UNIVERSITAT DE BARCELONA

Photovoltaic Installation project in Ribelles

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Introduction

Energy demand

The human body is at a constant temperature of about 37°C. It hence contains *thermal energy*. As the body is continuously cooled by the surroundings, thermal energy is lost to the outside. Further, blood is pumped through the blood vessels. As it travels through the vessels, its *kinetic energy* is reduced because of internal friction and friction at the walls of the blood vessels, that means*,* the kinetic energy is converted into heat. To keep the blood moving, the heart consumes energy. Also, if we want our body to move this consumes energy. Further, the human brain consumes a lot of energy. All this energy has to be supplied to the body from the outside, in the form of food.

In modern society, humans do not only require energy to keep their body running, but in fact we consume energy for many different purposes. We use energy for heating the water in our houses and for heating our houses. If water is heated, its thermal energy increases, and this energy must be supplied. Further, we use a lot of energy for transportation of people and products by cars, trains, trucks and planes. We use energy to produce our goods and also to produce food. At the moment, you are consuming energy if you read this final master project on a computer or tablet. But also, if you read this in a printed version, you implicitly consumed the energy that was required to print it and to transport it to you place. [1]

The world population is still rapidly growing, and some studies predict a world population of 9 billion around 2040 in contrast to the 7 billion people living on the planet today [2]. All these people will need energy, which increases the global energy demand. The increasing demand in energy has economic impact and it is related to the fact that our energy infrastructure heavily depends on fossil fuels like oil, coal and gas. Fossil fuels are nothing, but millions and millions of years of solar energy stored in the form of chemical energy. The problem is that humans deplete these fossil fuels much faster than they are generated through the photosynthetic process in nature. Therefore, fossil fuels are not a sustainable energy source. The more fossil fuels we consume, the less easily available gas and oil resources will be available. [3]

An ever growing population means an ever growing requirement for energy. Nowadays, enormity of energy cannot be denied. It is essential in every walk of life. Energy sources can be broadly classified as renewable and nonrenewable. Knowing the dreadful fact that nonrenewable sources will eventually deplete, the importance of renewable sources cannot be underestimated. The most important aspect while utilizing them is their impact on the environment. [4]

Climate change

Fossil fuels are basically compounds of hydrocarbons comprising of coal, natural gas and oil. The main dilemma of fossil fuels is not the use of them but the ill side effects their usage creates. Fossil fuels are not sustainable. It means they will eventually deplete. When they are burnt, they produce large amounts of harmful gases, the most noteworthy being carbon dioxide gas. This gas is the greatest culprit in producing global warming. This global warming is continuously playing its negative part in increasing the temperature of the planet and endangering the lives of species on it. Moreover, due to these high temperatures, ice has been constantly melting at Arctic and Antarctica which is making the sea levels higher than normal. This can lead to floods and can severely affect agricultural and fishing activities [5]

The reserves of fossil fuels that currently power society will fall short of this demand over the long term, and their continued use produces harmful side effects such as pollution that threatens human health and greenhouse gases associated with climate change. Alternative renewable fuels are at present far from competitive with fossil fuels in cost and production capacity. Without viable options for supplying double or triple today's energy use, the world's economic, technological, and political horizons will be severely limited. [6]

Climate change is already affecting regions around the world. Unabated, its future negative impacts will likely be vast, costing much more than preventing it. The recent IPCC *Special Report on Global Warming of 1.5°C* has underlined the urgency of taking decisive steps to tackle climate change, including through the transformation of global energy use. Considering that two thirds of greenhouse gas (GHG) emissions originate from the energy sector, the IPCC unequivocally calls for an immediate, large-scale shift to renewable energy and energy efficiency. [7]

There is an unprecedented momentum for leaving the fossil fuel age behind us. And we must do it now. Every Friday millions of young people take to the streets to force decision makers to understand the climate crisis we are facing. Patience and faith in politicians who hesitate, and waver are fading away.

The world faces unprecedented threats from climate change and increasing variability, which severely impacts human society and the natural environment. To reduce future climate change and ensure our economies can grow in a sustainable way, sustainable energy development is considered to be an effective approach. In this context, sustainable energy development involves augmenting our energy supplies and managing demands in a fashion that societal energy needs are met with a minimal effect on greenhouse gas emissions and a nominal resultant contribution to future climate change.

Urgent action is needed now to change our energy systems. Moreover, we will never meet the objectives under UN Sustainable Development Goal 7 for increasing renewable energy, energy efficiency, and energy access if we continue down our current energy path. [8]

Sustainable development

Development and environment are two words that are often called together in nowadays and important in global area. These words handled officially together first in United Nations Conference on the Human Environment in 1972 in Stockholm. However, the expressions "Sustainable development" is first defined officially by the World Commission on Environment and Development (WCED) in the report called "our common future" in 1987. According to this report, Sustainable development is development that meets de needs of the present without compromising the ability of future generations to meet their own needs [9].

Energy for sustainable development has recently been one of the popular topics in literature and seems like it will stay as a popular topic in the future. Talking about this topic reminds researches about renewable energy sources because are unlimited, clean and environmentally friendly and these proprieties make them important for sustainable development in developing countries.

Talking all the positive effect of renewable energy production into account, renewable energy is one of the most necessary instruments for paving the way for sustainable development.

Renewable energy

The most significant feature of renewable energy is its plentiful supply. It is infinite. Renewable energy sources are hygienic sources of energy that have a much lesser negative environmental impact than conventional fossil energy technologies.

With technological advancements in mass communication, people have now become aware of the demerits of burning fossil fuels. Renewable energy is the need of the hour. Its clean and sustainable nature has compelled the human beings to think seriously about it. Scientists and Engineers, around the world, are continuously working and researching in this domain. They are finding new ways to use these sources of energy effectively. To put an end to this apocalypse; we must resort to renewable sources. This is because they are cleaner and do not produce poisonous harmful gases. [10]

Renewable energy is dependable and copious and will potentially be very cheap, once this technology and its present infrastructure are enhanced. The major sources of renewable energy include solar, wind, biomass, geothermal, hydropower and tidal energy. Renewable energy produces only small levels of carbon emissions and therefore, helps battle climate change caused by fossil fuel burning. [11]

The renewable energy sector is comparatively new in most countries and this sector can attract a lot of companies to invest in it. This can create a pool of new jobs for the unemployed. Therefore, renewable energy can play a very significant role in bringing the unemployment scale down in many countries, especially developing ones. This, in turn, will make a substantial difference to their economies. Renewable energy can make electric prices stable. It is because their cost is dependent only on the initial invested capital and is free of the fluctuating costs of coal, oil and natural gas. [11]

The daily price of oil depends on various factors which also includes political stability in various regions of the globe. In the past, political discords have caused severe energy crises. Renewable energy can be locally produced and therefore, it is not vulnerable to distant political disturbances.

