SIMULATION AND VERIFICATION OF A PV SYSTEM WITH ACCUMULATION INTO HOT WATER IN CASE OF MODERATE CLIMATE AND LOW FEED-IN TARIFF.

MASTER´S THESIS

CZECH TECHNICAL UNIVERSITY OF PRAGUE
FACULTY OF ELECTRICAL ENGINEERING

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1. ECONOMIC EVALUATION IN SPAIN

This study is going to consist of a survey about the cost of photovoltaic (PV) installation in the Spanish market. This economic evaluation is going to be divided in two different procedures. In the first one, the main goal is to gather information about the cost of PV modules in the Spanish market, in other words, PV modules provided by exclusively Spanish suppliers. In the second one, the study is going to focus on searching the cost of PV Kits and whole budgets of a complete PV installation. Again, the suppliers of these components must be Spanish.

1.1. PV MODULES IN SPANISH MARKET

As it has been said before, in this part a market survey about the cost of PV modules in Spain is going to be done. The first step for executing this study is finding national suppliers, in this case Spanish suppliers for photovoltaic modules. To achieve this, a googling research has been done using two methods.

The first one has consisted of taking the modules from other previous work database and from PVSOL available module database. This only led to Spanish suppliers rarely, however, adding the name of the nation (Spain) made the results appear easily. Sometimes some PV brands were not found, so they were googled directly and it led to other suppliers.

The other method which has been used is googling for websites of Spanish suppliers and checking if they supply the modules in which the research is looking for. Nevertheless, this mainly led to Spanish enterprise which worked on consultancy and installation, so it was necessary asked for a budget. Other times, it did lead to some websites where the prices could be found.

Furthermore, there have been some rules to select the module. The conditions set for this survey are:

- The first rule is that the module found must have a peak **power equal or higher than 250 W**. Most of the modules selected for household have a power higher than this value, so this rule have been stablished in order to make the economic evaluation more representative.
- The next rule is that the **modules** which have an **expensive price** have been **discarded** from the selection. Every photovoltaic project has its economic study, so if it does not obtain profit after its shelf life, it is going be discarded.
- The third rule establishes that the market survey has to distinguish between the type of cell, polycrystalline or monocrystalline.
- The last rule which has to be considered is that the module brand must be both Spanish and foreign.

After applying these previous rules, the results of the market survey are presented in the following table, where the PV modules which have been found in Spanish market are shown. The table is divided in two mainly cell types, monocrystalline and polycrystalline. Furthermore, these two sections are divided in turn into international manufacturers and Spanish manufacturers. This table includes some characteristics from every module, such as:

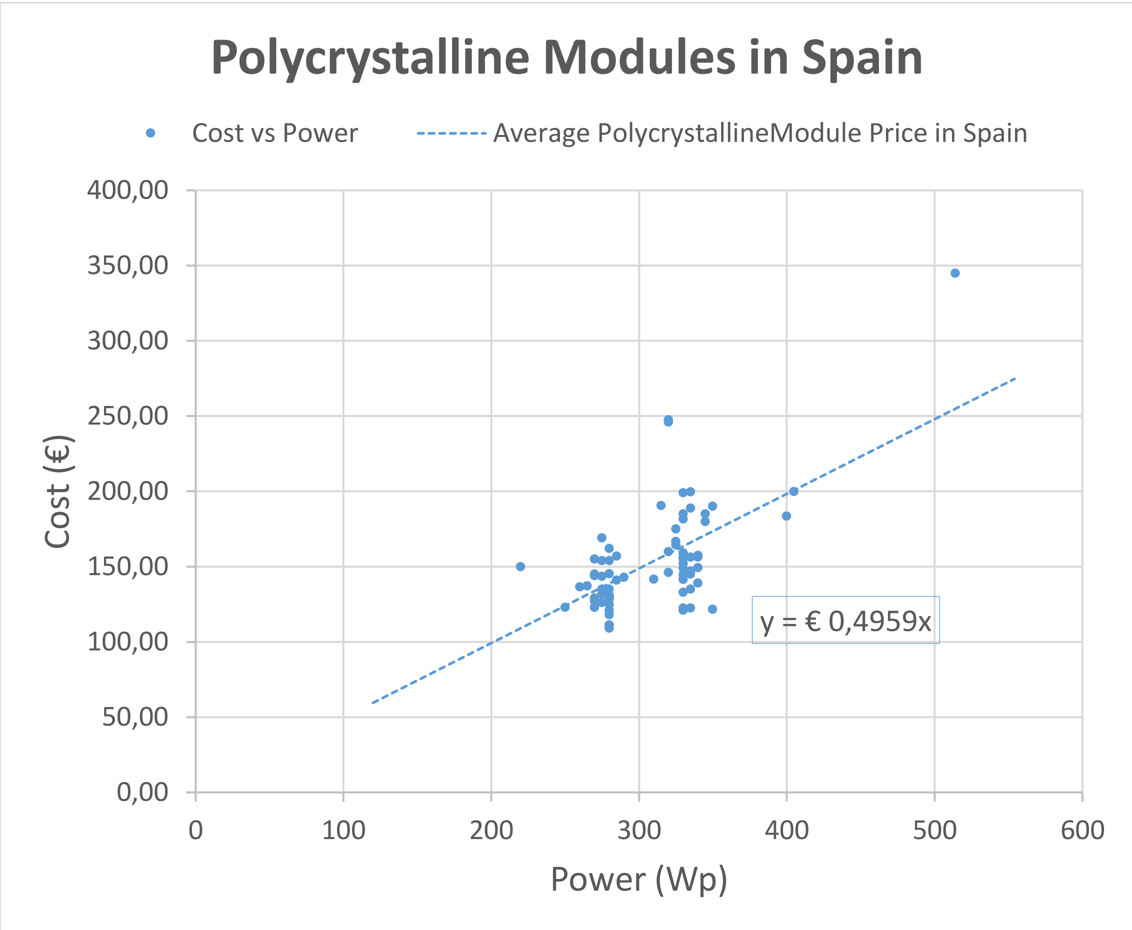
- Model and Brand
- Link to the selling supplier website
- Nominal Power (Wp)
- Efficiency (%)

