the models and in the Figure 55 there are the inputs of the deferrable load in the hybrid plant with no reduction of the feedstock.

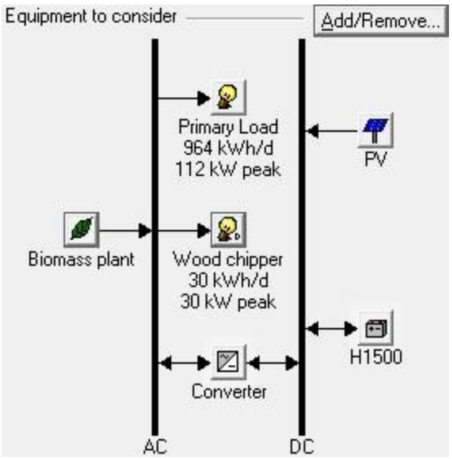


Figure 53. Wood chipper modelled as a deferrable load (no biomass reduction)

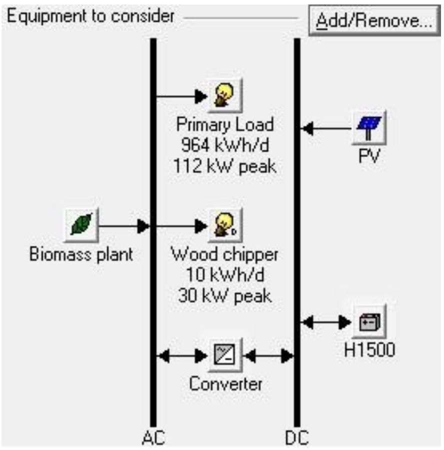


Figure 54. Wood chipper modelled as a deferrable load (with biomass reduction)

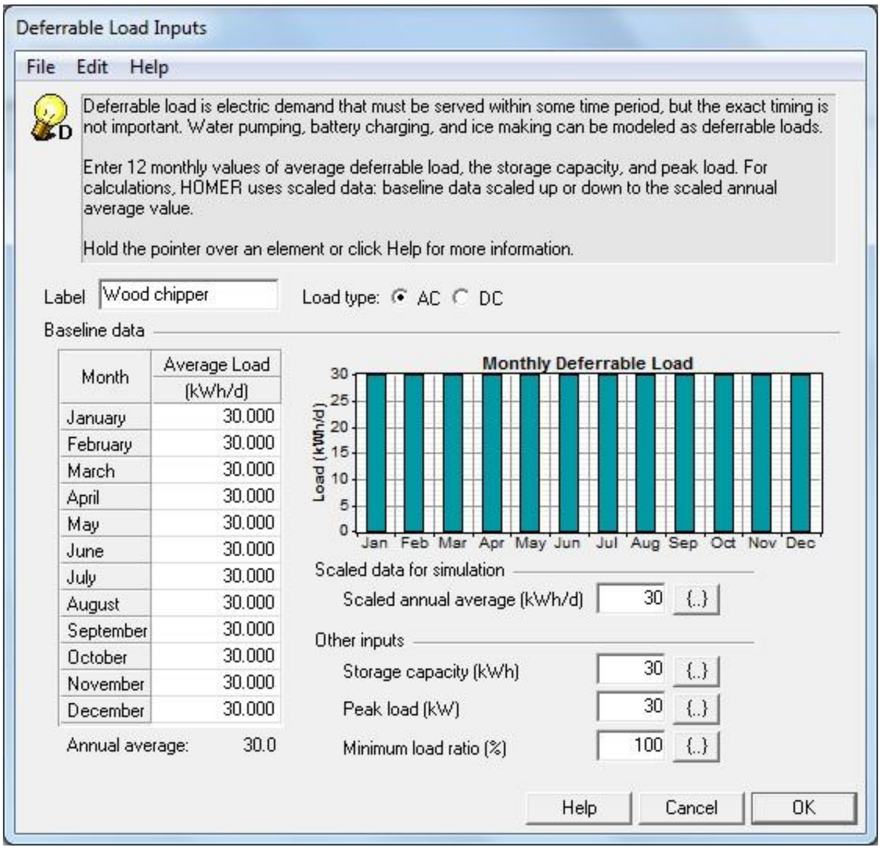


Figure 55. Deferrable load inputs

The model of the deferrable load in the case of biomass reduction is equivalent, only with 10 kW instead of 30 kW.

The Cost Of Energy is the same as the previous models (0,258 for the hybrid plant without the reduction of the feedstock and 0,262 for the plant with biomass reduced) and variations in the NPC are small, but in the case of modelling the wood chipper as a deferrable load in the plant without a biomass reduction the unmet load is higher than other cases (8,22 kWh/year).

6.7.5 Comparison of the different models

For a simpler comprehension of the differences between the models, I created a summary table, where in addition to the economic indicators I put the unmet electric load.

	Capital	Fuel	NPC	COE	Operating cost	Salvage cost	Unmet electric load
	€	€	€	€/kWh	€/year	€	kWh/year
Hybrid plant (HP)	878.621,00	163.664,00	1.789.274,00	0,258	47.580,00	83.968,00	0,000161
HP bio. red.	878.621,00	160.241,00	1.785.379,00	0,262	47.377,00	84.128,00	0,000140
HP, wood chipper 2 hours	878.621,00	163.768,00	1.789.706,00	0,258	47.586,00	83.149,00	0,000395
HP, deferrable load	878.621,00	163.668,00	1.790.053,00	0,258	47.621,00	83.823,00	8,22
HP bio. red., deferrable load	878.621,00	160.706,00	1.785.238,00	0,262	47.369,00	84.017,00	0,000150

Table 25. Comparison between hybrid plants

From this table is possible to deduce that the best choice for modelling the hybrid plant is the first, because the COE is lower and the unmet electric load is sufficiently low.
Another good choice could be the second model, with a reduction of biomass, that has a COE slightly higher, but a lower unmet load.

6.8 Possible location of the hybrid plant

The plant does not have a great need of space, because the surface covered by the solar panels is about 63 m^2 and the biomass plant needs about 84 m^2.

One possible location of the plant is shown in the following figure (red circle).

Figure 56. Possible location of the hybrid plant

In this site the plant is easily accessible due to the presence of a small road and there is far enough from the households for safety issues.

There is also enough space for the creation of an electrical substation from where electrical lines will start.

7 Conclusions

For this thesis I was inspired by an article of the World Energy Outlook, which reported that about 1,3 billion people in the world do not have access to electricity.

I decided to make a feasibility study of an off-grid hybrid plant located in Ouango (Central African Republic) because during my researches I was astonished to read that in this country all schools do not have electricity and this is the worst situation in the whole African continent.

The choice of the sources and the off-grid nature of the plant were a consequence of the location election, due to the good availability of sun and biomass and the lack of electric power infrastructures.

For this feasibility study, the starting point was to make assumptions about the loads that can be useful for the single household and the ones needed by the whole community.

After that, I generated a load curve of a typical day and I looked for data related to solar energy and biomass.

Designing the solar plant was easier because data of monthly radiation in Ouango are available in the PVGIS database. So, after retrieving these values it was possible to choose the panel that suited best the photovoltaic plant and to calculate the type of controllers and inverters needed.

I chose to use fifty Panasonic VBHN240SE10 modules, because they have a high module efficiency and a low temperature coefficient, which is perfect for working also at high temperatures. The peak power of the photovoltaic plant is 12 kW.

Solar charge controllers Xantrex XW MPPT 80 600 have a high input voltage (from 195 to 550 V) and a maximum output power of 4800 W, so it is possible to connect up to twenty modules for every controller and this reduces the number of controllers required. In this plant I used three controllers.

For creating a three-phase grid were used six XW X6048 inverters/chargers, that convert DC to AC current and also charge batteries. The total output power is 36 kW, so in the future it is possible to expand the system.

After designing the photovoltaic plant, I started looking for biomass data and spent a lot of time in this research, because it is quite difficult to find updated information of Central African Republic.

I individuated a useful area but I had to make some assumptions like the types of biomass available near the town and the related quantities using the FAO Crop Calendar.

With the help of Phyllis2 and Feedipedia, I characterized the biomass and selected the most suitable for the biomass plant, taking into account ash percentage, moisture content and higher heating value (HHV).

I created some tables of the monthly biomass distribution and the monthly energy provided by the residues, then I individuated a gasifier to convert biomass to syngas (the BioMax® Modular Bioenergy System).

For the functioning of the BioMax® system a wood chipper that reduces residues dimensions to a size suitable for the plant is required.

Using HOMER, a commercial tool that models and evaluates the economic and technical feasibility of a plant, I performed some simulations of the hybrid plant and compared the results with a traditional diesel power plant, because at present the only way to produce energy in many parts of Central African Republic is to use diesel generators.

The result was that, even if the hybrid power has an initial capital cost 95% higher than a traditional diesel plant, its Cost Of Energy is lower (0,258 €/kWh versus 0,717 €/kWh) due to the fuel costs that are almost zero.

I also tried different models of the hybrid plant, reducing the biomass feedstock and modelling in different ways the wood chipper. The hybrid plant solution turns to be still convenient, even though biomass reduction slightly raises the COE (0,262 €/kWh).

This feasibility study demonstrates that a hybrid power plant with solar and biomass energy could be a valid alternative to the traditional diesel plants and could help improving life quality in rural areas.

There is a lot of other work to do, for example there is the need of real data taken on site to verify this preliminary study.

Fundamental data to focus on are the followings:

- population of Ouango and their real energy needs
- real biomass availability *in situ* and its quantity
- emissions
- land surveys for the best positioning of the photovoltaic panels (e.g., to avoid shades) and the biomass plant

There is also the need to investigate the possibility to dispatch the different solar panels or to separate the solar plant from the biomass plant.

One last problem to be examined is the stability of the off grid solution, a question that is still under consideration.

8 ANNEXES

8.1 Field hospital

Generatori

Il GCU dispone di tre generatori di corrente con caratteristiche e potenzialità diverse.

1. **Un generatore capace di erogare 12 Kw** in grado di sopportare il peso dell'assorbimento contemporaneo dei vari dispositivi elettrici posti in funzione (**Elettrobisturi, Autoclave per sterilizzazioni ecc.**)
2. **Un generatore capace di erogare 10 Kw utilizzato come vicario** e in serie rispetto al primo come previsto dalle disposizioni vigenti nella CEE.
3. **Un generatore capace di erogare 3 Kw utilizzato per alimentare le soffianti** in fase di allestimento del campo e/o **per alimentare il PMA di 2° Livello** senza utilizzo della Sala Operatoria.

Due torri faro telescopiche per illuminazione del campo.

Come previsto dalle Norme Vigenti CEE per erogazione di energia ad ambulatori di Tipo A l'energia elettrica a 220 V e/o commutata a 12 V, deve essere veicolata e condizionata da un **Trasformatore di Isolamento.**

Tutto il **cablaggio** risponde **a norme CEE** e gli **innesti antiumidità** rispondono allo **Standard IP 65** per il grado di isolamento.

Source: www.gcupisa.it/le-strutture/generatori/

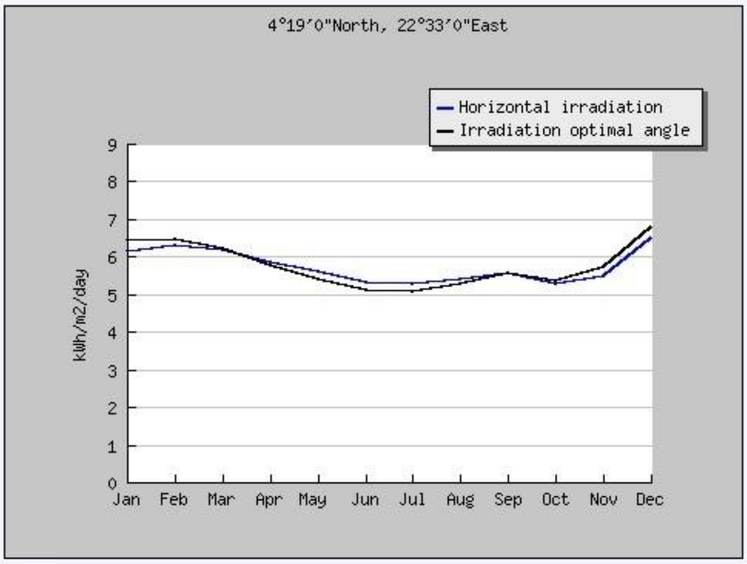
8.2 Loads tables

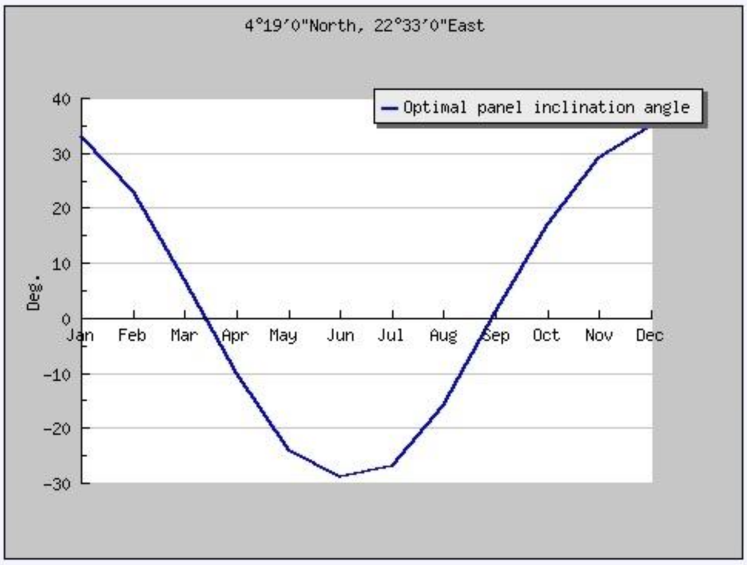
HOUSEHOLD LOADS	Total Power [W]	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-0
Lights	80,00	0	0	0	0	0	0	40	40	40	0	0	0	0	0	0	0	0	0	40	80	80	80	0	0
Mobile charger	6,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Floor fan	90,00	0	0	0	0	0	0	0	0	0	45	45	90	90	90	90	90	45	45	0	0	0	0	0	0
		0	0	0	0	0	0	40	40	40	45	45	90	90	90	90	90	45	45	46	80	80	80	0	0