Alternative energy sources are here to stay. They have become an integral part of the energy portfolio. The objective in using renewable energy sources is to reduce the pessimistic environmental effects associated with non renewable energy sources such as coal, oil and natural gas. Choosing to use a renewable energy source will not only translate into cost savings over the long term but will also help protect the environment from the risks of fossil fuel emissions. Energy conservation awareness campaigns must be initiated at government level to make people aware of the importance of conserving energy. Moreover, power companies should gradually resort to the use of renewable resources as they are profuse and will never deplete. Social media can play a key role in this by educating people about energy sources and their utilization. Colleges and universities should teach a compulsory subject on energy conservation and utilization. [12]

Given that these steps are followed accurately, the time is not far when the entire world will be reliant on renewable sources for power production because this is the definitive future of energy.

The solar energy

The energy contained in sunlight, called *solar energy*, can be converted into electricity. If this energy is converted into electricity directly using devices based on semiconductor materials, we call it *photovoltaics* (PV). The term *photovoltaic* consists of the greek word *φως* (phos), which means light, and volt, which refers to electricity and is a reverence to the Italian physicist Alessandro Volta (1745-1827) who invented the battery. Typical efficiencies of the most commercial *solar modules* are in the range of 15-20%. Solar light can also be converted into heat. This application is called *solar thermal energy*. However, all efforts will be focus on PV system, the one that will be installed. [13]

The working principle of solar cells is based on the *photovoltaic effect*, *i.e.* the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation. The photovoltaic effect is closely related to the photoelectric effect, where electrons are emitted from a material that has absorbed light with a frequency above a material-dependent threshold frequency. In 1905, Albert Einstein under- stood that this effect can be explained by assuming that the light consists of well-defined energy quanta, called *photons* [14]. The energy of such a photon is given by *equation* where h is Planck's constant and v is the frequency of the light

$$E = h\,v \qquad \text{(Equation 1)}$$

The photovoltaic effect can be divided into three basic processes;

1. Generation of charge carriers due to the absorption of photons in the materials that form a junction.

Absorption of a photon in a material means that its energy is used to excite an electron from an initial energy level E_i to a higher energy level E_f, as shown in *Fig. 1 (a)* Photons can only be absorbed if electron energy levels E_i and E_f are present so that their difference equals to the photon energy.

$$hv = E_f - E_i \qquad \text{(Equation 2)}$$

In an ideal semiconductor electrons can populate energy levels below the called *valence band* edge, E_V, and above the so called *conduction band* edge, E_C. Between those two bands

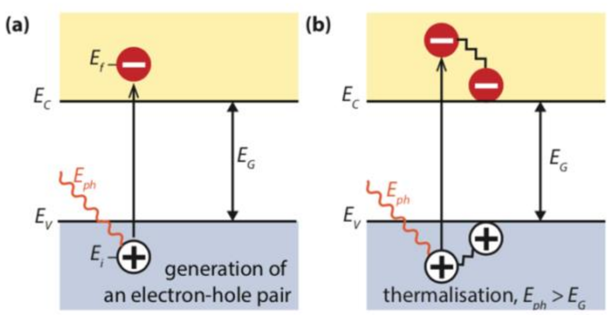


*Figure 1. Absorption of a photon in a semiconductor. a) The photon with energy E = h v excites an electron. b) When E > Eg a part of energy is thermalized. **Source**: [14]*

no allowed energy states exist, which could be populated by electrons. Hence, this energy difference is called the *bandgap*.

$$E_g = E_C - E_V \qquad \text{(Equation 3)}$$

If a photon with an energy smaller than E_g reaches an ideal semiconductor, it will not be absorbed but will traverse the material without interaction.

In a real semiconductor, the valence and conduction bands are not flat, but vary depending on the called *k*-vector that describes the crystal momentum of the semiconductor. If the maximum of the valence band and the minimum of the conduction band occur at the same *k*-vector, an electron can be excited from the valence to the conduction band without a change in the crystal momentum. Such a semiconductor is called a *direct bandgap* material. If the electron cannot be excited without changing the crystal momentum, we speak of an *indirect bandgap* material. The absorption coefficient in a direct bandgap material is much higher than in an indirect bandgap material, thus the absorber can be much thinner [15].

If an electron is excited from E_i to E_f , a void is created at E_i. This void behaves like a particle with a positive elementary charge and is called a *hole*. The absorption of a photon therefore leads to the creation of an electron-hole pair, as illustrated in *Fig. 2 (n1)* .

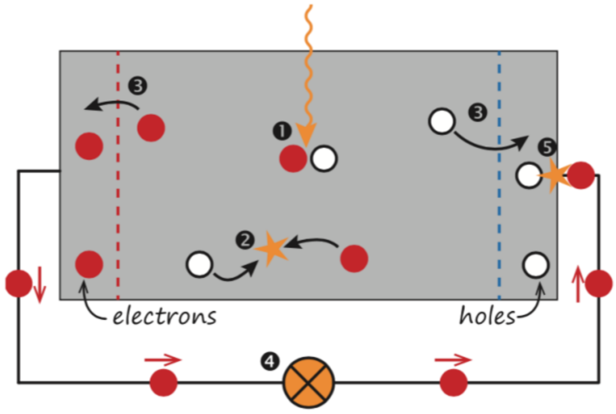


Figure 2. *Solar cell model. With all the process from the absorption of a photon and electron-hole pair generation (n1) to the electric circuit and the recombination of the electrons with the holes (n5).* ***Source:*** *[16]*

The *radiative energy* of the photon is *converted* to the *chemical energy* of the electron-hole pair. The maximal conversion efficiency from radiative energy to chemical energy is limited by thermodynamics. This *thermodynamic limit* lies in between 67% for non-concentrated sunlight and 86% for fully concentrated sunlight [16].

2. Subsequent separation of the photo-generated charge carriers in the junction.

Usually, the electron-hole pair will recombine, *so* the electron will fall back to the initial energy level E_i, as illustrated in *Fig. 2 (n2)* The energy will then be released either as photon (*radiative recombination*) or transferred to other electrons or holes or lattice vibrations (*non- radiative recombination*). If one wants to use the energy stored in the electron-hole pair for performing work in an external circuit, *semipermeable membranes* must be present on both sides of the absorber, such that electrons only can flow out through one membrane and holes only can flow out through the other membrane [16], as illustrated in *Fig.2 (n3).* In most solar cells, these membranes are formed by *n*- and *p*-type materials.

A solar cell has to be designed such that the electrons and holes can reach the membranes before they recombine, *so.* the time it requires the charge carriers to reach the membranes must be shorter than their lifetime. This requirement limits the thickness of the absorber.