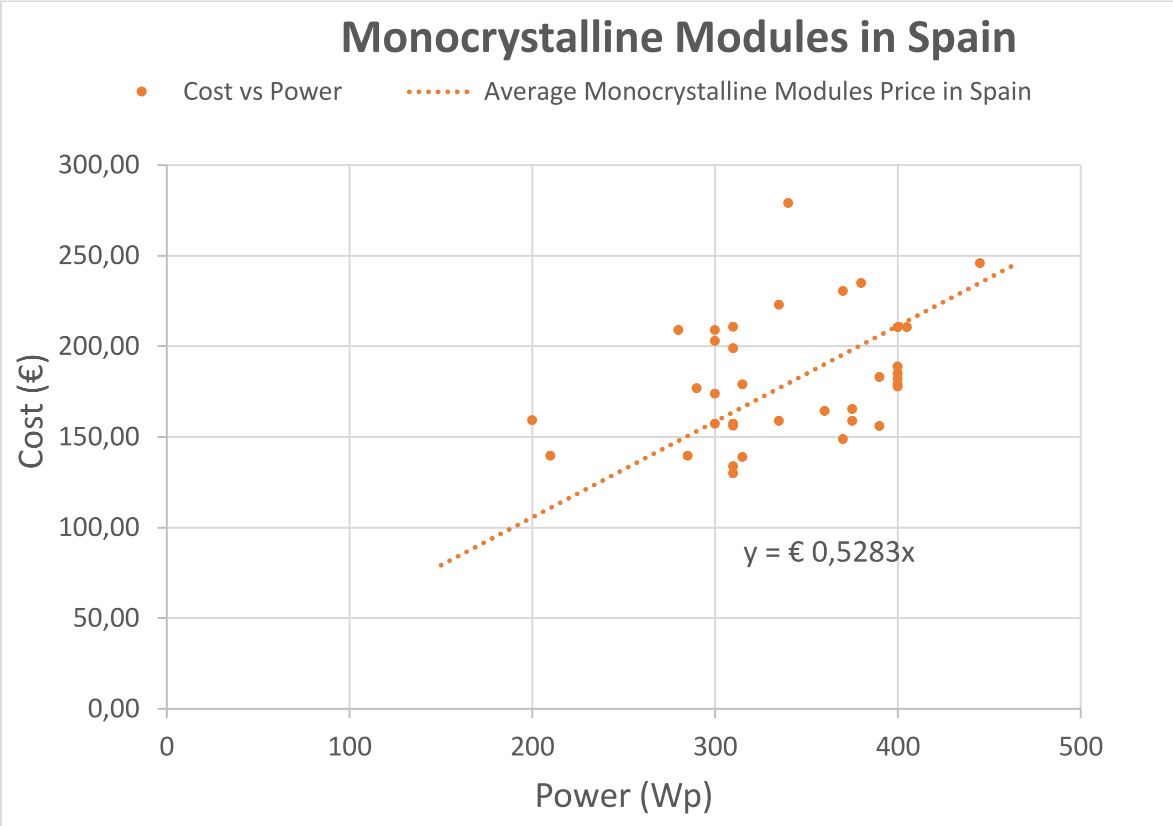
- Calculated Efficiency (%): $\frac{Pn(Wp)/10}{A(m^2)}$
- Height (mm), Width (mm) and Area (mm^2)
- Price (€)
- Module Coast (€/m^2)
- Datapoint (€/m^2): this parameter represents the total cost of a PV system after adding the BOS cost to the module cost.

The BOS or Balance of system is a parameter which represents the cost of all components of a PV system other than PV modules. It is going be explained with more details in the next part.

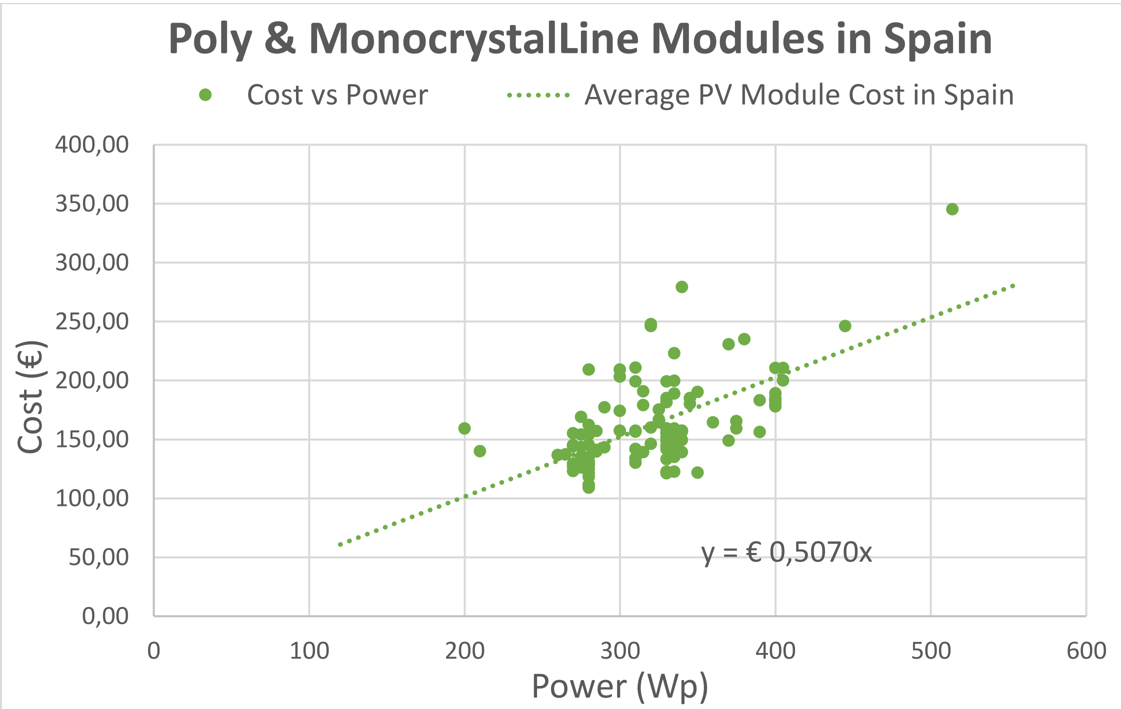
The results of the market research are fully represented in the Annex 1 and 2.

The following graphs plots the relation between the cost of the modules versus their power for pollycrystaline and monocrystalline module. A slightly linear trend can be observable but the correlation is not strong enough. However, it must be claimed that the cost is raised by the power.





Monocrystalline Modules in Spain
Cost vs Power
Average Monocrystalline Modules Price in Spain
300,00
250,00
200,00
150,00
100,00
50,00
0,00
Cost (€)
0
100
200
300
400
500
Power (Wp)
y = € 0,5283x



Poly & MonocrystalLine Modules in Spain
Cost vs Power
Average PV Module Cost in Spain
400,00
350,00
300,00
250,00
200,00
150,00
100,00
50,00
0,00
Cost (€)
0
100
200
300
400
500
600
Power (Wp)
y = € 0,5070x

1.2. KITS AND WHOLE BUDGETS MARKET SURVEY

The second part of this economic study consists of a market survey about the full cost of a PV installation in Spain. This study includes two types of searching, where one of them is going to focus on PV Kits and installation costs and the other one is going to search for whole budgets of a PV installation.

The first step of this part was necessarily asking for the typical power range of a PV installation in Spain. Several companies were contacted to ascertain the most common value of the installation power. The result obtained after this market survey was a range between 2kW and 5kW. So this means that every Kit or every budget has to be between this range.