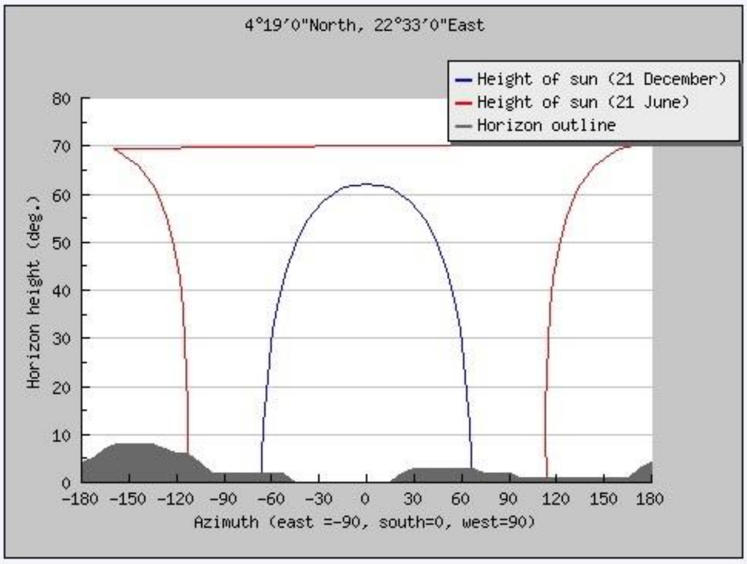
PUBLIC LOADS	Total Power [W]	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-0
Mobile Phone Antenna	25,00	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
School Lights	160,00	0	0	0	0	0	0	0	0	160	160	160	0	0	0	0	0	160	160	0	0	0	0	0	0
Lights (various)	120,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	120	0	0	0
Fridges	300,00	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
Freezers	300,00	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
TV	400,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400	400	0	0	0
Computers	200,00	0	0	0	0	0	0	0	0	40	40	40	40	40	40	40	40	40	40	0	0	0	0	0	0
Field Hospital	10.000,00	500	500	500	500	500	500	2.000	2.500	2.500	2.500	2.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	2.000	1.000	500	500
		723	723	723	723	723	723	2.223	2.723	2.923	2.923	2.923	1.263	1.263	1.263	1.263	1.263	1.423	1.423	2.223	2.743	2.743	1.223	723	723

	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-0
HOUSEHOLD LOADS	0	0	0	0	0	0	40	40	40	45	45	90	90	90	90	90	45	45	46	80	80	80	0	0
HOUSEHOLDS LOADS	0	0	0	0	0	0	36.000	36.000	36.000	40.500	40.500	81.000	81.000	81.000	81.000	81.000	40.500	40.500	41.400	72.000	72.000	72.000	0	0
PUBLIC LOADS	723	723	723	723	723	723	2.223	2.723	2.923	2.923	2.923	1.263	1.263	1.263	1.263	1.263	1.423	1.423	2.223	2.743	2.743	1.223	723	723
GLOBAL LOADS	723	723	723	723	723	723	38.223	38.723	38.923	43.423	43.423	82.263	82.263	82.263	82.263	82.263	41.923	41.923	43.623	74.743	74.743	73.223	723	723

8.3 Solar irradiation graphs







Source: PVGIS

8.4 Table of monthly coefficients

	J	F	M	A	M	J	J	A	S	O	N	D
Irradiation	199,02	180,88	192,82	173,10	168,02	153,60	157,79	163,99	166,50	166,47	171,30	210,80
Cons 12 V	3.093.596	2.794.216	3.093.596	2.993.802	3.093.596	2.993.802	3.093.596	3.093.596	2.993.802	3.093.596	2.993.802	3.093.596
Cons 24 V	1.546.798	1.397.108	1.546.798	1.496.901	1.546.798	1.496.901	1.546.798	1.546.798	1.496.901	1.546.798	1.496.901	1.546.798
Cons 48 V	773.399	698.554	773.399	748.451	773.399	748.451	773.399	773.399	748.451	773.399	748.451	773.399
Coef 12 V	15.544,15	15.447,90	16.043,96	17.295,22	18.412,07	19.490,90	19.605,78	18.864,54	17.980,80	18.583,50	17.476,96	14.675,50
Coef 24 V	7.772,07	7.723,95	8.021,98	8.647,61	9.206,03	9.745,45	9.802,89	9.432,27	8.990,40	9.291,75	8.738,48	7.337,75
Coef 48 V	3.886,04	3.861,97	4.010,99	4.323,80	4.603,02	4.872,73	4.901,44	4.716,13	4.495,20	4.645,88	4.369,24	3.668,88

8.5 Fact sheet Panasonic VBHN240SE10 module

Panasonic
ideas for life

HIT® photovoltaic module

N240
N235

R&D technology adaptation
Improvement of cell efficiency to reduce
- carrier recombination loss
- optical absorption loss
- resistance loss

New tab design
Application of three tabs
- Reducing electrical loss between the cell fingers and tabs
- Making the tab width thinner to expand the light receiving surface

Anti-reflection glass
Light capturing technology
- Reducing reflection and scattering of incoming light
- Improving generated electricity levels in morning and evening times

19.0%*
190 W/m²

* For N240

HIT cell technology

The HIT (Heterojunction with Intrinsic Thin layer) solar cell is made of a thin monocrystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. This product provides the industry's leading performance and value using state-of-the-art manufacturing techniques. The development of the HIT solar cell was supported in part by the New Energy and Industrial Technology Development Organization (NEDO).

Quality

Panasonic is truly committed to quality since it began developing and manufacturing solar PV modules in 1975. Our long track record is supported with our claim-rate of only 0.0034% out of 3,200,497 solar modules produced in our European factory in Dorog, Hungary (as of July 2012).

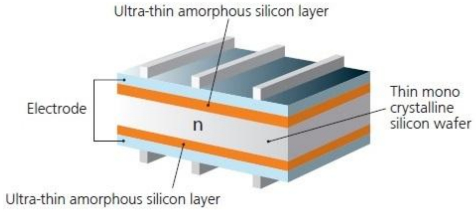
Special features

HIT solar modules are 100% emission free, have no moving parts and produce no noise. The dimensions of the HIT modules enable a space saving installation and the achievement of maximum output power possible on a given roof area.

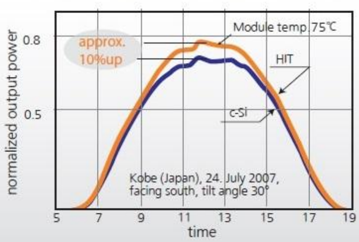
High performance at high temperatures

Even at high temperatures, the HIT solar cell can maintain higher efficiency than a conventional crystalline silicon solar cell.

HIT® solar cell structure



Changes in generated power daytime



HIT®
Photovoltaic Module

"HIT" is a registered trademark of the Panasonic Group.
The name "HIT" comes from "Heterojunction with Intrinsic Thin-layer" which is an original technology of the Panasonic Group.

The HIT cell and module have very high conversion efficiency in mass production.

Model	Cell Efficiency	Module Efficiency	Output/m²
N240	21.6%	19.0%	190 W/m²
N235	21.1%	18.6%	186 W/m²

Electrical and Mechanical Characteristics N240, N235

HIT® Photovoltaic Module

Electrical data (at STC)

	VBHN240SE10	VBHN235SE10
Max. power (Pmax) [W]	240	235
Max. power voltage (Vmp) [V]	43.7	43.0
Max. power current (Imp) [A]	5.51	5.48
Open circuit voltage (Voc) [V]	52.4	51.8
Short circuit current (Isc) [A]	5.85	5.84
Max. over current rating [A]	15	
Production tolerance power [%]	+10/-5*	
Max. system voltage [V]	1000	

Note: Standard Test Conditions: Air mass 1.5; Irradiance = 1000W/m²; cell temp. 25°C
* All modules measured by Panasonic facility have output with positive tolerance.

Temperature characteristics

	VBHN240SE10	VBHN235SE10
Temperature (NOCT) [°C]	44.0	44.0
Temp. coefficient of Pmax [%/°C]	-0.29	-0.29
Temp. coefficient of Voc [V/°C]	-0.131	-0.130
Temp. coefficient of Isc [mA/°C]	1.76	1.75

At NOCT

	VBHN240SE10	VBHN235SE10
Max. power (Pmax) [W]	182	179
Max. power voltage (Vmp) [V]	41.1	40.5
Max. power current (Imp) [A]	4.44	4.41
Open circuit voltage (Voc) [V]	49.4	48.9
Short circuit current (Isc) [A]	4.71	4.70

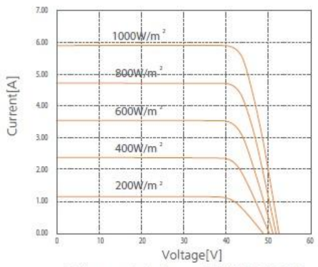
Note: Nominal Operating Cell Temp.: Air mass 1.5 spectrum; Irradiance = 800W/m²; Air temperature 20°C; wind speed 1 m/s

At low irradiance

	VBHN240SE10	VBHN235SE10
Max. power (Pmax) [W]	45.9	44.7
Max. power voltage (Vmp) [V]	41.7	41.0
Max. power current (Imp) [A]	1.10	1.09
Open circuit voltage (Voc) [V]	49.0	48.4
Short circuit current (Isc) [A]	1.17	1.17

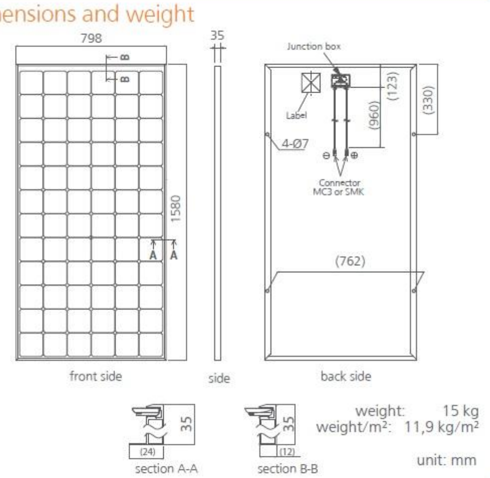
Note: Low irradiance: Air mass 1.5 spectrum; Irradiance = 200W/m²; cell temp. = 25°C

Dependence on irradiance



Reference data for model VBHN240SE10 (Cell temperature: 25°C)

Dimensions and weight



weight: 15 kg
weight/m²: 11,9 kg/m²
unit: mm

Guarantee

Power output: 10 years (90% of Pmin), 25 years (80% of Pmin)
Product workmanship: 10 years
(Based on guarantee document)

Materials

Cell material: 5 inch HIT cells
Glass material: AR coated tempered glass
Frame materials: Black anodized aluminium
Connectors type: MC3 or SMK

Certificates

Member of

PV CYCLE

Please consult your local dealer for more information.

⚠CAUTION! Please read the installation manual carefully before using the products.

Panasonic Eco Solutions Energy Management Europe
SANYO Component Europe GmbH

Stahlgruberring 4
81829 Munich, Germany
Tel.+49-(0)89-460095-0
Fax +49-(0)89-460095-170
http://www.eu-solar.panasonic.net

Panasonic

All Rights Reserved © 2012 COPYRIGHT SANYO Component Europe GmbH
Specifications are subject to change without notice.
10/2012