3. Collection of the photo-generated charge carriers at the terminals of the junction.

Finally, the charge carriers are extracted from the solar cells with electrical contacts so that they can perform work in an external circuit (*Fig.2 (n4)*). The *chemical energy* of the electron-hole pairs is finally converted to *electric energy*. After the electrons passed through the circuit, they will recombine with holes at a metal- absorber interface, as illustrated in *Fig.2 (n5).*

Loss mechanisms

The two most important *loss mechanisms* in single bandgap solar cells are the inability to convert photons with energies below the bandgap to electricity and thermalisation of photon energies exceeding the bandgap, as illustrated in *Fig.1 (b).* These two mechanisms alone amount to the loss of about half the incident solar energy in the conversion process [17]. Thus, the maximal energy conversion efficiency of a single-junction solar cell is considerably below the thermodynamic limit. This *single bandgap limit* was first calculated by Shockley and Queisser in 1961 [18].

The project: Photovoltaic installation

In 2014 my parents decided to build a chicken farm. The farm is located in Ribelles, a small town in the municipally of Vilanova de l'Aguda, in the province of Lleida. As we can see in the *Fig. 3*. the farm called Casa Perot has a latitude in decimal degrees of 45.815, a longitude of 1.275 and an elevation of 412m. On November 4th of 2015 the new farm entered the first 30.000 chickens and it had been working since today.

Figure 3. *The location of the farm in Ribelles, Casa Perot.* ***Source*** *Google Maps*

Nowadays, the farm is working with gas natural (a source of fossil energy that, like coal or oil, is made up of a mixture of hydrocarbons, molecules made up of carbon and hydrogen atoms) and with electricity.
In Catalunya the production of natural gas is currently zero, which is why the energy dependence of this resource is total. The main sources of heating in the farm is the gas tank, however in the future we are going to replace those technologies for electric ones. The gasoil group works when there is no input of electricity from the gird due to technical problems. This is very important because with no ventilation the chickens could die in less than 15 minutes due to the high temperatures.

The consumption

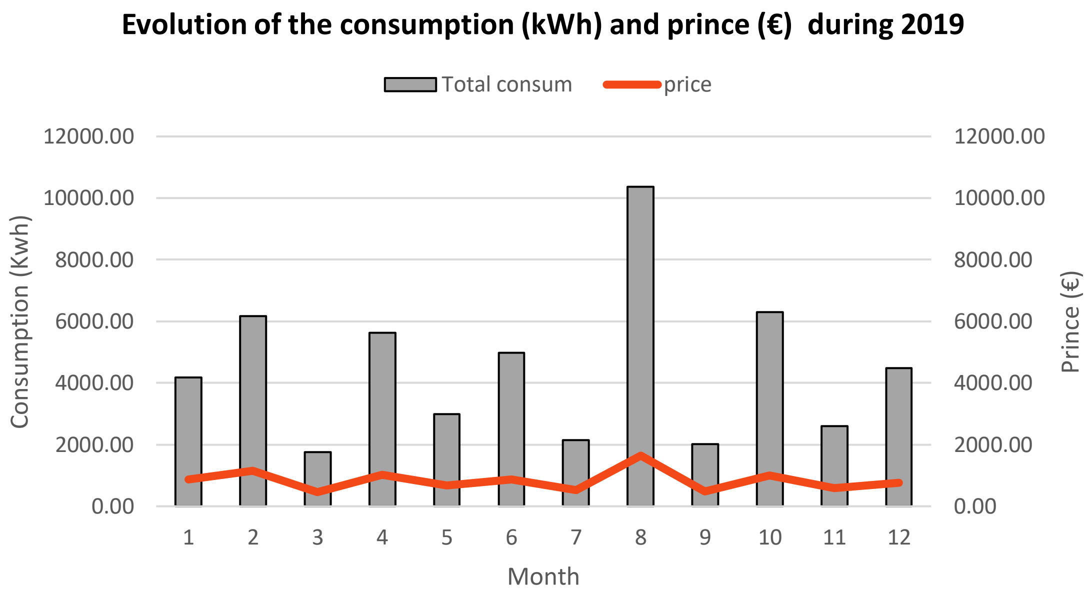
For the actual consumption study, it is necessary to consider the period of time that the chickens spend on the farm; between 35 and 40 days. After this period of time, the farm has to be ready for the new chickens to arrive, indeed with a period of 10 days proximally for cleaning.

Table 1 shows the electricity consumed by the farm in different months depending on the light bill. All consumption is from 2019 because due to Covid-19, the farm does not work in its full capacity. *Graph 2* will show the evolution.

BILL DATE	***BILLED PERIOD***		***DAYS BILLED***	***TOTAL CONSUMPTION***	***TOTAL***
	Start	*End*	*Days*	*Kwh*	*€*
15/2/19	*16/12/18*	*15/1/19*	*30*	*4176,00*	*879,91*
18/3/19	*15/1/19*	*18/2/19*	*34*	*6160,00*	*1160,12*
17/4/19	*18/2/19*	*13/3/19*	*23*	*1760,00*	*457,89*
17/5/19	*13/3/19*	*16/4/19*	*34*	*5625,00*	*1022,64*
19/6/19	*16/4/19*	*17/5/19*	*31*	*3000,00*	*667,87*
17/7/19	*25/7/19*	*13/6/19*	*27*	*4982,00*	*869,16*
20/8/19	*13/6/19*	*11/7/19*	*28*	*2142,00*	*533,29*
20/9/19	*11/7/19*	*20/8/19*	*40*	*10367,00*	*1643,54*
18/10/19	*20/8/19*	*16/9/19*	*27*	*2011,00*	*485,16*
20/11/19	*16/9/19*	*15/10/19*	*29*	*6303,00*	*1009,52*
19/12/19	*15/10/19*	*14/11/19*	*30*	*2610*	*589,55*
20/1/20	*14/11/19*	*13/12/19*	*29*	*4491*	*772,37*

Table 1. *Consumption of the farm in Ribelles during 2019*

The highest electricity consumption belongs to the period of time between 11th of July and 20th of August with a value of 10.365,0 kwh and 1643,54 € due to the high temperatures during daytime reaching the 35 ºC where all the air conditioning system is working to prevent the death of the animals. The yearly consumption is 53.627,0 kwh.



Graphic 2. *Consumption of the farm in Ribelles during 2019.*

Irradiation study

The Earth movement and the atmosphere fluctuations make difficult the prediction of the energy delivered by a solar energy conversion system. The accurate calculation of the energy delivered by a solar energy system depend on the energy provided by the sun and on the details of the conversion system. For a photovoltaic system the spectral composition of the light influences the conversion efficiency.

Different atmospheric phenomena affect the solar radiation: clouds, dust (most of them due to human activity), turbidity. The sun rays are absorbed and dispersed by these effects. The geographical location of the site, specially the latitude and altitude over the sea level, highly affects the irradiation reaching the Earth surface.