1.2.1. PV Kits survey

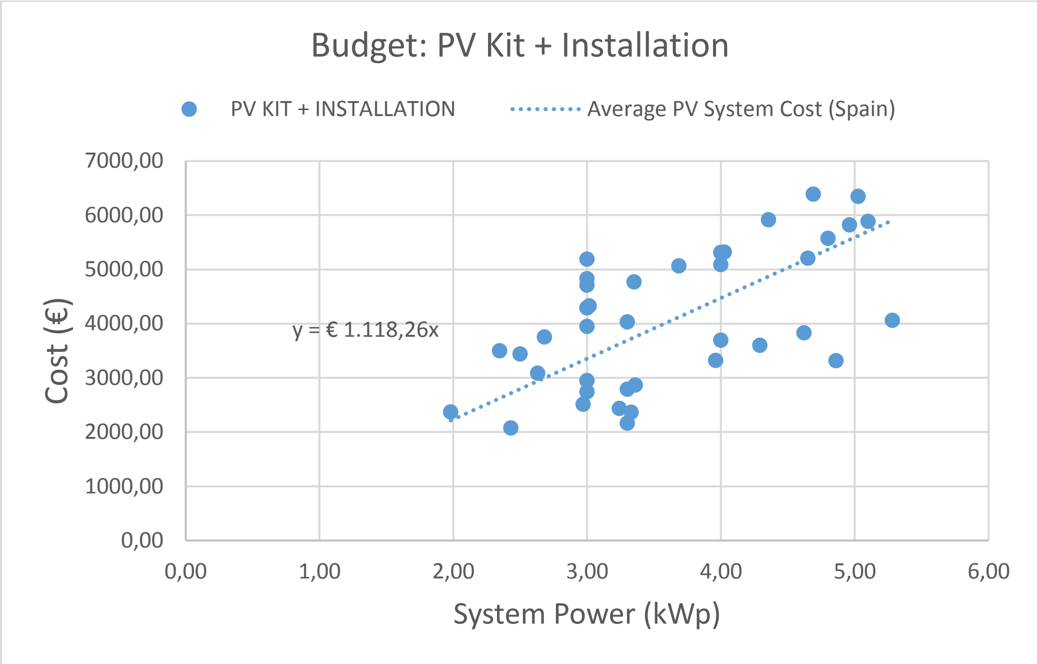
This survey has been done in a similar way to the PV modules survey. By googling for Spanish PV Kits, some results were found. However, the main way of obtaining results has been searching for the Kits on the same websites that the PV modules were found.

A Kit is composed by every essential component of a PV installation: modules, inverter, structure, batteries (not in this case), protection devices, wires, etc. Nevertheless, the installation and the legalization (Electrical Installation Certificate) must be done too. Usually, the cost of the Kit does not include these two costs, but they are given apart separately.

The results found are presented in the following table and it includes:

- Website/company
- Total installed power (kWp)
- PV module Brand and module
- Inverter and power
- Number of modules
- Kit price
- Installation price
- Legalization price
- Total price

The following graph shows the representation of the cost of every PV Kit+Installation found in the Spanish market against its total power. A slight linear trend between the power and the cost is observable is this graph, but the correlation is not very strong. In total, 40 Kits from 7 different companies were found and the average cost is 1467.55 €/kWp.



1.2.2. Whole Budget survey

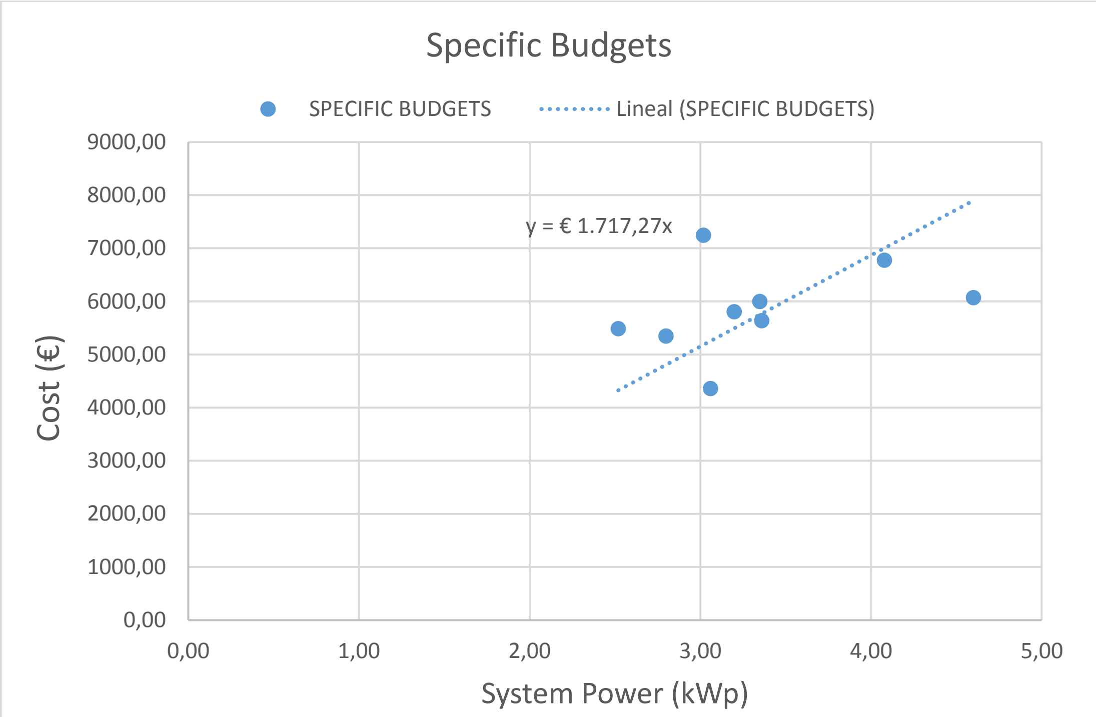
For this research, several Spanish companies were contacted in other to obtain information about the full cost of a PV installation in Spain. This market survey differs from the Kits survey in that the companies contacted advice the customer in every detail. They make the energetic study for the household in question, determining the total power needed, the number of modules, the optimal angle, the inverter, etc. This will mean that price is going to increase respecting to Kit cost.

Another thing to take into account is that the customers cannot buy the components separately. They will have to buy all the components together from the PV Company. Furthermore, the company is going to be in charge of doing the installation, including this cost and the legalization cost in the whole budget.

In this survey, the resulting table is attached in the annex 7 and it will contain:

- Name of the company
- Installed Power
- Number of modules
- Inverter
- Total cost