8.6 Datasheet SE Xantrex XW MPPT 80 600 solar charge controller

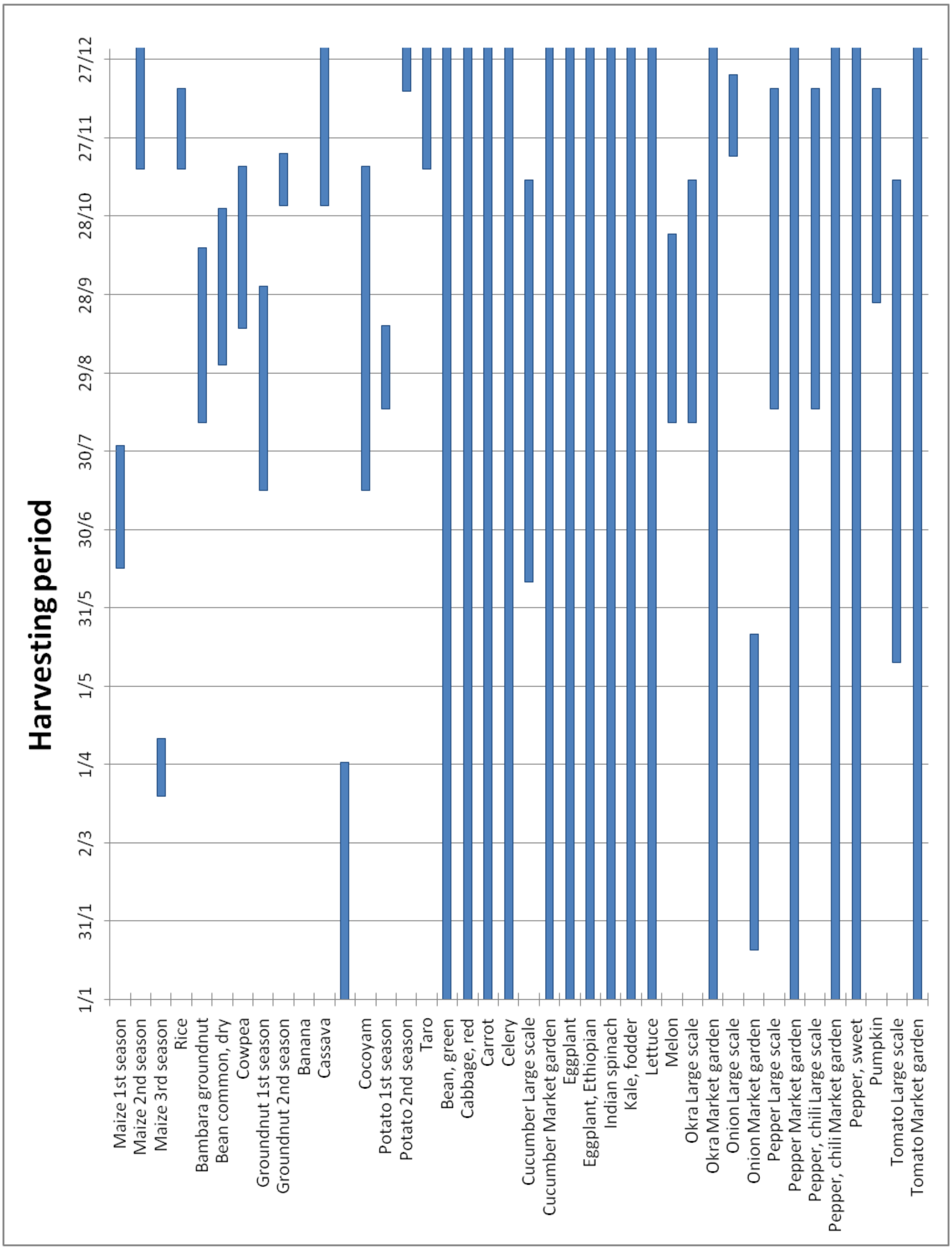
MPPT 80 600 solar charge controller

Device short name	MPPT 80 600
Electrical specifications	
Nominal battery voltage	24 and 48 V (Default is 48 V)
Max. PV array voltage (operating)	195 to 550 V
Max. PV array open circuit voltage	600 V including temperature correction factor
Battery voltage operating range	16 to 67 VDC
Array short-circuit current	35 A (28 A @ STC)
Max. charge current	80 A
Max. and min. wire size in conduit	#6 AWG to #14 AWG (13.5 to 2.5 mm²)
Max. output power	2560 W (nominal 24 V), 4800 W (nominal 48 V)
Charger regulation method	Three-stage (bulk, absorption, float) plus manual equalization Two-stage (bulk, absorption) plus manual equalization
Supported battery types	Flooded, GEL, AGM, Custom
Efficiency	
Max. power conversion efficiency	94% (nominal 24V), 96% (nominal 48V)
General specifications	
Power consumption, night time	< 1 W
Battery temperature sensor	Included
Auxiliary output	Dry contact switching up to 60VDC, 30VAC, 8A
Enclosure material	Indoor, ventilated, aluminum sheet metal chassis with 22.22 mm and 27.76 mm (7/8 in and 1 in) knockouts and aluminum heat sink
IP degree of protection	IP20
Product weight	13.5 kg (29.8 lb)
Shipping weight	17.4 kg (38.3 lb)
Product dimensions (H x W x D)	76.0 x 22.0 x 22.0 cm (30.0 x 8.6 x 8.6 in)
Shipping dimensions (H x W x D)	87.0 x 33.0 x 27.0 cm (34.3 x 13.0 x 10.6 in)
Device mounting	Vertical wall mount
Ambient air temperature for operation	-20°C to 65°C (-4°F to 149°F), power derating above 45°C
Storage temperature range	-40°C to 85°C (-40°F to 185°F)
Operating altitude	Sea level to 2000 m (6562 ft)
System network and remote monitoring	Available
Warranty	Five-year standard
Part number	865-1032

8.7 Datasheet SE Conext XW inverter/charger 6048

Device short name	XW4024 230 50	XW4548 230 50	XW6048 230 50
Electrical specifications			
Continuous power	4.0 kVA	4.5 kVA	6.0 kVA
Surge rating	8.0 kVA (20 sec)	9.0 kVA (15 sec)	12.0 kVA (15 sec)
Output current	17.4 A	19.6 A	26.1 A
Peak output current (rms)	35 A	40 A	53 A
Input current at rated power	178 A	96 A	131 A
Type of signal	True sine wave	True sine wave	True sine wave
Automatic transfer relay	56 A	56 A	56 A
Typical transfer time	8 ms	8 ms	8 ms
DC input voltage (nominal)	25.2 V	50.4 V	50.4 V
Input voltage limits	20 to 32 V	40 to 64 V	40 to 64 V
Charging current	150 A	85 A	100 A
Power factor corrected charging	0.98	0.98	0.98
Auxiliary relay output	0 to 12 V, maximum 250 mA DC	0 to 12 V, maximum 250 mA DC	0 to 12 V, maximum 250 mA DC
Power consumption (search mode)	< 7 W	< 7 W	< 7 W
AC input voltage (nominal)	230 V +/- 3%	230 V +/- 3%	230 V +/- 3%
Input voltage limits (bypass/charge mode)	165 to 280 V (230 V nominal)	165 to 280 V (230 V nominal)	165 to 280 V (230 V nominal)
Frequency	50 Hz +/- 0.1 Hz	50 Hz +/- 0.1 Hz	50 Hz +/- 0.1 Hz
AC input frequency range (bypass/charge mode)	40 to 68 Hz (50 Hz nominal)	40 to 68 Hz (50 Hz nominal)	40 to 68 Hz (50 Hz nominal)
Total harmonic distortion (THD)	< 5% at rated power	< 5% at rated power	< 5% at rated power
AC connections	AC1 (Grid), AC2 (Generator)	AC1 (Grid), AC2 (Generator)	AC1 (Grid), AC2 (Generator)
AC input breaker	60 A single-pole	60 A single-pole	60 A single-pole
Efficiency			
Peak	94.0%	95.6%	95.4%
General specifications			
IP degree of protection	IP20 (sensitive electric components sealed inside enclosure)		
Product weight	52.5 kg (116.0 lb)	53.5 kg (118.0 lb)	55.2 kg (121.7 lb)
Shipping weight	74.0 kg (163.0 lb)	75.0 kg (165.0 lb)	76.7 kg (169.0 lb)
Product dimensions (H x W x D)	58 x 41 x 23 cm (23 x 16 x 9 in)	58 x 41 x 23 cm (23 x 16 x 9 in)	58 x 41 x 23 cm (23 x 16 x 9 in)
Shipping dimensions (H x W x D)	71.1 x 57.2 x 39.4 cm (28.0 x 22.5 x 15.5 in)	71.1 x 57.2 x 39.4 cm (28.0 x 22.5 x 15.5 in)	71.1 x 57.2 x 39.4 cm (28.0 x 22.5 x 15.5 in)
Device mounting	Wall mount (backplate included)	Wall mount (backplate included)	Wall mount (backplate included)
Ambient air temperature for operation	-25°C to 70°C (-13°F to 158°F) (power derated above 45°C (113°F)		
System network and remote monitoring	Available	Available	Available
Warranty (Depending on the country of installation)	2 or 5 years	2 or 5 years	2 or 5 years
Part number	865-1045-61	865-1040-61	865-1035-61
Features and options			
Display type	Status LEDs indicate AC In status, faults/warnings, equalize mode, On/Off and equalize button battery level. Three-character display indicates output power or charge current		
Supported battery types	Flooded (default), Gel, AGM, custom	Flooded (default), Gel, AGM, custom	Flooded (default), Gel, AGM, custom
Battery bank size	100 to 2000 Ah (scaled to PV array size)		
Battery temperature sensor	Included	Included	
Non volatile memory	Yes	Yes	
Multiple unit configurations	Single-phase: up to four parallel units. Three-phase: two units per phase		
Regulatory approval			
CE marked according to the following EU directives and standards:			
EMC directive	EN61000-6-1, EN61000-6-3, EN61000-3-2, EN61000-3-3		
Low voltage directive	EN50178		
RCM marked and compliant	AS 4777.2, AS 4777.3, AS/NZS 3100		

8.8 Harvesting calendar



8.9 Reference data agricultural (alphabetical order)

8.9.1 Bean straw

- Characterization (Feedipedia)

Common bean straw

Main analysis	Unit	Avg	SD	Min	Max	Nb
Dry matter	% as fed	88.0	4.1	81.2	94.4	8
Crude protein	% DM	7.1	1.8	4.8	10.7	13
Crude fibre	% DM	41.0	2.9	38.1	45.2	6
NDF	% DM	69.7	12.3	51.1	86.4	7
ADF	% DM	48.5	7.8	37.3	56.9	8
Lignin	% DM	8.0	1.4	5.4	9.3	6
Ether extract	% DM	1.1	0.5	0.7	1.8	6
Ash	% DM	8.9	1.4	7.2	12.1	13
Gross energy	MJ/kg DM	17.9				

Source: www.feedipedia.org

- Bean yield

Expected yields from commercial plantings of some vegetable crops can be listed under three headings:

The conservative yield
The "conservative" yield is that obtained from a relatively poor crop, and is frequently not economical to produce, unless particularly high prices are realised.

The likely yield
The "likely" yield is that achieved from the majority of plantings by the average grower.

The target yield
The "target" figures are those that a good grower could realistically achieve in practice. These are not considered to be the potential yields of the prospective crops. For example, the target figure for dwarf green beans is given as 10 to 15 tons per hectare. Yields of over 20 tons per hectare have been achieved by some growers, even from large plantings, and certain trial plots have yielded the equivalent of about 30 tons per hectare. Similarly, carrots could yield in excess of 70 tons per hectare, cabbage over 110 tons per hectare and tomatoes more than 100 tons per hectare, from specific commercial plantings. However, such yields are exceptional. Yields that a commercial grower may expect from the main vegetable crops grown, divided according to the above categories, are suggested in the following table.

Table 8.
Commercial yields of vegetable crops.

Crop	Yield in tons per hectare		
	Conservative	Likely	Target
Artichoke, globe	3	5	7 - 8
Asparagus	1,5	2,5	4
Bean, broad	3 - 4	5 - 6	7 - 8
Bean, dwarf, green	5	7 - 8	10 - 15
Bean, lima	5	7	10
Bean, runner, green	7	10	15 - 20

Source: http://www.kzndae.gov.za/Portals/0/Horticulture/Veg%20prod/expected_yields.pdf

- CR_P

Tabla 15.4. Coeficiente de generación de la biomasa procedente de diversos tipos de cultivo.

Tipo de cultivo	Coeficiente de generación (t residuo/t producto)
CEREALES GRANO	
Trigo	1,20
Cebada	1,35
Avena	1,35
Centeno	1,35
Maíz	2,00
Arroz	1,50
Sorgo	1,70
FRUTALES	
Cítricos	0,15
F. pepita	0,25
F. hueso	0,25
F. seco	3,15
Olivar	1,55
Viñedo	0,85
INDUSTRIALES	
Girasol	2,00
Algodón	2,00
Caña azúcar	1,50

Source: Book "Tratamiento y valorización energética de residuos" (Xavier Elías Castells)

8.9.2 Cassava residues

- Characterization (Feedipedia)

Cassava peels, dry

Main analysis	Unit	Avg	SD	Min	Max	Nb
Dry matter	% as fed	87.4	5.3	79.7	94.2	8
Crude protein	% DM	5.2	1.9	2.9	8.2	8
Crude fibre	% DM	14.0	10.1	7.6	38.4	8
NDF	% DM	51.4				1
ADF	% DM	37.4				1
Ether extract	% DM	1.4	0.8	0.7	3.0	8
Ash	% DM	5.8	1.1	4.7	7.5	8
Gross energy	MJ/kg DM	19.5		19.1	19.8	2

Cassava pomace, dehydrated

Main analysis	Unit	Avg	SD	Min	Max	Nb
Dry matter	% as fed	89.2	3.0	83.5	94.8	12
Crude protein	% DM	2.2	0.7	1.1	3.4	13
Crude fibre	% DM	16.7	4.4	12.1	26.9	9
NDF	% DM	36.7	11.7	7.3	46.7	9
ADF	% DM	19.3	11.5	3.3	35.2	9
Lignin	% DM	3.6				1
Ether extract	% DM	0.6	0.5	0.2	2.0	10
Ash	% DM	4.3	1.5	1.5	6.5	13
Starch (polarimetry)	% DM	52.3	7.0	42.8	64.0	8
Total sugars	% DM	3.3				1
Gross energy	MJ/kg DM	16.2	1.1	14.7	17.5	6

Source: www.feedipedia.org

- Cassava yield

Crop	Cassava
Scientific name	Manihot esculenta Crantz
Botanical family	Euphorbiaceae
Other names	Manioc
Sowing / Planting period	15/04 - 15/09
Harvesting period	-
Sowing / Planting rate	10,000-12,000 cuttings/ha
Planting material	Cuttings of 25-30 cm
Length of the cropping cycle	180-400 days
Comments	Most cultivated crop in terms of number of growers and land area. Stem cuttings planted in March are attacked by termites. The harvest is spaced out when the variety has outlived its cycle. Yields in farmers' fields vary from 4,000 to 6,000 kg/ha.

Source: FAO Crop Calendar

- CR_P

Description

The processing of cassava tubers yields the following by-products that can be valuable livestock feeds when properly processed (Aro et al., 2010):

- **Cassave peels** can represent 5 to 15% of the root (Aro et al., 2010; Nwokoro et al., 2005a). They are obtained after the tubers have been water-cleansed and peeled mechanically (Aro et al., 2010). They may contain high amounts of cyanogenic glycosides and have a higher protein content than other tuber parts (Tewe, 2004).
- **Cassave pomace**, also called **cassava fibre**, **cassava bran**, **cassava bagasse**, **cassava starch residue** and **cassava pulp**: all these terms refer to the solid fibrous residue (up to 17% of the tuber) that remains after the flour or starch content has been extracted (Aro et al., 2010). The quality and appearance of these residues vary with plant age, time after harvest and industrial equipment and method used (Cereda et al., 1996).
- **Cassava sievate** or **garri sievate** is the by-product of the production of garri (also spelled *gari* or *gary*), a popular West African food. Tubers are peeled, crushed and then fermented. The resulting product is then sieved and roasted. The sievate represents 15-17% of the root in weight (Nwokoro et al., 2005a).
- **Cassava stumps** are the ends trimmed off the cassava tubers as they are manually prepared for onward transmission into the rotary washer and peeler (Aro et al., 2010).
- **Cassava whey** is the liquid pressed out of the tuber after it has been crushed mechanically. The whey and the pomace may be mixed together to form an effluent (or slurry) (Aro et al., 2010).
- **Discarded tubers**: tubers that fail to meet quality standards for processing are discarded and can be used for animal feeding. Discarded tubers are sometimes still attached to the peduncle and therefore may contain more fibre. They may also be mixed with the stumps (Scapinello et al., 2005).