The irradiance G is the energy per unit surface, is usually measured in W/m^2 . The irradiance is time dependent, being almost zero during the night (only the solar radiation reflected on the moon that reaches the earth contribute to the small night irradiance). It is usual to use mean values for the irradiance. These values are hourly irradiance (G_h), daily irradiance (G_d), monthly irradiance (G_m) and yearly irradiance (G_y). [19].

Based on the measurements from the meteorological services and numerical simulation it is possible to produce accurate mean irradiance maps. For the calculations of solar radiation, we will use a freely available software with access to a huge amount of radiation data developed by the JRC (Joint Research Centre) of the EC in Ispra (Italy), the **PV-GIS**. For the knowledge of the solar irradiation on the top of the roof it will be necessary to calculate his slope angle.

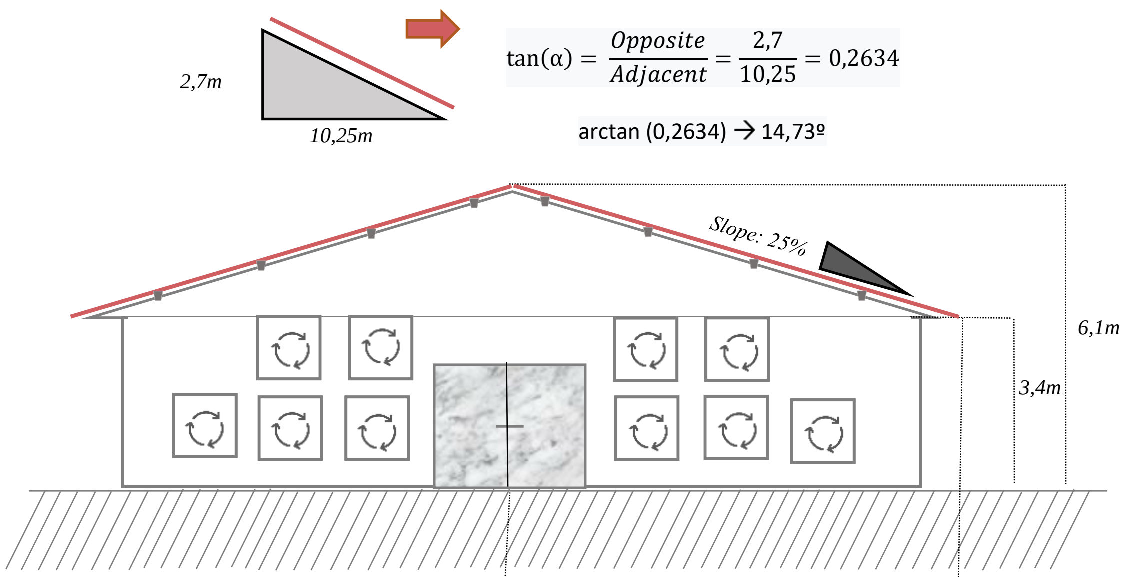
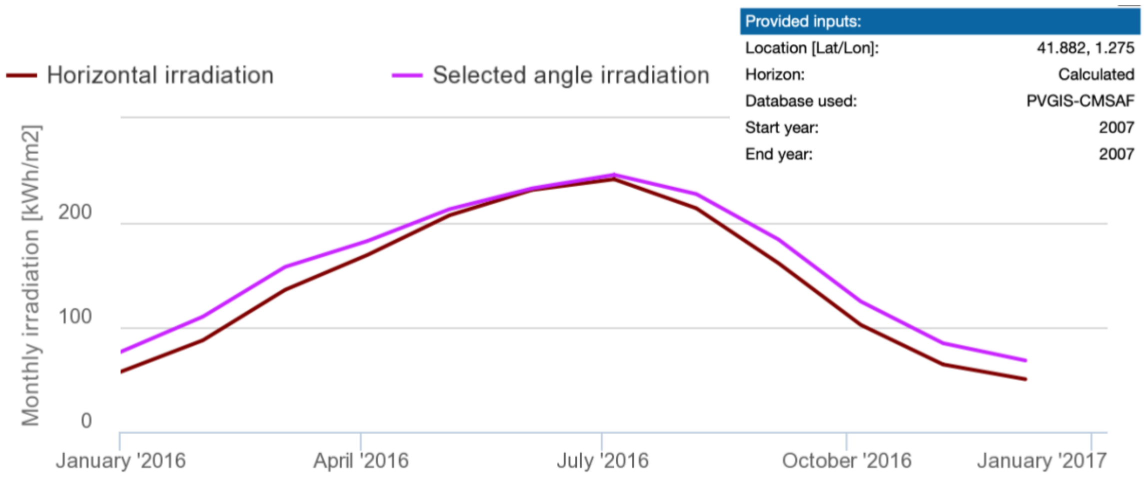


Figure 4. *Slope calculation of the roof. (Own Elaboration)*

Once we calculated the slope, with PV-GIS we will get the irradiation information, the red line for the horizontal irradiation, always below the pink line that represents de irradiation in a selected angle of 14,7º that has been calculated early.



Graphic 2. *Monthly solar irradiation estimates with PVGIS, in red the horitzontal irradiation and in pink the irradiation with and angle of 14,7º.*

Photovoltaic modules

Once the decision to install a photovoltaic system is done, it is important to know what kind of photovoltaic module to buy; which will depend on the needs and the characteristics of the place where it will be installed. This is not about buying the most expensive module, but the one that best covers the demands.

After deep researches, the final decision goes to the model LR6-60HBD 300-320M from the company LONGI Solar. (*Annex 1 shows the technical data*). The design of the module and the most important parameters are shown in *Table 2* and *Figure 5.*

LR6-60HBD 300-320M

EFFICIENCY	18,9	%
DIMENSIONS	1698x996x30	mm
SURFACE	1,691208	m2
MAXIMIUM POWER (PMAX/W)	320	STC
VOLTAGE AT MAXIMUM POWER (VMP/V)	34	STC
TEMPERATURE COEFFICENT OF VOC	-0,3	%/C
KW$_P$	0,319638312	*Kwh*
LIFETIME	30	*years*