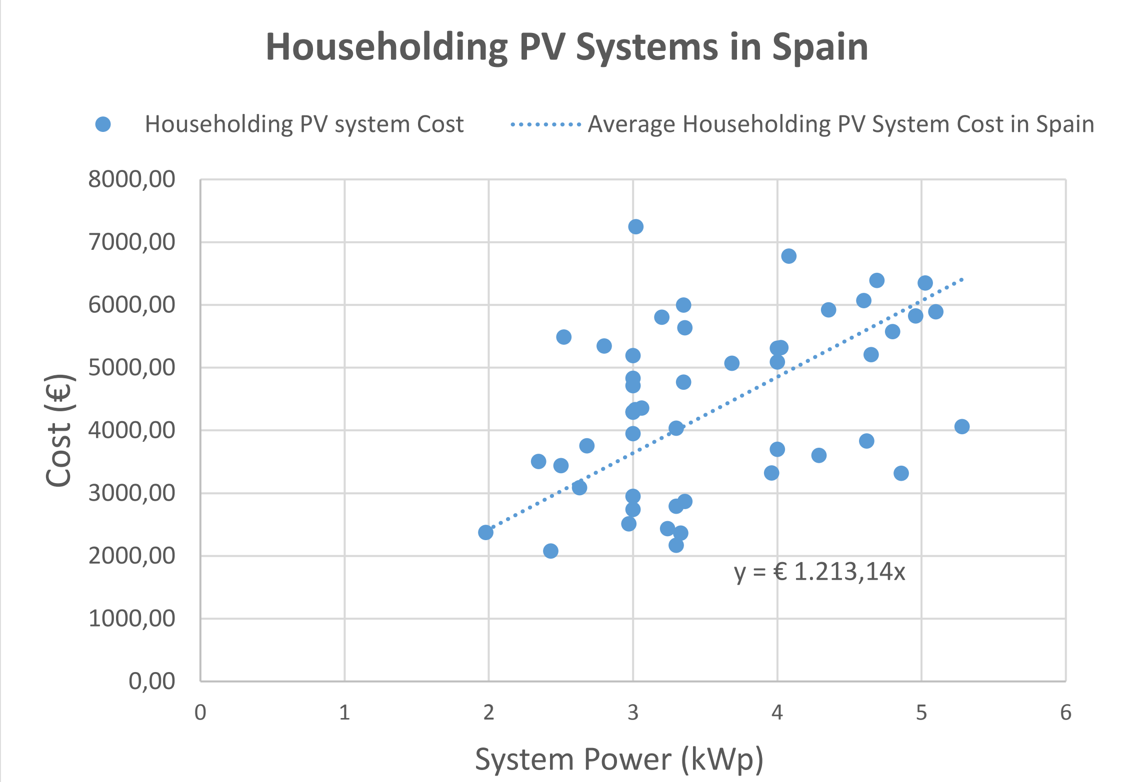
The next graph represents the cost against the power of every specific budget for a complete PV system found in the Spanish market. The points represented are really scattered and the linear trend is weak although it is still observable. In total, 9 different companies were contacted for a specific budget and the average price given is 1797.86 €/kWp, 330 €/kWp more expensive than the Kit cost. This is explained by the reason that the company advice the customer and select the system for him, so this has an extra cost.



1.2.3. Compiled results

Lastly, both Kits survey and Specific Budget survey are going to be compiled in an only resulting table. The objective of this is obtaining the average cost of a PV installation in Spain without distinguishing the way of obtaining the cost.

The following table represented every budget found from Kits and specific budget. Newly, it can be seen that the point are scattered and the linear trend between power and cost is weak.



1.3. BALANCE OF SYSTEM (BOS)

The balance of system (BOS) is a parameter whose objective is encompassing all components of a photovoltaic system apart from the PV modules. It obtains the average cost of components such as wiring, inverters, structure or mounting system, batteries, charge controller, etc. So the purpose of this parameter is obtaining a value which has to be added to PV modules in order to get the average total of the installation.

1.3.1. How to obtain BOS value

For this case, the BOS is going to be obtained in$\left[\frac{€}{m^2}\right]$. The equation followed for obtaining the BOS value is:

$$BOS = AMC \left[\frac{€}{m^2}\right] * \left(\frac{A\ PV\ Cost\left[\frac{€}{Wp}\right] - AMC\left[\frac{€}{Wp}\right]}{AMC\left[\frac{€}{Wp}\right]}\right)$$

Where AMC means “Average module Cost” and APV cost means “Average PV system cost”.
The values of these parameters are:

Average Module Cost [€/m²]	Average Module Cost [€/Wp]	Average PV System Cost [€/Wp]
90,23	0,51	1,2697

Finally, substituting these parameters in equation, the BOS obtained value is:

$$BOS = 133.95\ €/\mathrm{m}^2$$

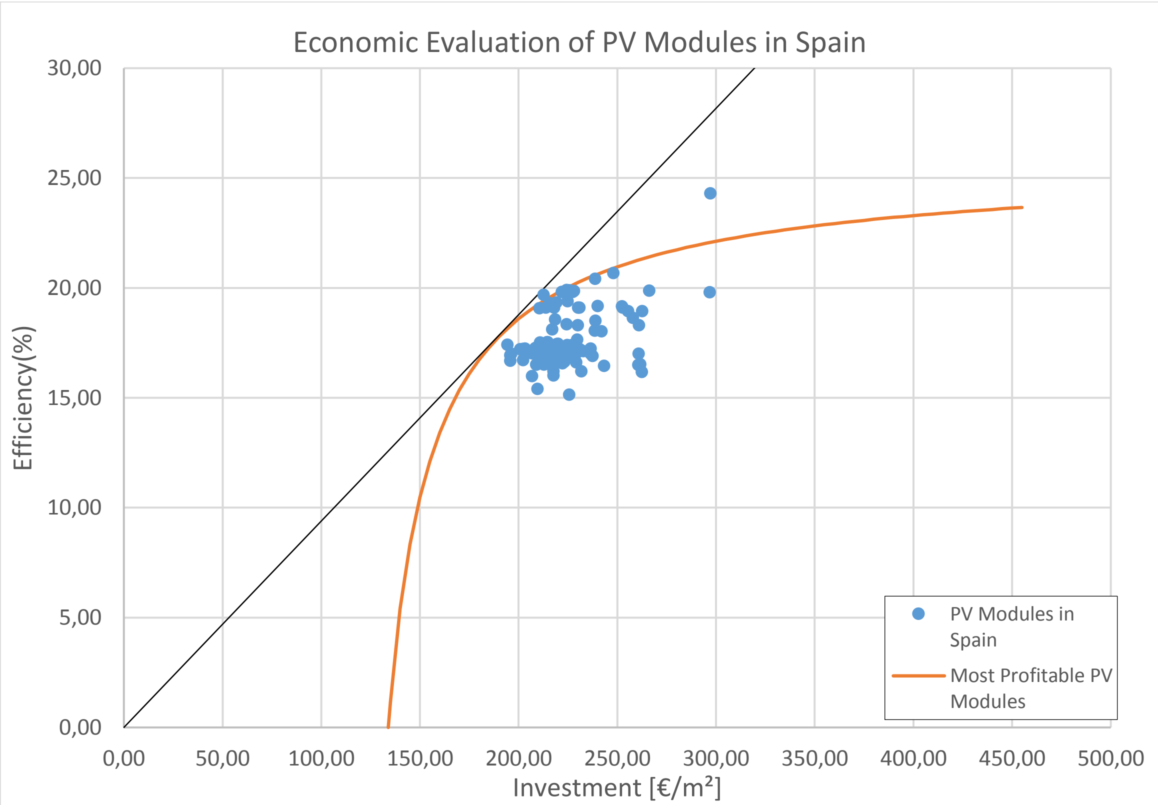
It is also possible to calculate the function which represents the current situation of PV systems cost in Spanish market. It is obtained with the following parameters:

Equation:	$y = \frac{-c}{(x-a)^g} + b$	
Parameters		
Maximum Efficiency (%)	b	26,00
Techonology Cost (BOS)	xo	133,9466
Sharpness	g	0,83
Horizontal Shift	a	115,28702
Position (Vertical)	c	295

$$a = xo - \left(\frac{b}{c}\right)^{\frac{-1}{g}}$$

1.3.2. BOS representation

The following graph represents the efficiency of a PV system depending on the investment done in $€/\mathrm{m}^2$. Each point represents the total Cost of a PV system after adding the BOS cost to the cost of the module in question. The black line represents the cost of the electricity in Spain and the orange curve is the function obtained before. If the points are following the line or close to it means that the relation between the investment and the efficiency is the best that maker offers. If a point is higher than the line means that price is cheaper than average and usually is an special offer or not reliable offer and must be removed.