Source: www.feedipedia.org/node/526

8.9.3 Corn stalks

- Characterization (Pyillis2)

corn stalks (#2790)

ID-number	#2790
Material	corn stalks
Classification	ECN Phyllis classification ▸ straw (stalk/cob/ear) ▸ maize/corn ▸ corn stalks
	NTA 8003 classification ▸ [200] biomassa uit land- en tuinbouw ▸ [240] gewassen ▸ [241] mais
Submitter organisation	ECN (Netherlands)
Submission date	2006-07-10
Literature	Y.J. Lu, L.J. Guo, C.M. Ji, X.M. Zhang, X.H. Hao, Q.H. Yan:Hydrogen production by biomass gasification in supercritical water: a parametric study. Int J Hydrogen Energy 31 (2006) 822-831

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▾ Fuel Properties										
▾ Proximate Analysis										
Moisture content	wt%	8.02	← Edit							
Ash content	wt%	6.46	7.02							
Volatile matter	wt%	67.55	73.44	78.98						
Fixed carbon	wt%	17.97	19.54	21.02					Calculated	
▾ Ultimate Analysis										
Carbon	wt%	41.18	44.77	48.15					Measured	
Hydrogen	wt%	4.96	5.39	5.80					Measured	
Nitrogen	wt%	0.78	0.85	0.91					Measured	
Sulphur	wt%	0.19	0.21	0.22					Measured	
Oxygen	wt%	38.41	41.76	44.91					Calculated	
Total (with halides)	wt%	100.00	100.00	100.00					Calculated	
▾ Calorific Values										
Net calorific value (LHV)	MJ/kg	14.30	15.76	16.95						
Gross calorific value (HHV)	MJ/kg	15.58	16.94	18.22						
HHV_{Milne}	MJ/kg	15.82	17.20	18.50					Calculated	

- Corn yield

Crop	Maize First season
Scientific name	Zea mays L.
Botanical family	Poaceae
Other names	Corn
Sowing / Planting period	15/03 - 30/04
Harvesting period	15/06 - 31/07
Sowing / Planting rate	15-25 kg/ha
Planting material	
Length of the cropping cycle	90-120 days
Comments	Rainfed crop, manual, without fertilization, sometimes associated with legumes. Yields in farmers' fields vary from 1,500 to 3,000 kg/ha.

Source: FAO Crop Calendar

- CR_P

Tabla 15.4. Coeficiente de generación de la biomasa procedente de diversos tipos de cultivo.

Tipo de cultivo	Coeficiente de generación (t residuo/t producto)
CEREALES GRANO	
Trigo	1,20
Cebada	1,35
Avena	1,35
Centeno	1,35
Maíz	2,00
Arroz	1,50
Sorgo	1,70
FRUTALES	
Cítricos	0,15
F. pepita	0,25
F. hueso	0,25
F. seco	3,15
Olivar	1,55
Viñedo	0,85
INDUSTRIALES	
Girasol	2,00
Algodón	2,00
Caña azúcar	1,50

Source: Book "Tratamiento y valorización energética de residuos" (Xavier Elías Castells)

8.9.4 Groundnut shells

- Characterization (Feedipedia)

Bambara groundnut shells

Main analysis	Unit	Avg	SD	Min	Max	Nb
Dry matter	% as fed	91.8				1
Crude protein	% DM	6.7				1
NDF	% DM	47.6				1
ADF	% DM	29.8				1
Lignin	% DM	10.0				1
Ether extract	% DM	2.6				1
Ash	% DM	3.9				1
Gross energy	MJ/kg DM	18.3				1

Source: www.feedipedia.org

- Yield

Yield (Hg/Ha)

	item	2012	
Central African Republic	Avocados	78750	Fc
Central African Republic	Bananas	60952	Fc
Central African Republic	Bastfibres, other	2160	Fc
Central African Republic	Cassava	28132	Fc
Central African Republic	Chillies and peppers, dry	15000	Fc
Central African Republic	Cocoa, beans	500	Fc
Central African Republic	Coffee, green	4643	Fc
Central African Republic	Grapefruit (inc. pomelos)	76119	Fc
Central African Republic	Groundnuts, with shell	15595	Fc
Central African Republic	Lemons and limes	57447	Fc

Source: FAOSTAT

- CR_P

Right beside the buildings NOVASEN has large storage area for 6,000 t of groundnuts. Each conditioner supplies two screw presses with horizontal axis (**Figure 2**), and has a capacity of 100 t per day. With 300 working days per year. the annual capacity of the NOVASEN plant amounts to 60,000 t. In 1999 and 2000, the plant operated for about 200 days and produced between 35,000 and 42,000 t of groundnut oil per year. From the total groundnut weight, about 25 % is for the shells. NOVASEN has a shelling plant with a daily capacity of 90 t; the same amount of shelled ground nuts is brought from two other shelling plants operated by NOVASEN elsewhere in Kaolack (there, whole groundnuts are prepared for export).

Source: www.novator.se/bioint/NOVASEN.PDF

8.10 Data area harvested

Area harvested (Ha)

country	item	2012	
Congo	Beans, dry	5500	F
Congo	Beans, green	1000	F

country	item	2012	
Central African Republic	Avocados	800	F
Central African Republic	Bananas	21000	F
Central African Republic	Bastfibres, other	500	F
Central African Republic	Cassava	243219	
Central African Republic	Chillies and peppers, dry	80	F
Central African Republic	Cocoa, beans	2400	F
Central African Republic	Coffee, green	14000	F
Central African Republic	Grapefruit (inc. pomelos)	670	F
Central African Republic	Groundnuts, with shell	95715	
Central African Republic	Lemons and limes	470	F
Central African Republic	Maize	92261	

F = FAO estimate

Source: FAOSTAT

8.11 Reference data forestry (alphabetical order)

8.11.1 African oak

- Characterization (Phyllis2)

wood, oak (#2148)

ID-number	#2148
Material	wood, oak
Classification	ECN Phyllis classification ▸ untreated wood ▸ oak ▸ wood, oak NTA 8003 classification ▸ [100] hout ▸ [110] vers hout ▸ [120] loofhout ▸ [125] hard loofhout
Submitter organisation	ECN (Netherlands)
Submission date	2001-04-20
Remarks	water content in sample as analysed
Literature	Jones,J.M.; Pourkashanian,M.; Ross,A.; Danos,L.; Bartle,K.D.; Williams,A.; Kubica,K.; Andersson,J.; Kerst,M.; Danihelka,P.: The combustion of coal and biomass in a fixed bed furnace. Proc. 5th Eur. Conf. on Industrial Furnaces&Boilers 2000,vol.2,p.45-54.

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▾ Fuel Properties										
▾ Proximate Analysis										
Moisture content	wt%	5.30	← Edit							
Ash content	wt%	0.30	0.32							
Volatile matter	wt%	80.02	84.50	84.77						
Fixed carbon	wt%	14.38	15.18	15.23					Calculated	
▾ Ultimate Analysis										
Carbon	wt%	46.80	49.42	49.58					Measured	
Hydrogen	wt%	5.25	5.54	5.56					Measured	
Nitrogen	wt%	0.77	0.81	0.82					Measured	
Sulphur	wt%	0.08	0.08	0.08					Measured	
Oxygen	wt%	41.51	43.83	43.97					Calculated	
Total (with halides)	wt%	100.01	100.01	100.01					Calculated	
▾ Calorific Values										
Net calorific value (LHV)	MJ/kg	15.92	16.95	17.01						
Gross calorific value (HHV)	MJ/kg	17.20	18.16	18.22						
HHV_{Milne}	MJ/kg	17.83	18.82	18.89					Calculated	

8.11.2 Bamboo

- Characterization (Phyllis2)

bamboo (#2065)

ID-number	#2065
Material	bamboo
Classification	ECN Phyllis classification ▸ grass/plant ▸ other plants ▸ bamboo NTA 8003 classification ▸ [200] biomassa uit land- en tuinbouw ▸ [210] gras ▸ [219] overig gras
Submitter organisation	ECN (Netherlands)
Submission date	2001-04-05
Remarks	charcoal yield 45.9% at 1 MPa, fixed-C yield 32.1%
Literature	Antal,M.J., Allen,S.G., Dai,X, Shimizu,B., Tam,M.S. and Grønli: Attainment of the theoretical yield of carbon from biomass. Ind. Eng. Chem. Res. 39 (2000) 4024-4031

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▾ Fuel Properties										
▾ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		3.91							
▾ Ultimate Analysis										
Carbon	wt%		47.65	49.59					Measured	
Hydrogen	wt%		5.77	6.00					Measured	
Nitrogen	wt%		0.27	0.28					Measured	
Sulphur	wt%		0.11	0.11					Measured	
Oxygen	wt%		44.23	46.03					Measured	
Total (with halides)	wt%		101.94	102.02					Calculated	
▾ Calorific Values										
HHV_{Milne}	MJ/kg		18.49	19.24					Calculated	
▾ Chemical Analyses										
▾ Biochemical composition										
Cellulose	wt% (dry)			39.50					Sugar Analysis	
Hemicellulose	wt% (dry)			17.60					Sugar Analysis	
Lignin	wt% (dry)			25.20					Measured	
Lignin acid insoluble (AIL)	wt% (dry)			25.20					Measured	
▾ C5										
Arabinan	wt% (dry)			0.00						
Xylan	wt% (dry)			20.00						
Sum C5	wt% (dry)			20.00					Calculated	
▾ C6										
Mannan	wt% (dry)			0.00						
Galactan	wt% (dry)			0.00						
Glucan	wt% (dry)			43.90						
Sum C6	wt% (dry)			43.90					Calculated	
Total ash + biochemical	wt% (dry)			86.21					Calculated	

- Moisture content

4.3. Contenido de humedad en el Bambú

El contenido de humedad (CH) es un valor importante que debe ser conocido al momento de utilizar el bambú como un elemento estructural de una edificación. En relación con el contenido de humedad en el bambú es importante mencionar:

1. El bambú es un material higroscópico, el contenido de humedad depende del ambiente al que esté expuesto.
2. Entre menos contacto tenga el bambú con el agua, o esté expuesto en un ambiente húmedo, el contenido de humedad se estabiliza con un porcentaje entre 10 y 25 %, lo cual dependerá de la humedad relativa y la temperatura del ambiente. Este valor del contenido de humedad es mucho menor que cuando el bambú ha sido cortado. El secado natural producto de la temperatura atmosférica, disminuye el contenido de humedad que el bambú retiene.

Source: www.bdigital.unal.edu.co/6307/1/299844.2011.pdf

8.11.3 Casuarina wood

- Characterization (Phyllis2)

wood, casuarina (#1951)

ID-number	#1951
Material	wood, casuarina
Classification	ECN Phyllis classification ▸ untreated wood ▸ tropical hard wood ▸ wood, casuarina
	NTA 8003 classification ▸ [100] hout ▸ [110] vers hout ▸ [120] loofhout ▸ [125] hard loofhout
Submitter organisation	ECN (Netherlands)
Submission date	2001-02-21
Literature	S. Gaur and T.B. Reed; An Atlas of Thermal Data For Biomass and Other Fuels. NREL/TP-433-7965, June 1995

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▼ Fuel Properties										
▼ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		1.83							
Volatile matter	wt%		78.58	80.04						
Fixed carbon	wt%		19.59	19.96					Calculated	
▼ Ultimate Analysis										
Carbon	wt%		48.50	49.40					Measured	
Hydrogen	wt%		6.04	6.15					Measured	
Nitrogen	wt%		0.31	0.32					Measured	
Oxygen	wt%		43.32	44.13					Calculated	
Total (with halides)	wt%		100.00	100.00					Calculated	
▼ Calorific Values										
Net calorific value (LHV)	MJ/kg		17.45	17.78						
Gross calorific value (HHV)	MJ/kg		18.77	19.12						
HHV_{Milne}	MJ/kg		19.26	19.62					Calculated	

- Moisture content

SPECIAL USES

Casuarina wood is very hard and heavy (specific gravity of 0.80 to 1.20 g/cm³ for air-dried wood and 0.61 g/cm³ for wood with a moisture content of 46 percent *[117]*) and is exceptionally strong and tough *(25, 60)*. The heartwood is a dull reddish brown, occasionally with dark-brown streaks, and is not easily separated from the pinkish sapwood. The wood has a very fine texture, medium luster, and tightly interlocked grain. The wood dries at a moderate rate and degrades considerably during the process. Seasoning is accompanied by heavy and relatively uneven shrinkage. Casuarina logs are very difficult to saw in small circular sawmills, and because of its density and hardness, air-dried casuarina lumber is also difficult to machine, although machined surfaces are usually of good quality *(60)*. Casuarina is rated as a good wood for boring and mortising, and it sands to a very smooth finish. For a wood of such high density, casuarina's tightly interlocked grain gives it good resis-

Source:
www.fs.fed.us/global/iitf/pubs/sm_iitf056%20%20(11).pdf

8.11.4 Cedar bark

- Characterization (Phyllis2)

bark, cedar (#1944)

ID-number	#1944
Material	bark, cedar
Classification	ECN Phyllis classification ▸ untreated wood ▸ bark
	NTA 8003 classification ▸ [100] hout ▸ [110] vers hout ▸ [112] schors
Submitter organisation	ECN (Netherlands)
Submission date	2001-02-20
Literature	S. Gaur and T.B. Reed; An Atlas of Thermal Data For Biomass and Other Fuels. NREL/TP-433-7965, June 1995

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▼ Fuel Properties										
▼ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		5.10							
Volatile matter	wt%		73.00	76.92						
Fixed carbon	wt%		21.90	23.08					Calculated	
▼ Ultimate Analysis										
Carbon	wt%		51.00	53.74					Measured	
Hydrogen	wt%		5.70	6.01					Measured	
Oxygen	wt%		38.20	40.25					Calculated	
Total (with halides)	wt%		100.00	100.00					Calculated	
▼ Calorific Values										
Net calorific value (LHV)	MJ/kg		18.79	19.80						
Gross calorific value (HHV)	MJ/kg		20.03	21.11						
HHV_{Milne}	MJ/kg		20.27	21.36					Calculated	

- Moisture content

Common name	Genus	Species	FIA Code	Wood Specific gravity (green volume basis dry weight)	Reference	Bark Specific gravity (green volume basis dry weight)	Reference	Avg. moisture content of wood as a % of oven-dry weight	Reference	Avg. moisture content of bark as a % of oven-dry weight	Reference
Alligator juniper	Juniperus	deppeana	63	0.48	2	0.40	e	34	28	60	e
Western juniper	Juniperus	occidentalis	64	0.45	a	0.40	a	36	a	60	a
Utah juniper	Juniperus	osteosperma	65	0.68	3	0.40	e	35	e	60	e
Rocky Mountain juniper	Juniperus	scopulorum	66	0.45	a	0.40	a	36	a	60	a
Southern redcedar	Juniperus	virginiana	67	0.42	2	0.40	e	41	e	60	e
Eastern redcedar	Juniperus	virginiana	68	0.44	25	0.40	23	35	29	60	e
Oneseed juniper	Juniperus	monosperma	69	0.45	a	0.40	a	36	a	60	a

Source: www.nrs.fs.fed.us/pubs/rn/rn_nrs38.pdf

8.11.5 Leucaena wood

- Characterization (Phyllis2)

wood, leucaena (#1317)

ID-number	#1317
Material	wood, leucaena
Classification	ECN Phyllis classification ▸ untreated wood ▸ tropical hard wood ▸ wood, leucaena
	NTA 8003 classification ▸ [100] hout ▸ [110] vers hout ▸ [120] loofhout ▸ [125] hard loofhout
Submitter organisation	ECN (Netherlands)
Submission date	1998-08-28
Literature	O. Kitani and C. W. Hall: Biomass Handbook, Gordon and Breach science publishers, New York (1989).