Table 2. *Specifications of the module LR6-60HBD 300-320*

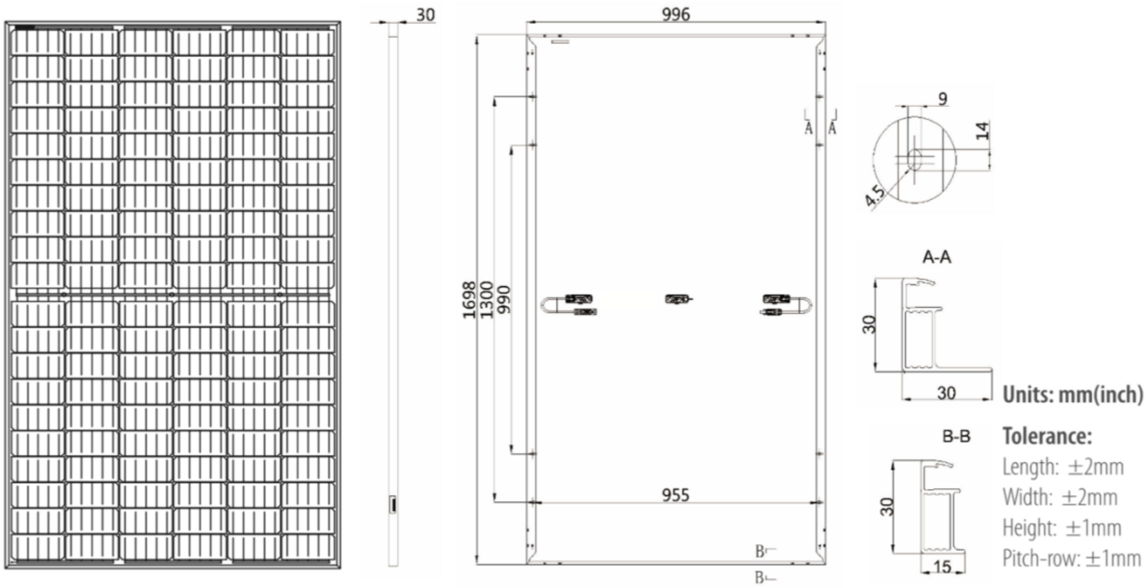


Figure 5. *Design of the module LR6-60HBD 300-320*

The Kwp is the power that the manufacturer declares that the PV array can produce under standard test conditions, which are a constant 1000W of solar irradiation per square meter in the plane of the array, at an array temperature of 25°C. The peak power should be entered in kilowatt-peak (kW_p). As declared peak power of the modules it is not known but instead know the area of the modules and the declared conversion efficiency (in percent), it is possible to calculate the peak power as;

$$\boldsymbol{kW_p = Module\ efficiency * Module\ surface} = 0{,}189 * 1{,}69 = 0{,}319$$

Considering total system loss about **13%** and the technologies used, the data base, the kWp and the inclination angle in the latitude and longitude location, the PV-GIS gives the annual FV production.

Simulation outputs

Slope angle [º]	14,73
Azimuth angle [º]	-45
Yeraly PV energy production [kWh]	437,07
Yearly in-plane irradiation [kWh/m²]	1802,88
Year-to-year variability [kWh]	12,42
Total loss [%]	-24.89

Table 3. *Simulation outputs from PV-GIS*

As we can see in *Table 3* the Yearly PV energy production is **437,07** kWh.

The next step is the calculation of the yield plant (Y_p). Where E_{AC} is the electricity injected into the grid in a given period and the P_{DC} is the kWp that has been calculated.

$$\boldsymbol{Y_P} = \frac{\boldsymbol{E_{AC}}}{\boldsymbol{P_{DC}}} = \frac{Anual\ production}{kWp} = \frac{437{,}07\ kwh}{0{,}319kWp} = \mathbf{1370,125}\boldsymbol{h}$$

Therefore, the DC power of the farm considers the E_{AG} , the annual consumption of the farm divided by the Y_P.

$$\boldsymbol{P_{DC}} = \frac{\boldsymbol{E_{AG}}}{\boldsymbol{Y_P}} = \frac{53627{,}0kwh}{1370{,}125h} = \mathbf{39,14022}\ \boldsymbol{kW}$$

When switching from direct current to alternating current, there are some losses that need to be valued. The efficiency of the inverter should be high, but really what is taken into account is the percentage of losses (13%) because it includes more factors to take into account. So, the new conversion will be;

$$\boldsymbol{P_{AC}} = \boldsymbol{P_{DC}} * (\mathbf{1-0,13}) = 39{,}14 * (1 - 0{,}13) = \mathbf{34,1\ kW}$$

The number of modules is given by;

$$Number\ of\ modules = \frac{\boldsymbol{E_{AG}}}{\boldsymbol{Anual\ production\ of\ 1\ module}} = \frac{53.627{,}0\ kwh,}{437{,}07\ kWh} = \mathbf{122,69}$$

However, this number of modules is imitated to the surface of the farm because the installation will be in the roof, it's a building integration installation. The actual surface is 853,02m^2, so there is no limitation.

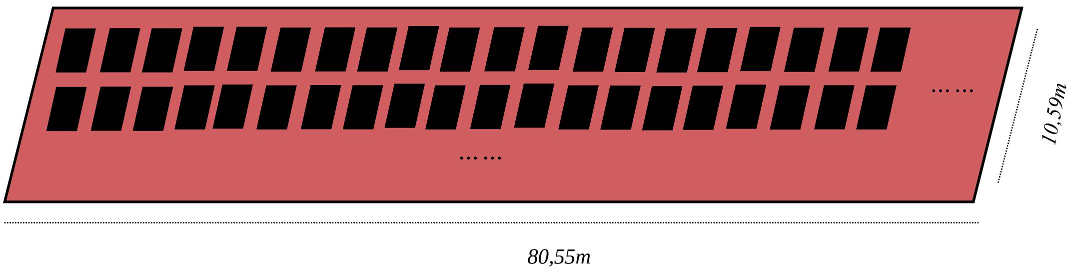


Figure 6. *Up-vision of the farm with drone*

Figure 7. *South-vision of the roof where modules will be developed.*

The inverter

An inverter is a device that allows DC to be converted from direct current (at the output of a PV module) to AC current, either for injection into the grid or for domestic use. Practically all PV systems include inverters, either in isolated or grid-connected systems.

Figure 8. Invertor model TRIO-20.0 TL-OUTD (v1)

The efficiency of an inverter is a key parameter, having greatly improved in recent years and normally reaching values above 95%. The efficiency of an inverter is defined as the AC output power divided by the DC input power:

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} = \frac{34,1kW}{39,13\ kW} = 0,87 \rightarrow \mathbf{87}\%$$

The nominal power of the installation must be taken into account when choosing the inverter;

$$\boldsymbol{P_{DC}} = \boldsymbol{N_{Modules}} * \boldsymbol{P_N} = 123 * 320 = 39,36kWh$$

The inverter chosen is the model TRIO-20.0 TL-OUTD (v1) (*Fig. 8*) from the company ABB because it meets the necessary electrical power requirements and has high performance for a good value for money. The following expression was used to calculate the total number of investors:

$$\boldsymbol{N_{module\ for\ invertor}} = \frac{\boldsymbol{P_{DC}}}{\boldsymbol{Invertor\ Power}} = \frac{39,36\ kw}{20kW} = 1,968\ inverters$$

Emissions

Another important aspect to be considered are the emissions from the elecreicity grid. In this case the corresponding distributor, Endesa, will be chosen from the list of energy mixes of distributors made by the OECC [20].

The emission factor of the electrical mix is the value that expresses the CO_2 emissions associated with the generation of the electricity consumed and, therefore, is an indicator of the energy sources used to produce that electricity, the lower the mix, the greater the contribution of energy sources of renewable or low carbon origin.