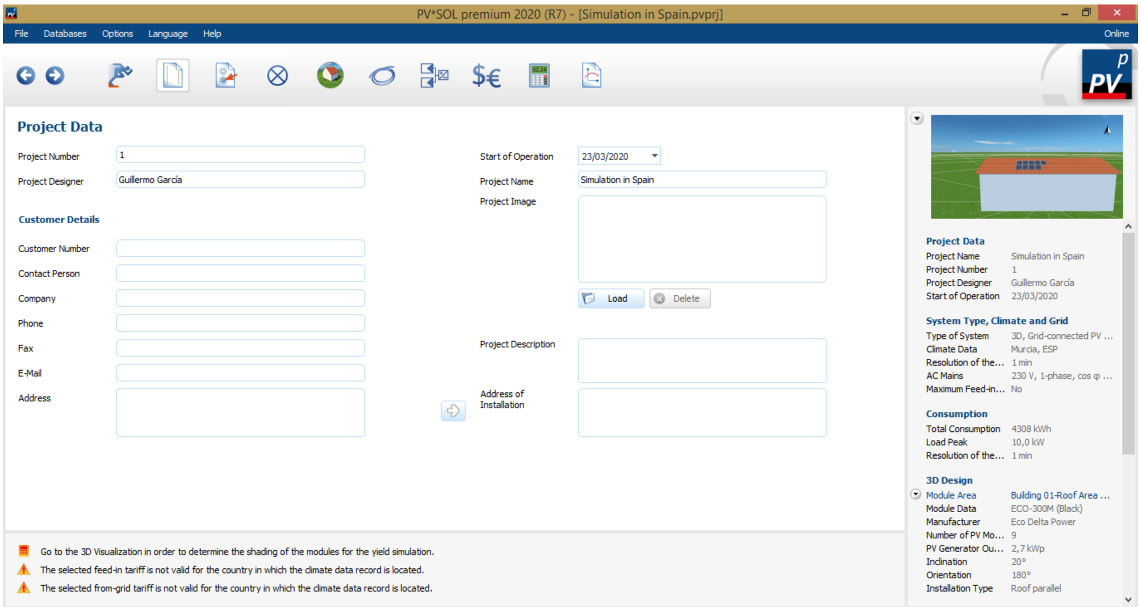


2. SIMULATION PV SOL

2.1. SIMULATION PROCEDURE

Once the market survey for PV modules in Spain is made, the next step is simulating the performance of each module for a typical Spanish PV location. This simulation is going to be done by the software PV*SOL Premium 2020. In the following paragraphs, the simulation process is going to be explained step by step.

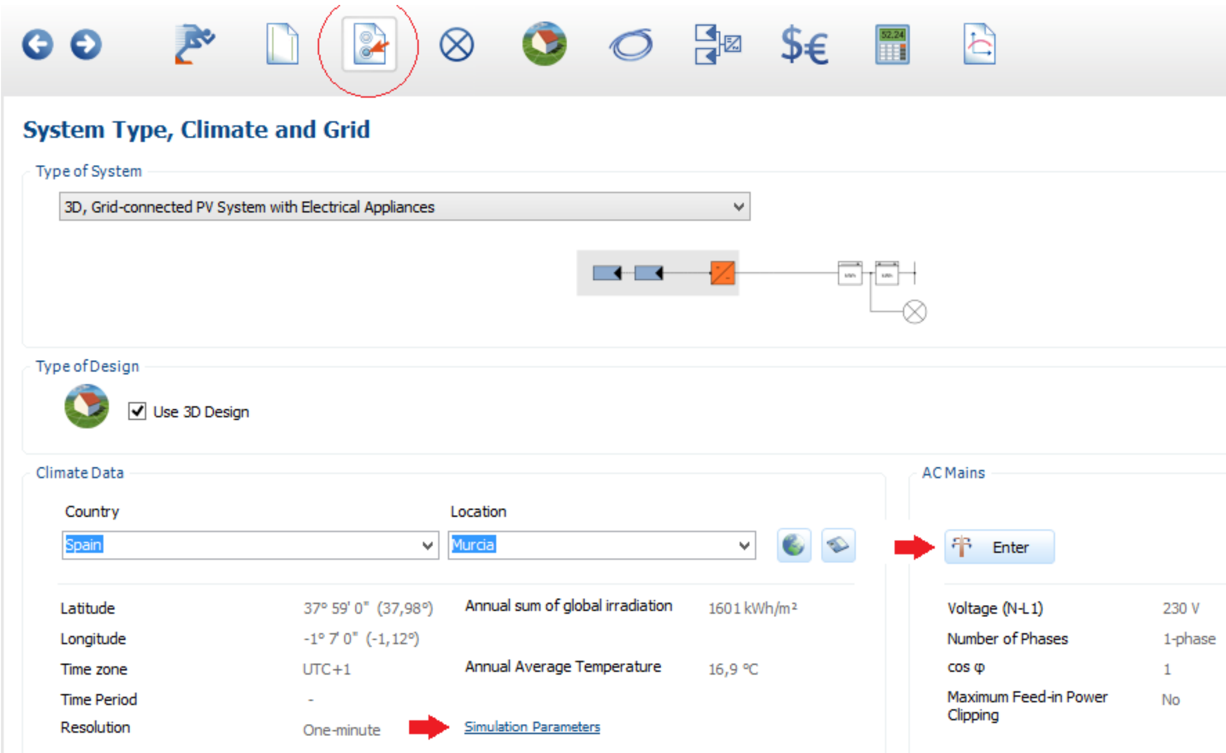
1. The first step is opening PV SOL and start a new project. This tab is only for introducing the project data, such as the project name, the designer or the description.



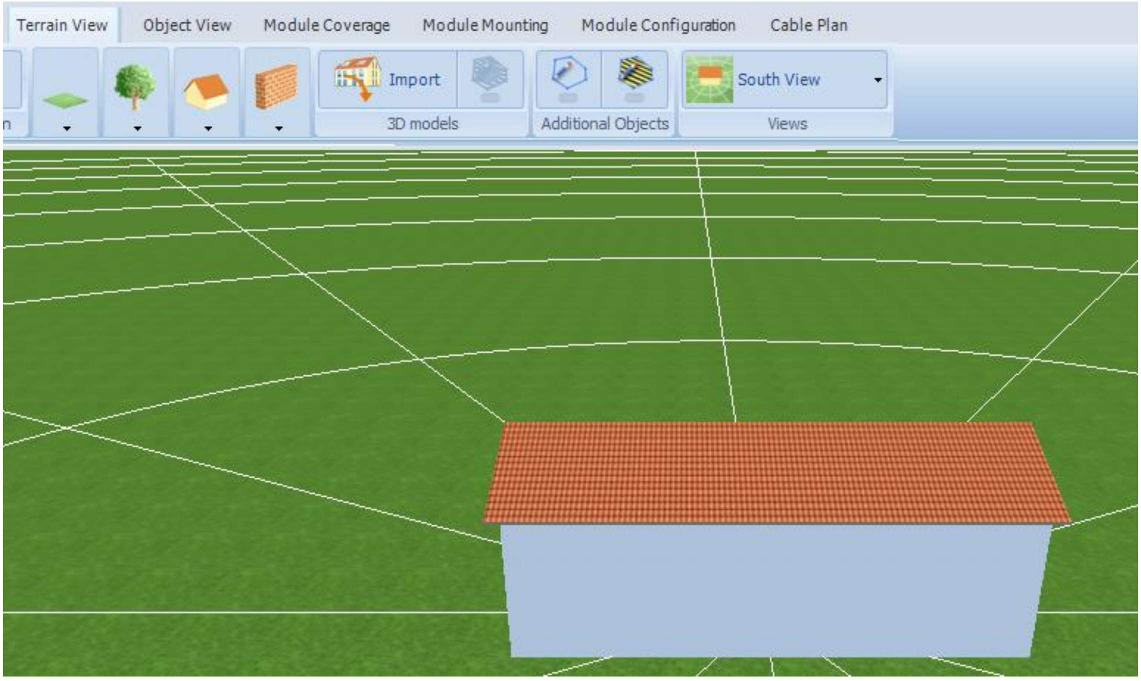
2. In the next tab it is necessary to introduce the type of electrical system, the location and climate data and the grid characteristics.
   Regarding to the system type in these simulations is going to be "Grid-connected PV system with electrical appliances". This means that there is not any battery or electric vehicles connected to the system. The energy generated flows directly to the home appliances.