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▼ Fuel Properties										
▼ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		1.53							
Volatile matter	wt%		80.94	82.20						
Fixed carbon	wt%		17.53	17.80					Calculated	
▼ Ultimate Analysis										
Carbon	wt%		49.20	49.96					Measured	
Hydrogen	wt%		6.05	6.14					Measured	
Nitrogen	wt%		0.47	0.48					Measured	
Sulphur	wt%		0.03	0.03					Measured	
Oxygen	wt%		42.74	43.40					Measured	
Total (with halides)	wt%		100.02	100.02					Calculated	
▼ Calorific Values										
Net calorific value (LHV)	MJ/kg		17.75	18.03						
Gross calorific value (HHV)	MJ/kg		19.07	19.37						
HHV_{Milne}	MJ/kg		19.57	19.87					Calculated	

- Moisture content

jonesii), can completely detoxify mimosine and DHP.|Leucaena wood has an exceptionally high density and energy value for a very fast-growing tree and makes excellent firewood and charcoal. The wood has a density of 500—600 kg/m^3 and a moisture content which varies between 30—50% depending on maturity. Energy values (bone-dry) of wood average 19 250 kJ/kg, of charcoal 48 400 kJ/kg. The bark is thin. The wood turns well, matures to a golden-brown colour and is hard enough for flooring. It is perishable outdoors, but accepts preservatives well. It does not resist termites. Pulp yields are high (50—52%), lignin levels low, fibres short (1.1—1.3 mm); paper quality generally is considered excellent.|The trees occasionally exude a gum very similar to gum arabic, with similar uses and properties; sterile hybrids, especially *Leucaena leucocephala* x *Leucaena esculenta* Benth., exude copiously.

Source: proseanet.org/prosea/e-prosea_detail.php?frt=&id=3025

8.11.6 Mango wood

- Characterization (Phyllis2)

wood, mango (#1936)

ID-number	#1936
Material	wood, mango
Classification	ECN Phyllis classification ▸ untreated wood ▸ tropical hard wood
	NTA 8003 classification ▸ [100] hout ▸ [110] vers hout ▸ [120] loofhout ▸ [125] hard loofhout
Submitter organisation	ECN (Netherlands)
Submission date	2001-02-20
Literature	S. Gaur and T.B. Reed; An Atlas of Thermal Data For Biomass and Other Fuels. NREL/TP-433-7965, June 1995

Values

Property	Unit	Value			Std dev	Det lim	Lab	Date	Method	Remarks
		ar	dry	daf						
▾ Fuel Properties										
▾ Proximate Analysis										
Moisture content	wt% (ar)		← Edit							
Ash content	wt%		2.98							
Volatile matter	wt%		85.64	88.27						
Fixed carbon	wt%		11.38	11.73					Calculated	
▾ Ultimate Analysis										
Carbon	wt%		46.24	47.66					Measured	
Hydrogen	wt%		6.08	6.27					Measured	
Nitrogen	wt%		0.28	0.29					Measured	
Oxygen	wt%		44.42	45.78					Calculated	
Total (with halides)	wt%		100.00	100.00					Calculated	
▾ Calorific Values										
Net calorific value (LHV)	MJ/kg		17.84	18.39						
Gross calorific value (HHV)	MJ/kg		19.17	19.76						
HHV_{Milne}	MJ/kg		18.40	18.96					Calculated	

- Moisture content

Common name	Genus	Species	FIA Code	Wood Specific gravity (green volume basis dry weight)	Reference	Bark Specific gravity (green volume basis dry weight)	Reference	Avg. moisture content of wood as a % of oven-dry weight	Reference
False tamarind	Lysiloma	latisiliquum	884	0.52	c	0.53	c	75	c
Mango	Mangifera	indica	885	0.52	c	0.53	c	75	c
Florida poisontree	Metopium	toxiferum	886	0.52	c	0.53	c	75	c
Fishpoison tree	Piscidia	piscipula	887	0.52	c	0.53	c	75	c

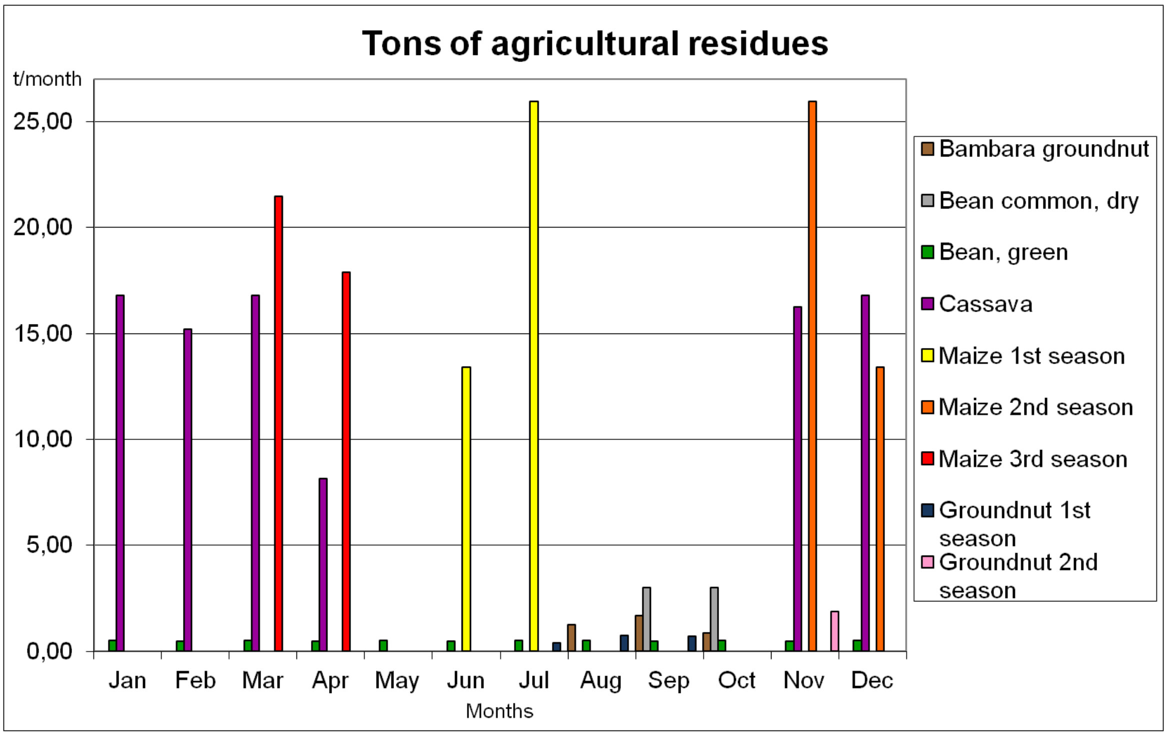
Source: www.nrs.fs.fed.us/pubs/rn/rn_nrs38.pdf

8.12 Monthly distribution of the residues

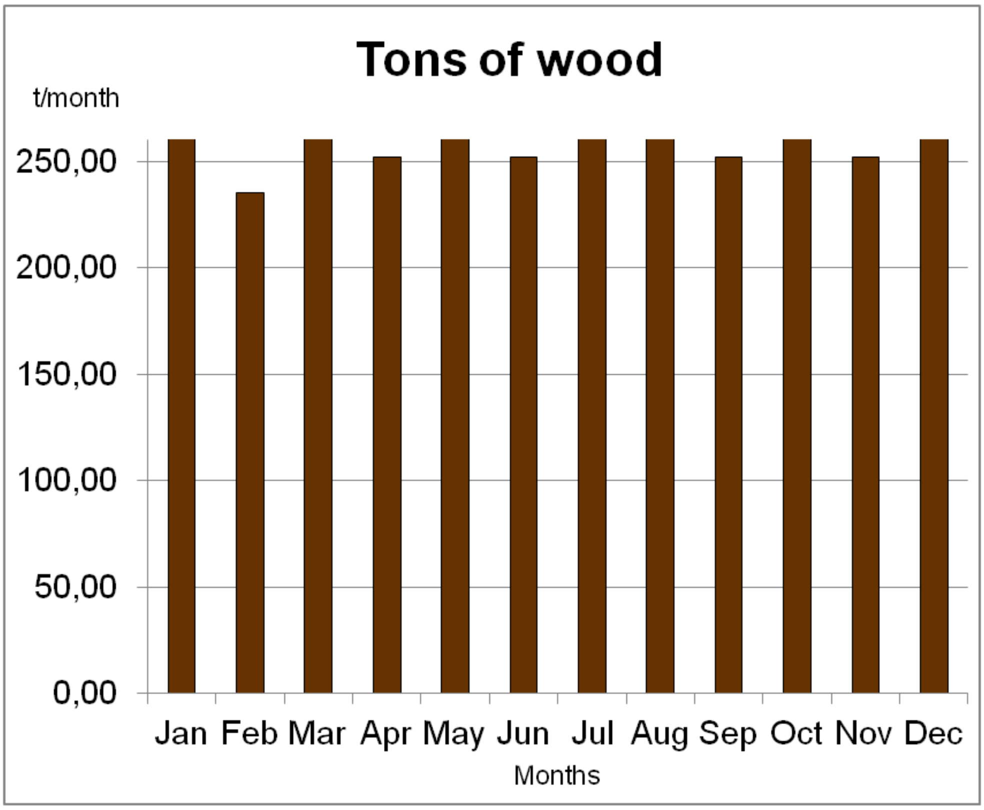
8.12.1 Table of monthly tonnes

	start	end	HARVESTING DAYS	%/day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Bambara groundnut	10/08	15/10	67	1,493								1,25	1,70	0,85			
Bean common, dry	01/09	30/10	60	1,667									2,95	2,95			
Bean, green	01/01	31/12	365	0,274	0,50	0,45	0,50	0,48	0,50	0,48	0,50	0,50	0,48	0,50	0,48	0,50	
Cassava	01/11	15/04	166	0,602	16,49	14,90	16,49	7,98							15,96	16,49	
Maize 1st season	15/06	31/07	47	2,128						13,40	25,96						
Maize 2nd season	15/11	31/12	47	2,128											25,96	13,40	
Maize 3rd season	20/03	10/04	22	4,545			21,47	17,89									
Groundnut 1st season	15/07	30/09	78	1,282							0,41	0,75	0,73				
Groundnut 2nd season	01/11	20/11	20	5,000											1,90		
WOOD	01/01	31/12	365	0,274	260,69	235,46	260,69	252,28	260,69	252,28	260,69	260,69	252,28	260,69	252,28	260,69	
					277,68	250,81	299,15	278,63	261,19	266,16	287,56	263,19	258,14	264,98	296,58	291,08	monthly tons
					8,957	8,957	9,650	9,288	8,425	8,872	9,276	8,490	8,605	8,548	9,886	9,390	tons/day