In the list, Endesa corresponds to emissions of 0.37 kg CO2 / kWh. Performing the annual calculation with the consumption;

$$53.627{,}0 \frac{kWh}{year} \cdot 0{,}37 \frac{kg\ CO_2}{kWh} = 19.841{,}99 \frac{kg\ CO_2}{year}$$

So, the carbon emissions of the farm are 19.841,99 each year.

Legal framework

RD-Law 15/2018 of October 5
- It is recognized the right to self-consume without charges - The right is recognized to the a self-consume shared. - Administrative and technical simplification - On the gate to the compensation of surplus energy (installation of power up to 100 kW) - In process of regulatory development
European Parliament directive November 2018
The Europeu Parliament has approved, in the form of a Directive, the new package of measures "Net energy for all Europeans", the self-consumption without sun taxes and the balance, to be transferred from Laws nationals by 2021. Binding objective that 32% of the energy consumed continued to be renewable in 2030 (July 2018 at 17.3% in the energy mix)

Table 2. *Legal Framework of the project*

Economic Analysis

Costs

Regarding the calculation of cost, the unit cost of each panel is 150€ and the criterion of 20% of the purchase cost will be applied for its transportation and installation. However, there are other items that will be necessary to include in the total price. *Table 4* shows all the details.

Component	Price	Quantity	Total
Longi Solar LR6-60HPB-315M	150€	123	18450€
ABB string inverters TRIO-20.0/27.6-TL-OUTD 20 to 27.6 kW	2888,90€	2	5777,8€
Meters (injection and control)	269€	2	538 €
Installation and transport	20%		3690 €
IVA	21%		5975,298 €
Total			34429,098€

Table 4. *Total cost of the project in euros.*

The total price of the project is 34.429,098€. However, there are some considerations that may vary this total amount.
My family and I realized that it is too expensive, and we can't afford this. So, we are going to start with less panels and then, in the future we are going to increase them to reduce the cost impacts in the begging.

Resizing the final project

We fixed the total cost of the project under the 20.000€. Trying to reduce the number of panels and use one only inverter. For the rentability of the plant the number of the plant it is going to start with 68 panels.
The electricity production in a year will be:

$$Number\ of\ modules * \ Anual\ production\ of\ 1\ module$$

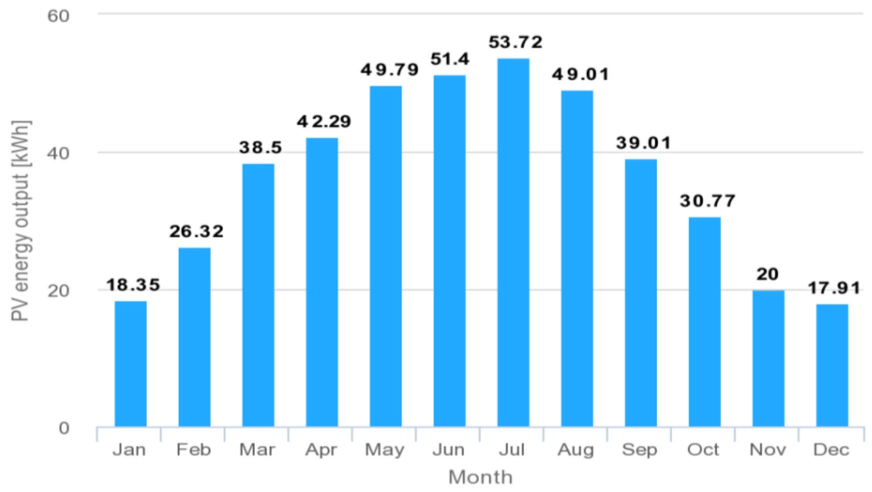
$$68\ * 437{,}07 = \mathbf{29.720{,}76kwh}$$

And the number of invertors:

$$\boldsymbol{P_{DC}} = \boldsymbol{N_{Modules}} * \boldsymbol{P_N} = 68 * 320W\ = \mathbf{21{,}76KW}$$

$$\boldsymbol{N_{module\ for\ invertor}} = \frac{\boldsymbol{P_{DC}}}{\boldsymbol{Invertor\ Power}} = \frac{21{,}76\ kW}{20kW} = \mathbf{1{,}088\ inverters}$$

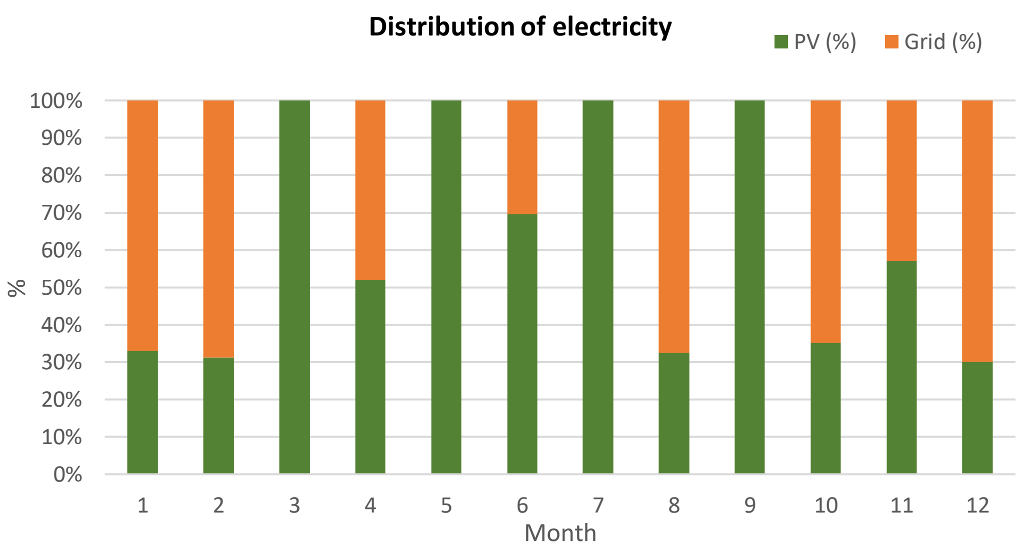
The next Graphic shows the electricity produced by the PV system each month. Followed by *table 5* and graphic 4 that shows the distribution of the electricity due to the PV system or the grid.