   Respecting the location, the goal is to look for an area in the country concered where there is already the most household PV installations. It should combine good irradiation and high population. For Spain, these simulations are going to take place in Murcia, located in southern Spain, where is the biggest PV plant in Spain. This region has a high population, irradiation and hours of sun.
   Under the Location, it is necessary to enter to "Simulation Parameters" -> "Project Options" -> "Simulation" and then check the box "Simulate the irradiance with synthesized minute values". This will provide the simulation a better resolution about shading.

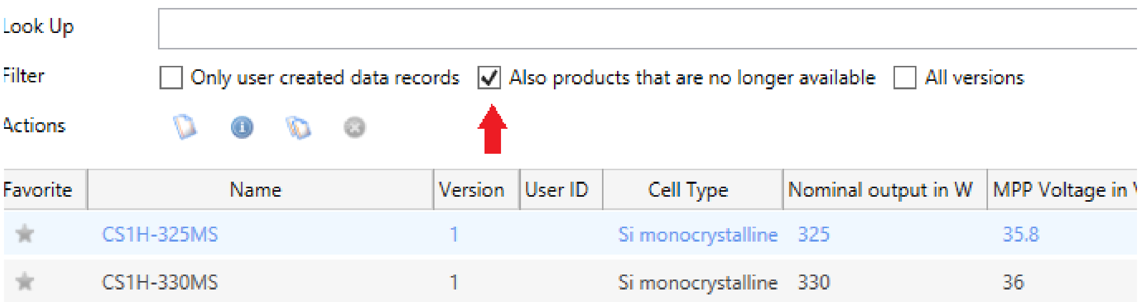
Finally, inside "AC mains" there is the option to change the number of phases and to introduce the proper voltage. Usually for PV installations for houses, having only 1 phase is more common, so 1-phase-inverter is suitable. The opposite happens in the industry, because the power is higher, so 3 phases are needed.
For these simulations the voltage is 230V and the number phases is 1.



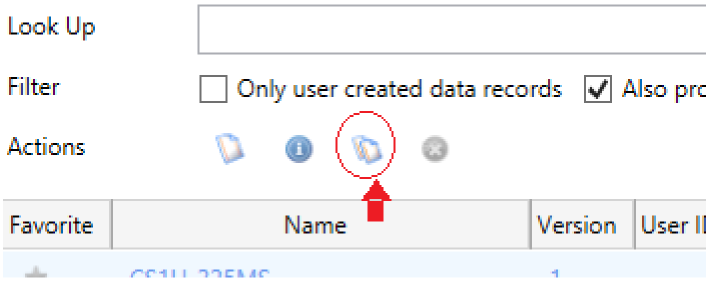
3. The third step is making the 3D design of the installation. These simulations are related to single-family homes, so the starting point is building the house. In "Terrain View" inside the tab "3D visualization", any type of building can be drawn, with any roof structure. Also other shadowing elements can be drawn, such as chimneys, pipes or trees.
   In each country, the angle of the roof is different. In Spain, the most common angle for the roof is 20º, so this is the angle which is going to be implemented into the simulations.



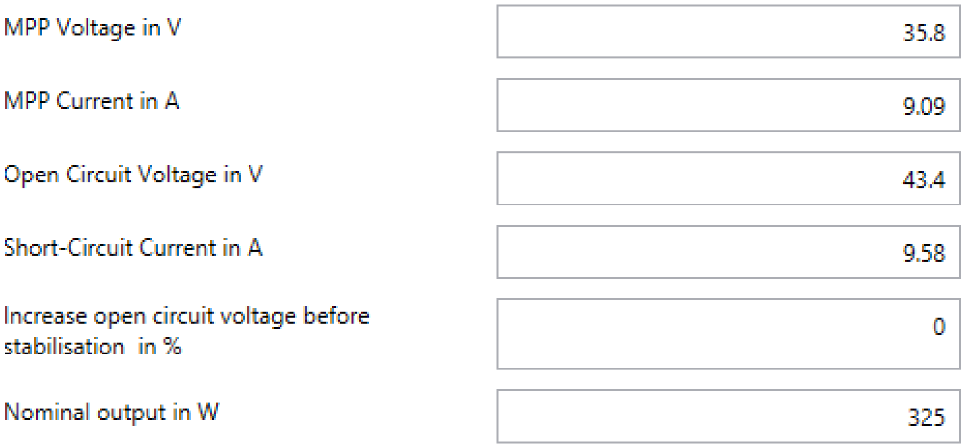
4. Staying inside “3D visualization” tab and selecting “Module Coverage”, it is possible to cover the roof with PV modules. For these simulations, the modules are going to be placed integrated with the roof, in other words, the modules are situated on the roof with the same angle and without any structure which modifies the angle. In the case of flat buildings, the selection has to be “Module Mounting”.
   For selecting the module, it is necessary to click on “New module”. If the module appears in the dialog box, the next step is just clicking on it, if not it is necessary to go to “detailed selection”. In this section, it is possible to look for every module of each brand, even the modules which are no longer available.