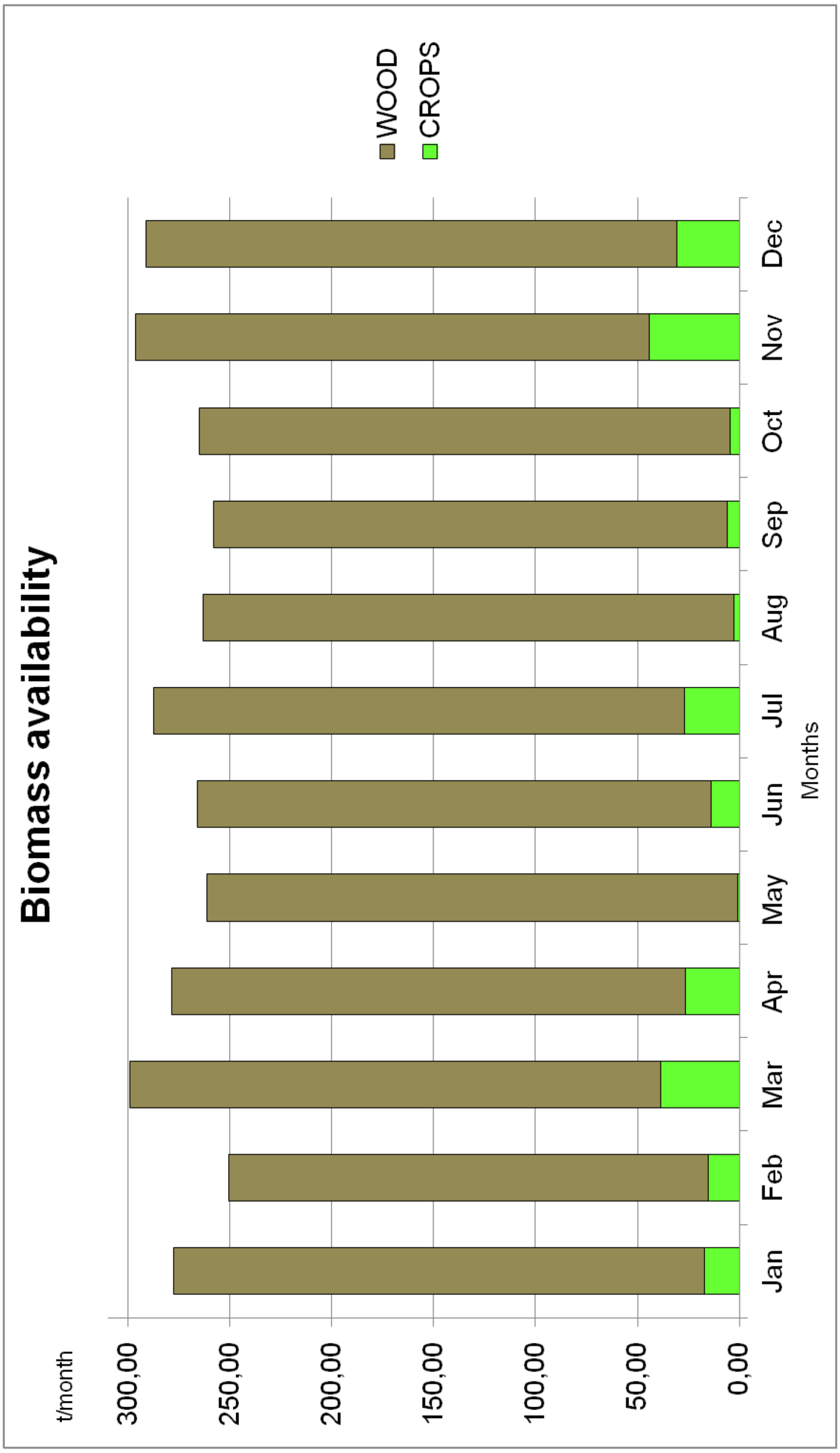
8.12.2 Monthly crops availability



8.12.3 Monthly wood availability



8.12.4 Monthly biomass availability

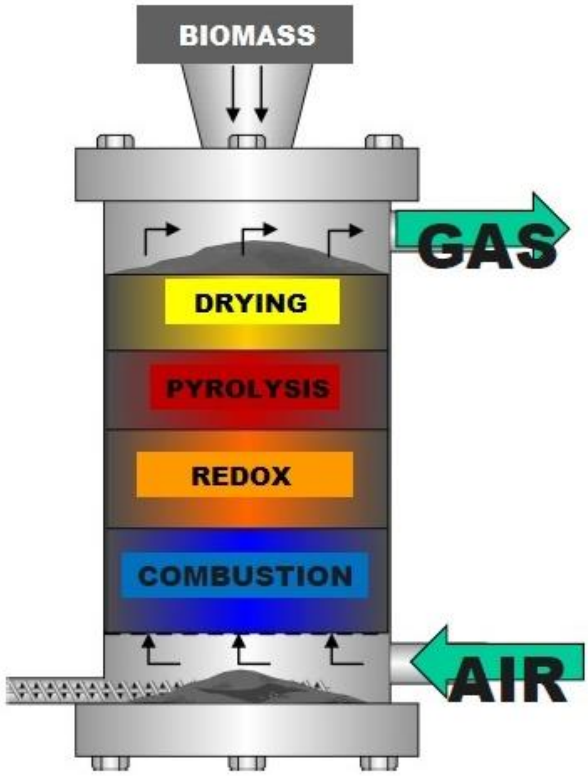


8.13 Energy from biomass

	start	end	HARVESTING DAYS	%/day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Bambara groundnut	10/08	15/10	67	1,493								1,25	1,70	0,85			
Bean common, dry	01/09	30/10	60	1,667									2,95	2,95			
Bean, green	01/01	31/12	365	0,274	0,50	0,45	0,50	0,48	0,50	0,48	0,50	0,50	0,48	0,50	0,48	0,50	
Cassava	01/11	15/04	166	0,602	16,49	14,90	16,49	7,98							15,96	16,49	
Maize 1st season	15/06	31/07	47	2,128						13,40	25,96						
Maize 2nd season	15/11	31/12	47	2,128											25,96	13,40	
Maize 3rd season	20/03	10/04	22	4,545			21,47	17,89									
Groundnut 1st season	15/07	30/09	78	1,282							0,41	0,75	0,73				
Groundnut 2nd season	01/11	20/11	20	5,000											1,90		
WOOD	01/01	31/12	365	0,274	260,69	235,46	260,69	252,28	260,69	252,28	260,69	260,69	252,28	260,69	252,28	260,69	
					277,68	250,81	299,15	278,63	261,19	266,16	287,56	263,19	258,14	264,98	296,58	291,08	monthly tons
					8,957	8,957	9,650	9,288	8,425	8,872	9,276	8,490	8,605	8,548	9,886	9,390	tons/day

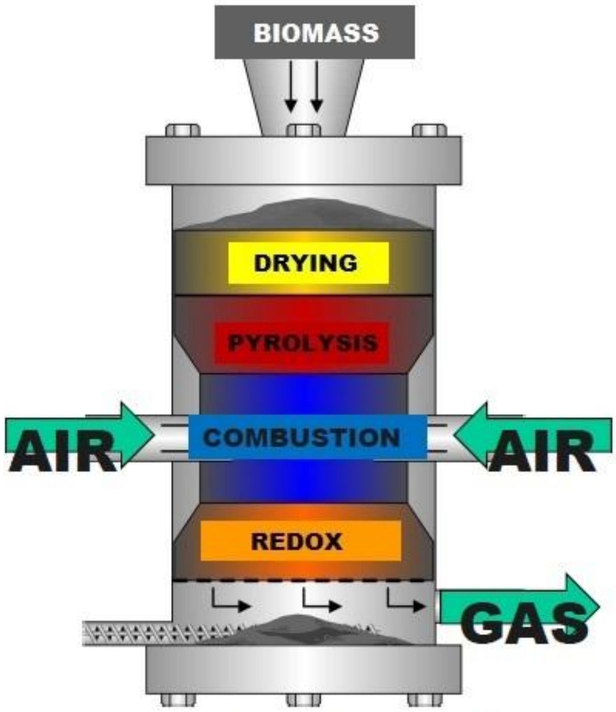
8.14 Gasifiers

8.14.1 "Up Draft"



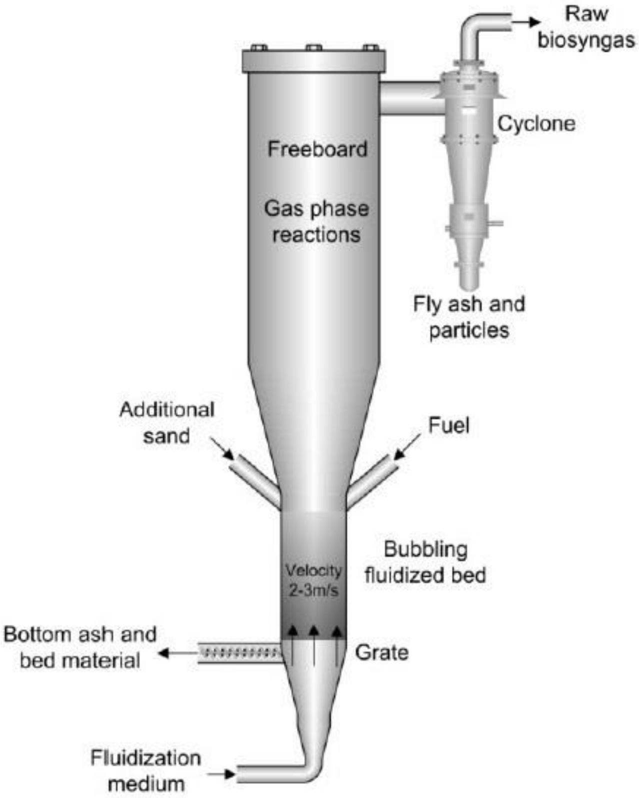
Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

8.14.2 "Down Draft"



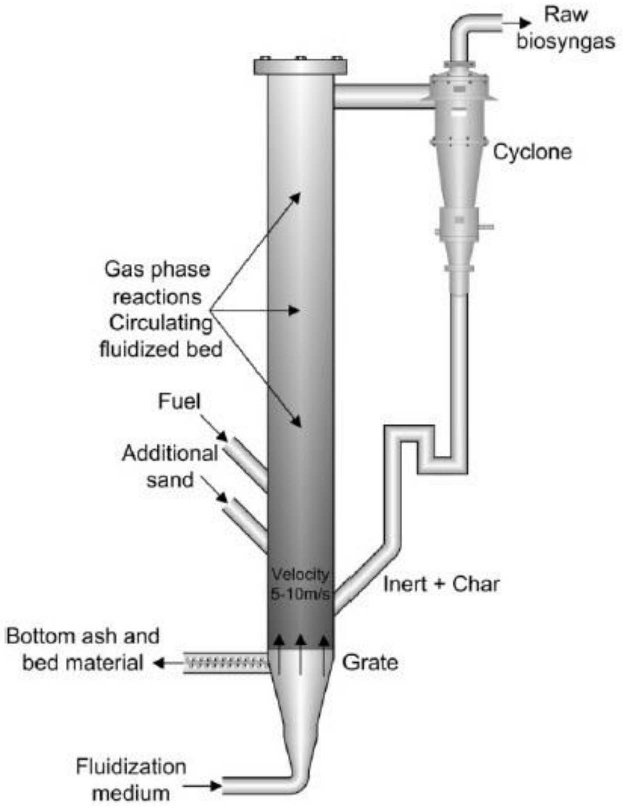
Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

8.14.3 BFB (bubbling fluidized bed)



Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

8.14.4 CFB (circulating fluidized bed)



Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

8.15 BioMax®100

Source: www.gocpc.com/

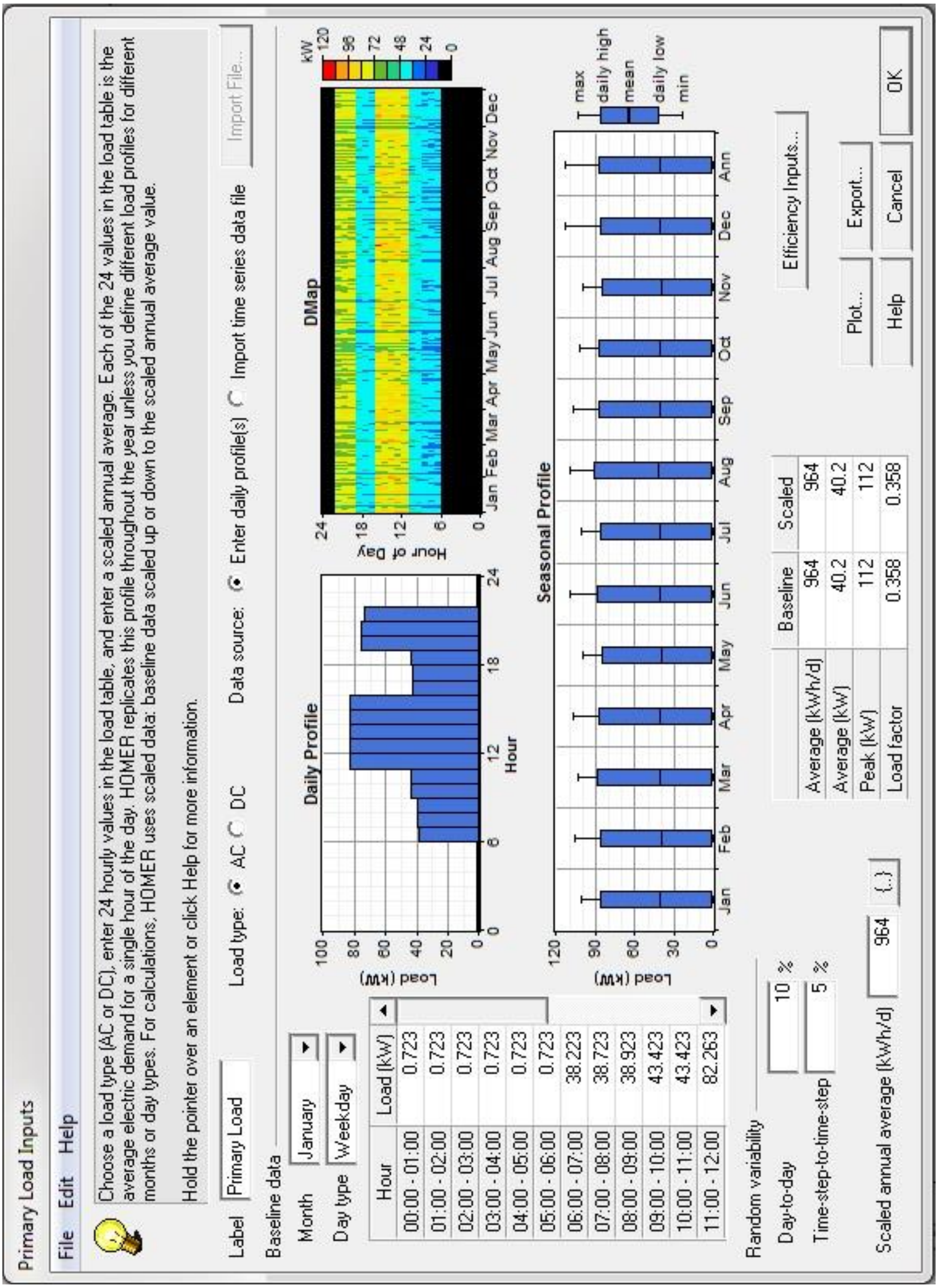
8.16 Pezzolato H 780/200 disc chipper

TECHNICAL DATA		H 780/200
Minimum tractor power	Hp/kW	60/44
Diesel engine power	Hp/kW	60/44
Maximum chipping diameter	mm	200
Dimensions charging mouth	mm	1360 x 940
Disc diameter	mm	780
Disc thickness	mm	35
Knives	n°	3
Hourly throughoutput	m^3	10/15
Weight (PTO version)	Kg	920