Graphic 3*. Monthly energy output from fix-angle PV-system (**Source**: PV-GIS)*

Month	Energy output (kWh)	68 modules	Consumption	Electricity grid
Jan	*20,25*	*1247,8*	*4176,00*	*2928,2*
Feb	*28,31*	*1789,76*	*6160,00*	*4370,24*
Mar	*40,04*	*2618*	*1760,00*	*0*
Apr	*42,9*	*2875,72*	*5625,00*	*2749,28*
May	*49,72*	*3385,72*	*3000,00*	*0*
Jun	*50,97*	*3495,2*	*4982,00*	*1486,8*
Jul	*53,62*	*3652,96*	*2142,00*	*0*
Aug	*49,51*	*3332,68*	*10367,00*	*7034,32*
Sep	*40,14*	*2652,68*	*2011,00*	*0*
Oct	*32,57*	*2092,36*	*6303,00*	*4210,64*
Nov	*21,92*	*1360*	*2610*	*1250*
Dec	*19,85*	*1217,88*	*4491*	*3273,12*

Table 5*. Consumes distribution between electricity grid and PV system (**Source**: Own elaboration)*



Graphic 4*. Distribution between electricity grid and PV system % during the year. (**Source**: Own elaboration)*

And the final emissions of the year compared with the other scenarios (*Table 6*)

$$29720{,}76 \frac{kWh}{year} \cdot 0{,}37 \ \frac{kg\ CO_2}{kWh} = 10.996{,}68 \frac{kg\ CO_2}{year}$$

100% Gird	123 modules	68 modules
19.841,99	Almost no emission	10.996,68

***Table 6**. Emission depending on the size of the project (**Source**: Own elaboration)*

Schematic diagram

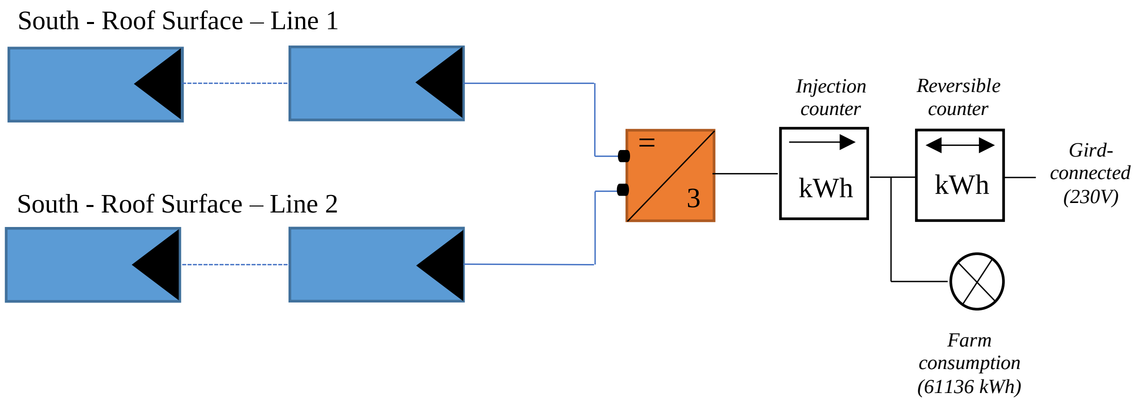


***Figure 9.** Schematic diagram of the installation considering the gird-connection (Own elaboration)*

When we consume energy from the electrical system, the marketing company that provides us with the service installs a meter so that we can bill ourselves according to our consumption. Also, it can be provided by the company that will develop the final project, more probably the company Novelec-Segre. However, for now, it is not going to consider the possibility of selling the electricity to the grid due to the cost of this bi-directional installation.

Second Economic Analysis

Costs

Component	Price	Quantity	Total
Longi Solar LR6-60HPB-315M	150€	68	10200€
ABB string inverters TRIO-20.0/27.6-TL-OUTD 20 to 27.6 kW	2888,90€	1	2888,9€
Meters (injection and control)	269€	2	538 €
Installation and transport 1	20%		2040 €
Installation and transport 2	20%		577,7€
Installation and transport 3	20%		107,6 €
			16.352,28€

IVA	21%		3.433,9788 €
Total			**19.786,36€**

***Table 7**. Total cost of the final project after resizing the project*

The total cost of the project its 19.786,36€ considering the law of the 20% for the installation and transport of the panels, the inverters and the meters.

Rentability Analysis

Summary

SYSTEM DATA

INJECTION INTO THE NETWORK IN THE FIRST YEAR	0	Kwh/year
PV GENERATOR POWER	21,76	kwp
CONSIDERATION PERIOD	25	years
START OF THE PROJECT	1/01/2021	
INVESTMENT	19.786,36	€
SUBVENCIONS	0	€
% OF KWH GROWTH	3,5	%/YEAR
COMPANY PROVIDING INPUTS	NOVELEC-SEGRE	
INSTALLATION COMPANY	BAIMO	

***Table 8**. System data summary of the project inputs*

Cash flow

Utility residential electricity prices have risen steadily in the last decade. According to the Energy Information Administration, residential electricity rates have increased nationally by around 15% in the last 10 years. The Energy Information Agency also predicts that electricity price is going to increase, both in the short-term as well as the long-term (out to 2040). Utility electricity rates go up and down throughout the year but have a long-term tendency to rise. These fluctuations, which are the result of fuel costs and a number of other factors, are completely outside of your control. For the cashflow readability analysis is going to consider a speculation of an increase of 3,5% of the prices for the electricity every year. [21]

	Gird (kWh)	PV (kWh)	COST (3,5%/year)	Real Cost	SAVE	CUMULATIVE	BALANCE
0	53.627	0	10091,02	10.091,02	0,00	0,00	-
1	23.906	29.720,76	10444,2057	4.655,90	5.788,31	5.788,31	-
2	23.906	29.720,76	10809,7529	4.818,85	5.990,90	11.779,21	-
3	23.906	29.720,76	11188,09425	4.987,51	6.200,58	17.979,80	-
4	23.906	29.720,76	11579,67755	5.162,07	6.417,60	24.397,40	+
5	23.906	29.720,76	11984,96626	5.342,75	6.642,22	31.039,62	+
6	23.906	29.720,76	12404,44008	5.529,74	6.874,70	37.914,32	+
7	23.906	29.720,76	12838,59549	5.723,28	7.115,31	45.029,63	+
8	23.906	29.720,76	13287,94633	5.923,60	7.364,35	52.393,97	+
9	23.906	29.720,76	13753,02445	6.130,92	7.622,10	60.016,07	+
10	23.906	29.720,76	14234,38031	6.345,51	7.888,87	67.904,95	+
11	23.906	29.720,76	14732,58362	6.567,60	8.164,98	76.069,93	+
12	23.906	29.720,76	15248,22404	6.797,47	8.450,76	84.520,69	+
13	23.906	29.720,76	15781,91188	7.035,38	8.746,53	93.267,22	+
14	23.906	29.720,76	16334,2788	7.281,62	9.052,66	102.319,89	+
15	23.906	29.720,76	16905,97856	7.536,47	9.369,51	111.689,39	+
16	23.906	29.720,76	17497,68781	7.800,25	9.697,44	121.386,83	+
17	23.906	29.720,76	18110,10688	8.073,26	10.036,85	131.423,68	+
18	23.906	29.720,76	18743,96062	8.355,82	10.388,14	141.811,82	+
19	23.906	29.720,76	19399,99924	8.648,27	10.751,72	152.563,55	+
20	23.906	29.720,76	20078,99922	8.950,96	11.128,03	163.691,58	+
21	23.906	29.720,76	20781,76419	9.264,25	11.517,52	175.209,10	+
22	23.906	29.720,76	21509,12594	9.588,50	11.920,63	187.129,73	+
23	23.906	29.720,76	22261,94534	9.924,09	12.337,85	199.467,58	+
24	23.906	29.720,76	23041,11343	10.271,44	12.769,68	212.237,25	+
25	23.906	29.720,76	23847,5524	10.630,94	13.217,61	225.453,87	+