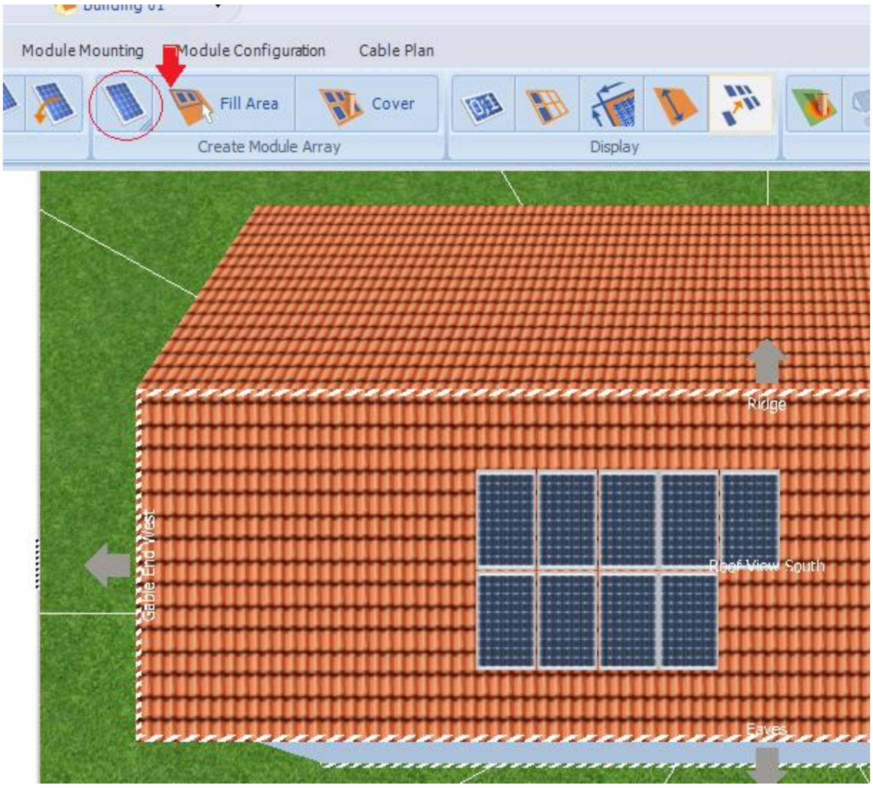
If is still not possible to find the module, there is an option which allows the creation of the module concerned. The next step is finding a module from the same brand, with similar features (power, model) to the one in question. Once this is done, it is required to press “Copy” to create the new module.



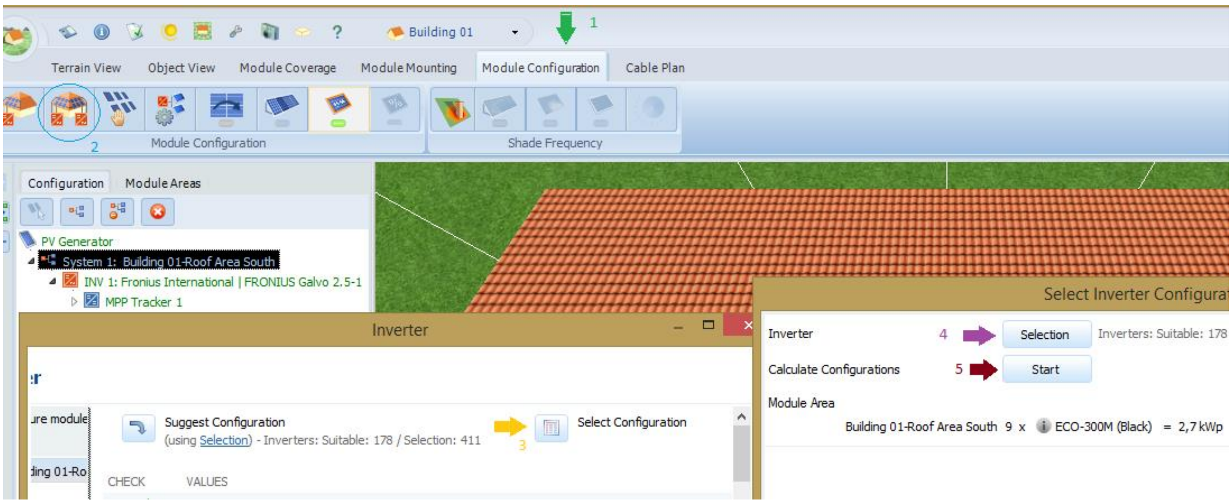
The different parameters, such as size, power, open circuit voltage, voltage coefficients, etc., have to be replaced for the ones belonging to the new module. They are easily found in the data sheet of the module.

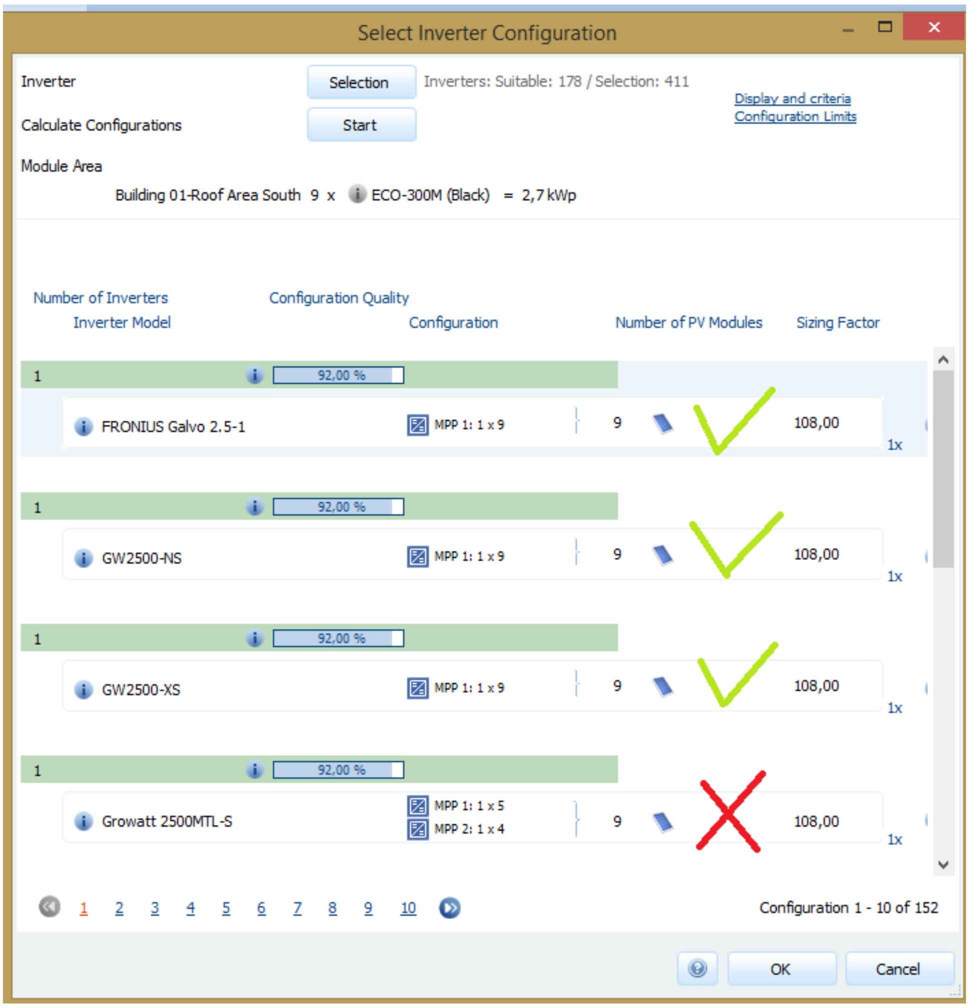


Placing the modules on the roof is done by clicking on “Filling area”, if it is required to do quickly and to cover certain area. It also can done one by one with the button on the left. The modules have to be placed on south-facing roofs if the installation is in the Northern Hemisphere; if the installation is in the in Southern Hemisphere, the modules have to be placed on north-facing roofs.