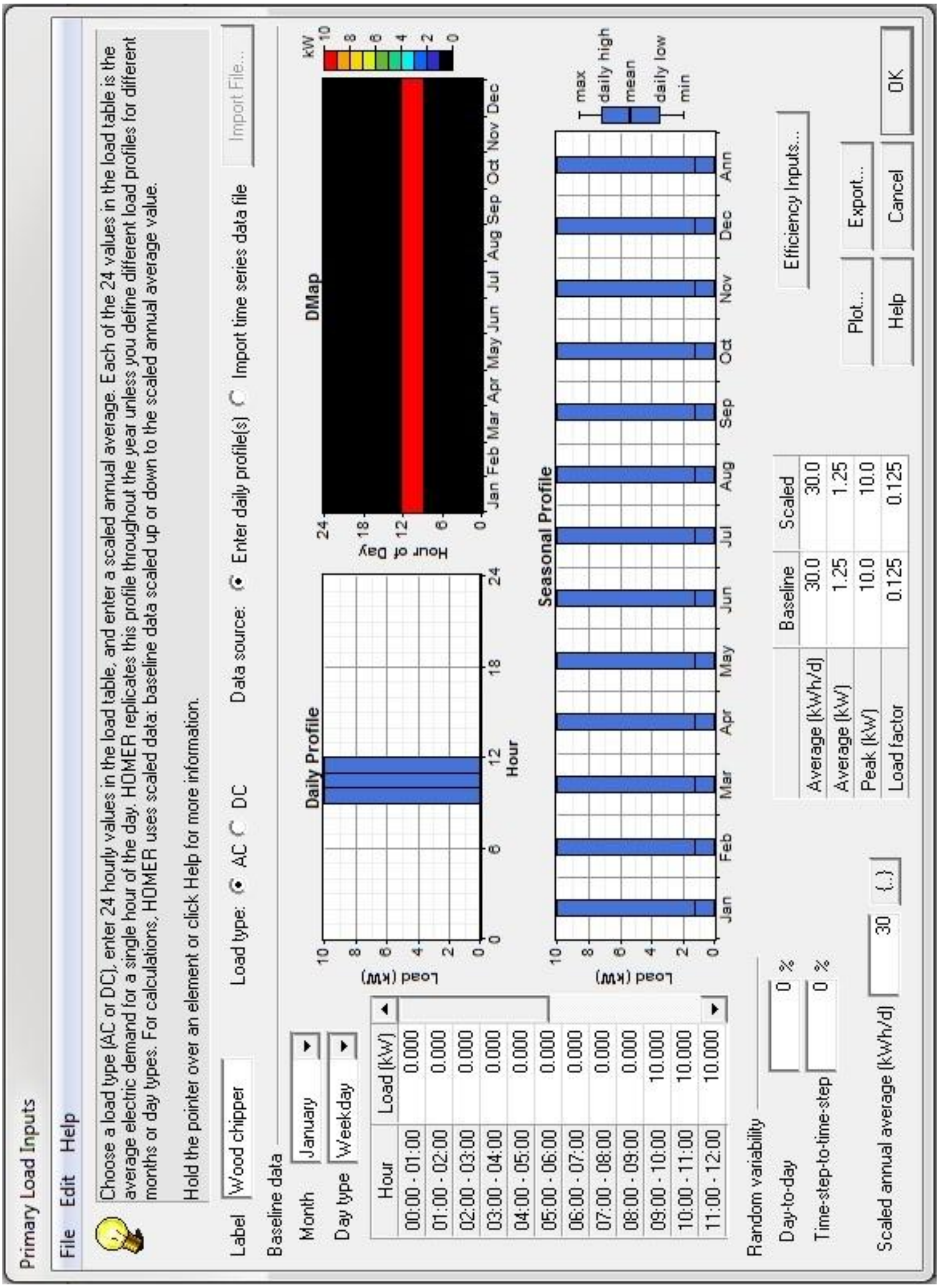
Source: www.pezzolato.it/en

8.17 Homer loads data

8.17.1 Primary Load



8.17.2 Wood chipper



8.18 Inverter and controller prices

Listino prezzi
gennaio 2014

Componenti
per impianti fotovoltaici

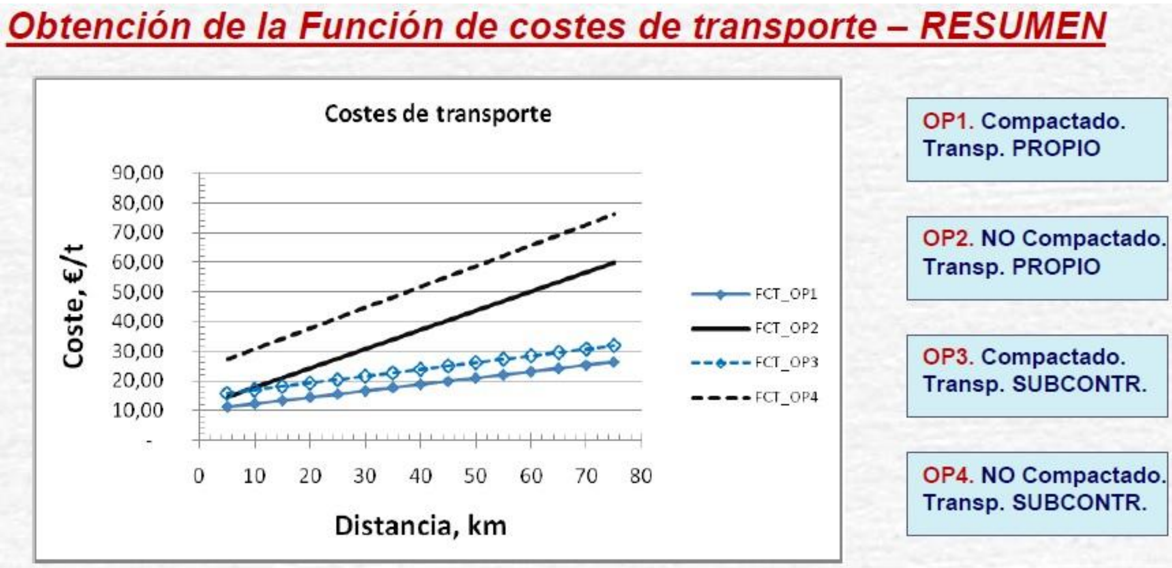
prezzi in Euro

codice	descrizione	q.tà imb.	molt.	prezzo
PVS...				
PVSMC1002	RS485 Card per inverter SunEzy	1	1	**141,00**
PVSCMC1105	Web Server Ethernet Card per inverter Conext RL	1	1	**250,00**
PVSNVC3000	Inverter 3kW-Conext RL 3000E IP65	1	1	**1.289,50**
PVSNVC3000S	Inverter 3kW-Conext RL 3000E-S IP65 con sez. DC	1	1	**1.343,00**
PVSNVC4000	Inverter 4kW-Conext RL 4000E IP65	1	1	**1.575,00**
PVSNVC4000S	Inverter 4kW-Conext RL 4000E-S IP65 con sez. DC	1	1	**1.640,50**
PVSNVC5000	Inverter 5kW-Conext RL 5000E IP65	1	1	**1.713,00**
PVSNVC5000S	Inverter 5kW-Conext RL 5000E-S IP65 con sez. DC	1	1	**1.784,00**
PVSNVC8000	Inverter 8kW-Conext TL 8000E IP65 con sez. DC	1	1	**3.199,00**
PVSNVC10000	Inverter 10kW-Conext TL 10000E IP65 con sez. DC	1	1	**3.445,00**
PVSNVC15000	Inverter 15kW-Conext TL 15000E IP65 con sez. DC	1	1	**4.731,00**
PVSNVC20000	Inverter 20kW-Conext TL 20000E IP65 con sez. DC	1	1	**5.733,00**

codice	descrizione	q.tà imb.	molt.	prezzo
PVSNVXW4024	Inverter Ibrido 4kW 24Vcc	1	1	**2.983,00**
PVSNVXW4548	Inverter Ibrido 4.5kW 48Vcc	1	1	**3.322,00**
PVSNVXW6048	Inverter Ibrido 6kW 48Vcc	1	1	**3.670,00**
PVSNVXWMPPT60150	Reg.tore di carica MPPT 150Vcc	1	1	**646,00**
PVSNVXWMPPT80600	Reg.tore di carica MPPT 600Vcc	1	1	**1.739,00**
PVSNVXWSYSTEM	Pannello di Controllo XW	1	1	**197,00**
PVSNVXWSTART	Pannello di avvio Generatore XW	1	1	**137,50**
PVSNVC12	Regolatore di carica 12A 12-24Vcc	1	1	**102,00**
PVSNVC35	Regolatore di carica 35A 12-24Vcc	1	1	**110,00**
PVSNVC40	Regolatore di carica 40A 12-24-28Vcc	1	1	**152,00**
PVSNVC60	Regolatore di carica 60A 12-24Vcc	1	1	**174,00**
PVSNVAB2	Quadro di campo per 1 o 2 stringhe	1	1	**326,00**
PVSNVAB3	Quadro di campo per 3 stringhe	1	1	**375,00**
PVSNVAB4	Quadro di campo per 4 stringhe	1	1	**390,00**
PVSNVLOG	Web Datalogger	1	1	**1.743,00**
PVSNVSCADA	Web Server Fotovoltaico	1	1	**5.741,00**
PVSNVKIT	Web Server Fotovoltaico in Kit	1	1	**6.767,00**
PVSNVROUTER	Router HSDPA/UMTS	1	1	**609,00**
PVSNVMODEM	Modem GPRS/EDGE	1	1	**267,00**

Source: www.schneider-electric.it/sites/italy/it/prodotti-e-servizi/cataloghi-e-listini/listini.page

8.19 Transport costs



Source: Máster en Tecnología Energética para Desarrollo Sostenible (UPV)

8.20 Hoppecke 12 OPzS 1500 price

Batería Hoppecke Mod. 12-OPZS-1500 2V/2232Ah C100

Artículo para reposiciones, si usted precisa de los 6 vasos para formar el acumulador, éste es su producto: http://supermercadosolar.es/es/553-bater%C3%ADa-estacionaria-hoppecke-mod-12-opzs-1500-12v2232ah-c100.html

Referencia: 12 OPZS 1500

Cantidad 1

▸ Escribe tu opinión

540,62 € IVA incluído

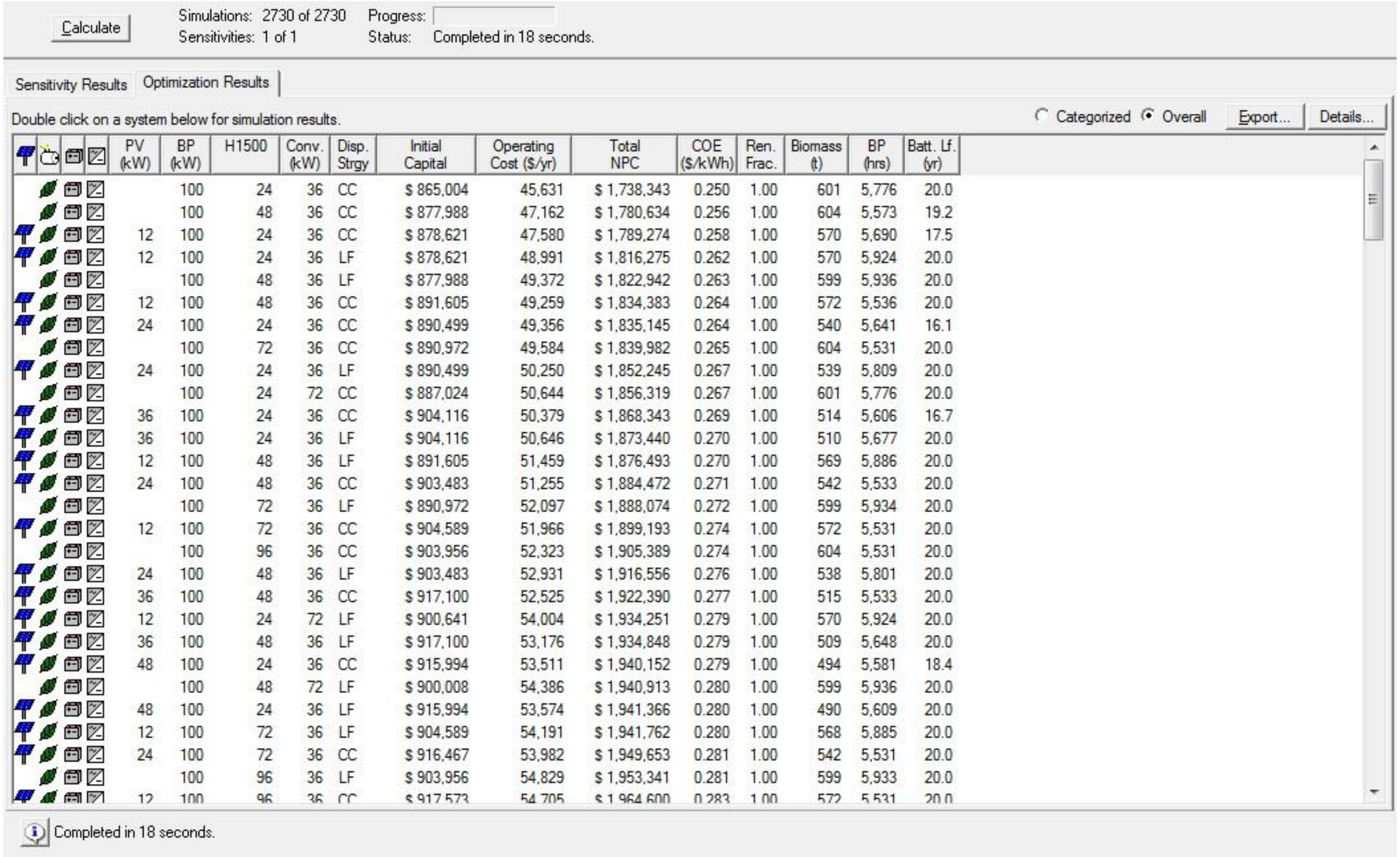
Source: supermercadosolar.es

8.21 EURIRS at 27/06/2014

EURIRS	26/06	25/06	24/06	23/06	20/06
5 ANNI	0.66	0.67	0.70	0.68	0.71
10 ANNI	1.44	1.47	1.51	1.50	1.54
15 ANNI	1.91	1.92	1.99	1.98	2.00
20 ANNI	2.10	2.14	2.19	2.17	2.20
25 ANNI	2.17	2.21	2.26	2.25	2.27
30 ANNI	2.20	2.23	2.28	2.27	2.30

Source: www.euribor.it

8.22 Optimization results of the hybrid power plant



Calculate

Simulations: 2730 of 2730 Progress:

Sensitivities: 1 of 1 Status: Completed in 18 seconds.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

Categorized | Overall | Export... | Details...