Table 9*. Rentability analysis during 35 years considering an increase of 3.5% per year of the electricity.*

Conclusions

The economic results based on the premises adopted in this work show clear results. Depside the fact of the initial investment, this gets completely covered by the 5 first years. Also, this study doesn't contemplate the possibility of selling the electricity to the gird, which in the future will suppose an important input of capital.

The reduction on the emissions by using a green source of energy plays a very important role. By implementing 68 panels, we can see a significant reduction on the emissions of 45%.

The first and most important is the fact that a significant economic investment is required to carry out a photovoltaic installation. The subsidies that the government awards are very difficult to acquire, the processing depends on many factors that are not dynamic, such as, for example, processing in the municipalities. That is why it is required, by the institutions, greater ease, and subsidy to projects that focus on improving the energy system, through a transition to a less polluting system, that of renewable energy.

To conclude: In the future of action at the individual level it will be as important as at the industrial and state level to produce an impact on the climate change fight and to reach sustainability at a global level. By all accounts, the distributed generation has to open paths between the main motors of the fossil fuel era and non-sustainable energy forms.

Abstract

En el treball realitzat s'ha dimensionat un sistema fotovoltaic connectat a la red elèctrica per tal de cobrir en el consum elèctric actual en una masia de Ribelles.
El projecte es centra en un instal·lació avícola amb un elevat consum elèctric d'aproximadament 52.000kwh/any. Es presenta un consum desigual a causa de les dinàmiques de creixement de les aus. Actualment el sistema queda limitat per la part econòmica, ja que no es disposa de suficient capital per realitza la instal·lació completa, es a dir, per cobrir el consum anual mitjançant 123 plaques i dos inversor i per tant s'ha reduït el nombre de plaques a 68 i un inversor.
Amb l'objectiu que en les 5 anys d'amortització del projecte es puguin incrementar les plaques solar, i aconseguir tenir font d'energia elèctrica completament renovable, així com també la possibilitat de venda l'electricitat sobrant a la red elèctrica ja que el consum desigual comentat anteriorment permet disposar de grans quantitats d'energia sobrant en alguns mesos de l'any.

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[21] Are Electricity Prices Going Up or Down in 2020, EnergySage, Solar News [23/07/2020]
<https://news.energysage.com/residential-electricity-prices-going-up-or-down/>

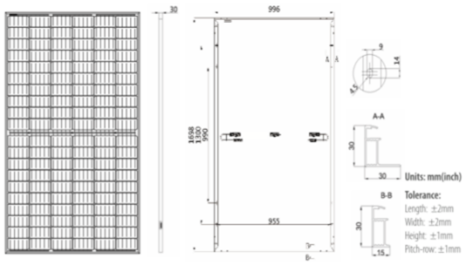
Annex

Annex 1

- Module; LR6-60HBD 300-320M

LR6-60HBD 300~325M

Design (mm)



Mechanical Parameters

Cell Orientation: 120 (6×20)

Junction Box: IP67, three diodes

Output Cable: 4mm², 300mm in length, length can be customized

Glass: Dual glass, 2.0mm tempered glass

Frame: Anodized aluminum alloy frame

Weight: 22.0kg

Dimension: 1698×996×30mm

Packaging: 35pcs per pallet, 210pcs per 20'GP, 910pcs per 40'HC

Operating Parameters

Operational Temperature: -40℃ ~ +85℃

Power Output Tolerance: 0 ~ +5 W

Voc and Isc Tolerance: ±3%

Maximum System Voltage: DC1500V (IEC/UL)

Maximum Series Fuse Rating: 20A

Nominal Operating Cell Temperature: 45±2℃

Safety Class: Class II

Fire Rating: UL type 6

Bifaciality: Coating≥75%, Glazing≥70%

Electrical Characteristics

Test uncertainty for Pmax: ±3%

Model Number	LR6-60HBD-300M		LR6-60HBD-305M		LR6-60HBD-310M		LR6-60HBD-315M		LR6-60HBD-320M		LR6-60HBD-325M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	300	223.1	305	226.8	310	230.5	315	234.2	320	237.9	325	241.7
Open Circuit Voltage (Voc/V)	40.3	37.5	40.5	37.7	40.7	37.9	40.9	38.1	41.1	38.3	41.3	38.5
Short Circuit Current (Isc/A)	9.44	7.64	9.55	7.73	9.66	7.82	9.75	7.90	9.86	7.98	9.95	8.06
Voltage at Maximum Power (Vmp/V)	33.3	30.9	33.5	31.1	33.6	31.2	33.8	31.4	34.0	31.6	34.2	31.8
Current at Maximum Power (Imp/A)	9.01	7.22	9.12	7.30	9.23	7.39	9.32	7.46	9.42	7.54	9.51	7.62
Module Efficiency(%)	17.7		18.0		18.3		18.6		18.9		19.2	
STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5												
NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20℃, Spectra at AM1.5, Wind at 1m/S												

Electrical characteristics with different rear side power gain (reference to 310W front)

Pmax /W	Voc/V	Isc /A	Vmp/V	Imp /A	Pmax gain
326	40.7	10.14	33.6	9.69	5%
341	40.7	10.62	33.6	10.15	10%
357	40.8	11.10	33.7	10.59	15%
372	40.8	11.59	33.7	11.04	20%
388	40.8	12.07	33.7	11.51	25%

Temperature Ratings (STC)

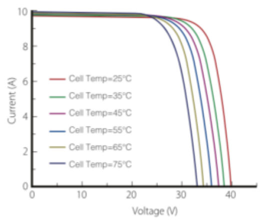
Temperature Coefficient of Isc	+0.060%/℃
Temperature Coefficient of Voc	-0.300%/℃
Temperature Coefficient of Pmax	-0.370%/℃

Mechanical Loading

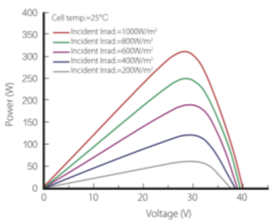
Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

I-V Curve

Current-Voltage Curve (LR6-60HBD-310M)



Power-Voltage Curve (LR6-60HBD-310M)



Current-Voltage Curve (LR6-60HBD-310M)