PV (kW)	BP (kW)	H1500	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	BP (hrs)	Batt. Lf. (yr)
	100	24	36	CC	$ 865,004	45,631	$ 1,738,343	0.250	1.00	601	5,776	20.0
	100	48	36	CC	$ 877,988	47,162	$ 1,780,634	0.256	1.00	604	5,573	19.2
12	100	24	36	CC	$ 878,621	47,580	$ 1,789,274	0.258	1.00	570	5,690	17.5
12	100	24	36	LF	$ 878,621	48,991	$ 1,816,275	0.262	1.00	570	5,924	20.0
	100	48	36	LF	$ 877,988	49,372	$ 1,822,942	0.263	1.00	599	5,936	20.0
12	100	48	36	CC	$ 891,605	49,259	$ 1,834,383	0.264	1.00	572	5,536	20.0
24	100	24	36	CC	$ 890,499	49,356	$ 1,835,145	0.264	1.00	540	5,641	16.1
	100	72	36	CC	$ 890,972	49,584	$ 1,839,982	0.265	1.00	604	5,531	20.0
24	100	24	36	LF	$ 890,499	50,250	$ 1,852,245	0.267	1.00	539	5,809	20.0
	100	24	72	CC	$ 887,024	50,644	$ 1,856,319	0.267	1.00	601	5,776	20.0
36	100	24	36	CC	$ 904,116	50,379	$ 1,868,343	0.269	1.00	514	5,606	16.7
36	100	24	36	LF	$ 904,116	50,646	$ 1,873,440	0.270	1.00	510	5,677	20.0
12	100	48	36	LF	$ 891,605	51,459	$ 1,876,493	0.270	1.00	569	5,886	20.0
24	100	48	36	CC	$ 903,483	51,255	$ 1,884,472	0.271	1.00	542	5,533	20.0
	100	72	36	LF	$ 890,972	52,097	$ 1,888,074	0.272	1.00	599	5,934	20.0
12	100	72	36	CC	$ 904,589	51,966	$ 1,899,193	0.274	1.00	572	5,531	20.0
	100	96	36	CC	$ 903,956	52,323	$ 1,905,389	0.274	1.00	604	5,531	20.0
24	100	48	36	LF	$ 903,483	52,931	$ 1,916,556	0.276	1.00	538	5,801	20.0
36	100	48	36	CC	$ 917,100	52,525	$ 1,922,390	0.277	1.00	515	5,533	20.0
12	100	24	72	LF	$ 900,641	54,004	$ 1,934,251	0.279	1.00	570	5,924	20.0
36	100	48	36	LF	$ 917,100	53,176	$ 1,934,848	0.279	1.00	509	5,648	20.0
48	100	24	36	CC	$ 915,994	53,511	$ 1,940,152	0.279	1.00	494	5,581	18.4
	100	48	72	LF	$ 900,008	54,386	$ 1,940,913	0.280	1.00	599	5,936	20.0
48	100	24	36	LF	$ 915,994	53,574	$ 1,941,366	0.280	1.00	490	5,609	20.0
12	100	72	36	LF	$ 904,589	54,191	$ 1,941,762	0.280	1.00	568	5,885	20.0
24	100	72	36	CC	$ 916,467	53,982	$ 1,949,653	0.281	1.00	542	5,531	20.0
	100	96	36	LF	$ 903,956	54,829	$ 1,953,341	0.281	1.00	599	5,933	20.0
12	100	96	36	CC	$ 917,573	54,705	$ 1,964,600	0.283	1.00	572	5,531	20.0

Completed in 18 seconds.

8.23 Diesel prices


150 kW 60 Hz
125 kW 50 Hz

GeneratorJoe, Defender 2™ Series, 150 kW (188 kVA) 60 Hz, or 125 kW (156.7 kVA) 50 Hz. SKU GJDF2-150T307, Model 150 DF2-3, (Open, No Enclosure)
Perkins 8.8L, three phase, LP/NG fueled, liquid cooled, 1800 RPM, electric start, auto start, EPA/CARB, UL2200

Factory Brochure
Product Details

Our Price $24,418.74
List Price ~~$36,305.00~~ GSA Schedule GS-07F-5964R

View
Compare

Package(s): Open, No Enclosure ($32,362.34) Weather Enclosure ($40,552.79) Weather/Sound Enclosure ($41,967.10)

150 kW 60 Hz
125 kW 50 Hz

GeneratorJoe, Sentry™ Series, 150 kW (150 kVA) 60 Hz, or 125 kW (125 kVA) 50 Hz. SKU GJSN-150T110, Model 150 SN,(Open, No Enclosure)
GM Powertrain 8.1L TCAC, single phase, NG/LP fueled, liquid cooled, 1800 RPM, electric start, auto start, EPA Certified, UL2200

Factory Brochure
Product Details

Our Price $32,847.66
List Price ~~$38,970.00~~ GSA Schedule GS-07F-5964R

View
Compare

Package(s): Open No Enclosure ($32,847.66) Weather Enclosed, Level 1 ($38,382.66) Weather Enclosed, Level 2 ($39,362.66)

75 kW 60 Hz
63 kW 50 Hz

GeneratorJoe, Centurion "J"™ Series, 75 kW (75 kVA) 60 Hz, or 62.5 kW (62.5 kVA) 50 Hz. SKU GJJD-075D106, Model 75 JD, (Open, No Enclosure)
John Deere 4045-HF285, single phase, diesel fueled, liquid cooled, 1800 RPM, electric start, auto start, EPA, UL2200

Factory Brochure
Product Details

Our Price $20,582.74
List Price ~~$24,420.00~~ GSA Schedule GS-07F-5964R

View
Compare

Package(s): Open No Enclosure, w/144 gallon tank ($24,037.74) Weather/Sound Level 1 Enclosed, w/144 gallon tank ($30,427.74) Weather/Sound Level 2 Enclosed, w/144 gallon tank ($31,240.24)

400 kW 60 Hz
333 kW 50 Hz

GeneratorJoe, Centurion "P"™ Series, 400 kW (500 kVA) 60 Hz, or 333.3 kW (416.7 kVA) 50 Hz. SKU GJCP-400D318, Model 400 CP3, (Open, No Enclosure)
Perkins 2206D-E13TAG3, three phase, diesel fueled, liquid cooled, 1800 RPM, electric start, auto start, Tier 3, UL2200

Factory Brochure
Product Details

Our Price $33,838.86
List Price ~~$47,795.00~~ GSA Schedule GS-07F-5964R

View
Compare

Package(s): Open No Enclosure, w/350 gallon tank ($57,671.69) Weather Enclosure, w/350 gallon tank ($66,975.51) Sound Enclosed, w/350 gallon tank ($69,109.26)

Source: www.generatorjoe.net/

8.24 Fuel prices

Pump price for diesel fuel (US$ per liter)

DATABANK | DOWNLOAD DATA | SHARE

Fuel prices refer to the pump prices of the most widely sold grade of diesel fuel. Prices have been converted from the local currency to U.S. dollars.

German Agency for International Cooperation (GIZ).

Catalog Sources World Development Indicators

View in WDI Tables

TABLE | MAP | GRAPH

Search all indicators

Go

Featured indicators

Urban Development ▼

- Improved sanitation facilities, urban (% of urban population with access)
- Improved water source, urban (% of urban population with access)
- Motor vehicles (per 1,000 people)
- Passenger cars (per 1,000 people)
- PM10, country level (micrograms per cubic meter)
- Population in the largest

1980-1983 | 1984-1988 | 1989-1993 | 1994-1998 | 1999-2003 | 2004-2008 | 2009-2013

Country name	2010	2012
Afghanistan	1.00	1.21
Albania	1.40	1.79
Algeria	0.19	0.17
American Samoa		
Andean Region		
Andorra	1.32	1.48
Angola	0.43	0.42
Antigua and Barbuda	0.96	
Argentina	1.05	1.33
Armenia	0.99	1.15
Aruba		
Australia	1.23	1.57
Austria	1.55	1.81
Azerbaijan	0.56	0.57
Bahamas, The		
Bahrain	0.13	0.17
Bangladesh	0.63	0.76
Barbados	1.14	
Belarus	0.86	0.90
Belgium	1.62	1.98
Belize	0.98	1.21
Benin	1.21	1.26
Bermuda		
Bhutan	0.82	0.86
Bolivia	0.54	0.54
Bosnia and Herzegovina	1.42	1.62
Botswana	0.97	1.25
Brazil	1.14	1.02
Brunei Darussalam	0.24	0.26
Bulgaria	1.58	1.68
Burkina Faso	1.28	1.28
Burundi	1.42	1.47
Cabo Verde	1.33	1.58
Cambodia	0.98	1.27
Cameroon	1.10	1.01
Canada	1.08	1.23
Cayman Islands		
Central African Republic	1.69	1.69
Chad	1.31	1.16

8.25 Hybrid plant changes

8.25.1 Table of monthly tonnes reduced

	start	end	HARVESTING DAYS	%/day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Bambara groundnut	10/08	15/10	67	1,493								0,42	0,57	0,28			
Bean common, dry	01/09	30/10	60	1,667									0,88	0,88			
Bean, green	01/01	31/12	365	0,274	0,15	0,14	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	
Cassava	01/11	15/04	166	0,602	4,95	4,47	4,95	2,39							4,79	4,95	
Maize 1st season	15/06	31/07	47	2,128						4,47	8,65						
Maize 2nd season	15/11	31/12	47	2,128											8,65	4,47	
Maize 3rd season	20/03	10/04	22	4,545			7,16	5,96									
Groundnut 1st season	15/07	30/09	78	1,282							0,14	0,25	0,24				
Groundnut 2nd season	01/11	20/11	20	5,000											0,63		
WOOD	01/01	31/12	365	0,274	71,91	64,95	71,91	69,59	71,91	69,59	71,91	71,91	69,59	71,91	69,59	71,91	
					77,01	69,56	84,17	78,10	72,06	74,21	80,86	72,73	71,43	73,23	83,81	81,48	monthly tons
					2,484	2,484	2,715	2,603	2,325	2,474	2,608	2,346	2,381	2,362	2,794	2,628	tons/day

8.25.2 Energy from reduced biomass

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bambara groundnut								6.976,53	9.513,45	4.756,73		
Bean common, dry									14.210,97	14.210,97		
Bean, green	2.413,92	2.180,31	2.413,92	2.336,05	2.413,92	2.336,05	2.413,92	2.413,92	2.336,05	2.413,92	2.336,05	2.413,92
Cassava	79.490,41	71.797,79	79.490,41	38.463,10							76.926,20	79.490,41
Maize 1st season						69.596,69	134.843,59					
Maize 2nd season											134.843,59	69.596,69
Maize 3rd season			111.512,88	92.927,40								
Groundnut 1st season							2.315,35	4.222,10	4.085,90			
Groundnut 2nd season											10.623,35	
WOOD	1.226.479,72	1.107.788,13	1.226.479,72	1.186.915,86	1.226.479,72	1.186.915,86	1.226.479,72	1.226.479,72	1.186.915,86	1.226.479,72	1.186.915,86	1.226.479,72
MJ/month	**1.308.384,04**	**1.181.766,23**	**1.419.896,93**	**1.320.642,41**	**1.228.893,64**	**1.258.848,60**	**1.366.052,58**	**1.240.092,27**	**1.217.062,23**	**1.247.861,33**	**1.411.645,05**	**1.377.980,74**
MJ/t	4.711,85	4.711,85	4.746,47	4.739,73	4.705,05	4.729,67	4.750,49	4.711,84	4.714,78	4.709,20	4.759,74	4.734,05

REFERENCES

[1] *Modern Energy for All. (2013). Retrieved from World Energy Outlook: http://www.worldenergyoutlook.org/resources/energydevelopment/*

[2] *Defining and modelling energy access. (2013). Retrieved from World Energy Outlook: http://www.worldenergyoutlook.org/resources/energydevelopment/definingandmodellingenergyaccess/*

[3] *Measuring energy and development. (2010). Retrieved from World Energy Outlook: http://www.worldenergyoutlook.org/resources/energydevelopment/measuringenergyanddevelopment/*

[4] *Electrical Power in Central African Republic. (2014). Retrieved from Mbendi: http://www.mbendi.com/indy/powr/af/cr/p0005.htm*

[5] *Policy and regulatory overviews. (2012). Retrieved from reegle: http://www.reegle.info/policy-and-regulatory-overviews/CF*

[6] *Generatori. (n.d.). Retrieved from Gruppo Chirurgia d'Urgenza: http://www.gcupisa.it/le-strutture/generatori/*

[7] *What Is Islanding? (2014). Retrieved from wiseGEEK: http://www.wisegeek.com/what-is-islanding.htm*

[8] *Peterschmidt, N. (n.d.). Hybrid Power Systems - An Introduction. Retrieved from WWEA: http://www.wwindea.org/technology/ch05/en/5_3_1.html*

[9] *What is solar energy? (n.d.). Retrieved from Greenough River Solar Farm: http://www.greenoughsolarfarm.com.au/solar-energy/what-solar-energy*

[10] *What is Photovoltaic Energy? (2014). Retrieved from wiseGEEK: http://www.wisegeek.com/what-is-photovoltaic-energy.htm*

[11] *What is BIOMASS? (n.d.). Retrieved from BIOMASS Energy Centre: http://www.biomassenergycentre.org.uk/portal/page?_pageid=76,15049&_dad=portal*

[12] *Autotroph. (n.d.). Retrieved from Dictionary.com: http://dictionary.reference.com/browse/autotroph*

[13] *Toothman, J., & Aldous, S. (2000, April 01). How Solar Cells Work. Retrieved from HowStuffWorks.com: http://science.howstuffworks.com/environmental/energy/solar-cell1.htm*

[14] *About PVGIS*. (n.d.). Retrieved from Joint Research Centre - Insitute for Energy and Transport (IET): http://re.jrc.ec.europa.eu/pvgis/about_pvgis/about_pvgis.htm

[15] *Database help*. (n.d.). Retrieved from PVGIS radiation databases: http://re.jrc.ec.europa.eu/pvgis/apps4/databasehelp_en.html

[16] *FAO crop calendar - agro ecological zones*. (n.d.). Retrieved from FAO: http://www.fao.org/agriculture/seed/cropcalendar/searchbycountry.do

[17] *Feedipedia: An on-line encyclopedia of animal feeds*. (n.d.). Retrieved from Feedipedia: http://www.feedipedia.org/

[18] *Gasification*. (n.d.). Retrieved from Community Power Corporation: http://www.gocpc.com/gasification.html

[19] *What is Syngas*. (2010). Retrieved from Biofuel.org.uk: http://biofuel.org.uk/what-is-syngas.html

[20] *FAQ*. (2014). Retrieved from Community Power Corporation: http://www.gocpc.com/more-information/faq.html

[21] HOMER Help. (n.d.). HOMER Energy.

[22] Aspectos Técnicos. (2014). *Curso de Energías Renovables* . Valencia: UPV.

[23] Solar, D. A., & Pérez-Navarro, Á. (2014). Máster en Tecnología Energética para Desarrollo Sostenible. Valencia: UPV.