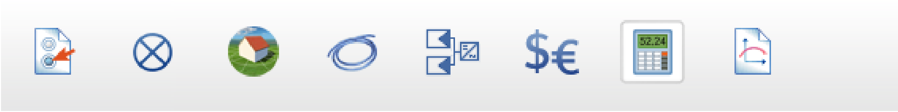
5. The final step is setting the inverter for the installation. The procedure starts at going to "Module Configuration" and then clicking on "Configure all unconfigured Modules". Then, by clicking on "Select Inverter Configuration", the software access to a new dialog box and by pressing "Selection", it allows to make preselection of the modules (or better just manufacturers) that are available on the concerned country's market. It is recommended to select enough manufacturers. Some famous manufacturers are Danfoss, GoodWe, Fronius, Kaco, Kostal, SMA, Solar Edge…
   By Pressing "Start" the software upload a list of inverter configurations and one of them has to be chosen. It is recommended to choose the configuration with the highest Configuration Quality (at least higher than 90%), also that it is using just one string and that the choice is green. For finalize the procedure, it is necessary to confirm everything, close "3D Visualization" application and adopt data to PV*SOL.





6. The tabs “Consumption”, “Cables”, “Plans and parts list” and “Financial Analysis” are not required to be modified for this simulation.

7. The simulation is run by clicking the button “Results.



PV System	
PV Generator Output	2,7 kWp
Spec. Annual Yield	1.500,95 kWh/kWp
Performance Ratio (PR)	84,5 %
Yield Reduction due to Shading	0,0 %/Year
PV Generator Energy (AC grid)	4.053 kWh/Year
Own Consumption	1.007 kWh/Year
Grid Feed-in	3.047 kWh/Year
Down-regulation at Feed-in Point	0 kWh/Year
Own Power Consumption	24,8 %
CO_2 Emissions avoided	1.905 kg / year
Appliances	
Appliances	4.308 kWh/Year
Standby Consumption (Inverter)	11 kWh/Year
Total Consumption	4.319 kWh/Year
covered by PV power	1.007 kWh/Year
covered by grid	3.312 kWh/Year

2.2. SIMULATION CONDITIONS

For this study, every module from the Spanish market survey available in PV*SOL is going to be simulated forming an installation of a certain power. To determinate the range of power of a typical PV installation of a Spanish house, another market survey has been done. In this case, the survey consisted of asking some PV companies which is the most common power range for PV installations for houses. According to this survey, the average power range is between 2kW and 5kW.

The location have to be a place where there are already a lot of PV systems for households installed. Also, it must have high irradiation and a large number of population. According to these premises, the place selected was Murcia, in south-east Spain. In this region, there is biggest photovoltaic plant in Spain, with 500 MW of power.

The next condition is placing the modules directly on the roof, without any structure. Because of this, it is necessary to determinate the typical angle of the roofs in this region. After asking to some architects, the value for the angle obtained was 20º. They also must be placed on the south face of the roof because the location is in the North Hemisphere. In summary, the conditions are:

- The modules have to be place on the southern face of the roof (N.H.)
- The typical inclination angle of a roof in Spain is 20º.
- The modules have to be placed directly on the roof (no other structures)
- Installation Power 2kw-5kw ; Modules Power >250 kw

2.3. OVERSIZING

One of the main purposes of this project was obtaining the performance of a PV installation after oversizing it. With the software PV*SOL, both oversized and non-oversized simulations are going to be run.

Oversizing an installation means setting its total power higher than the inverter power. In this case, the oversizing is established by 150% of the inverter power. The reason of oversizing is based on the optimization of the system. Usually, the modules do not reach their nominal power because some reasons such as:

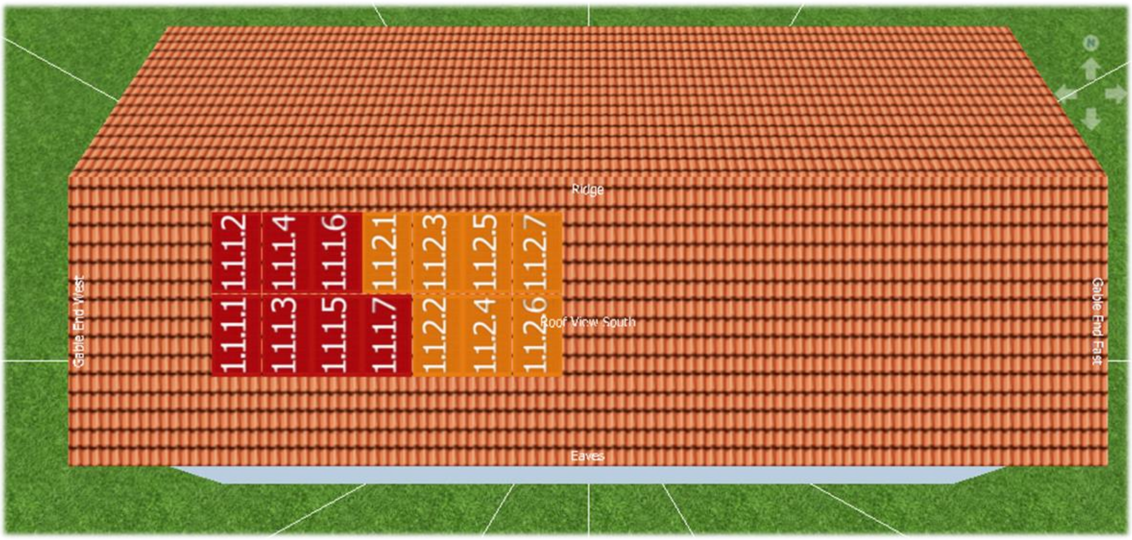
- Low irradiation during winter months.
- Ambient temperature too high (Voc decreases and consequently, power too).
- Suboptimal orientation of the modules.

- Pollution and degradation of the modules.
- Losses by shading or cabling.

Because of these causes, the inverter never works in its nominal capacity. The inverter works better and more optimized when it is under full load. It is possible to take advantage from this condition because PV system reaches its nominal power earlier in the morning and it remains more time connect to grid in the evening.

The process of oversizing is quite simple and it follows these steps:

1. The first step to do for oversizing is increasing the number of modules from the non-oversized installation. The total number of modules after oversizing is the closest even number after multiplying the previous number by 1.5. It is necessary to be careful with this because the new number of modules has to be even. This carries that the non-oversized number of modules cannot be whatever we want. So both numbers depend on each other. For example, if the installation is formed by 10 modules, after oversizing would be 15, but 15 is not an even number, so it would be better to have 9 modules before oversizing and 14 after it.
2. The new total installation power is easily obtained by multiplying the new number of modules by the module power.
3. The inverter power has to be the same for oversize its capacity, so it is mandatory to maintain the same inverter.
4. After oversizing, the modules connection to inverter is divided in two strings.



2.4. SIMULATION RESULTS

After explaining how the simulation is run, the conditions of it and what is the oversizing, the simulation in PV*SOL of every module found is the Spanish market is going to be run.

First of all, the simulation of non-oversized installation are going to take place. The installation and inverter have similar power between 2 and 3.5 kW. In the attached table, the results of the simulation are represented and it includes:

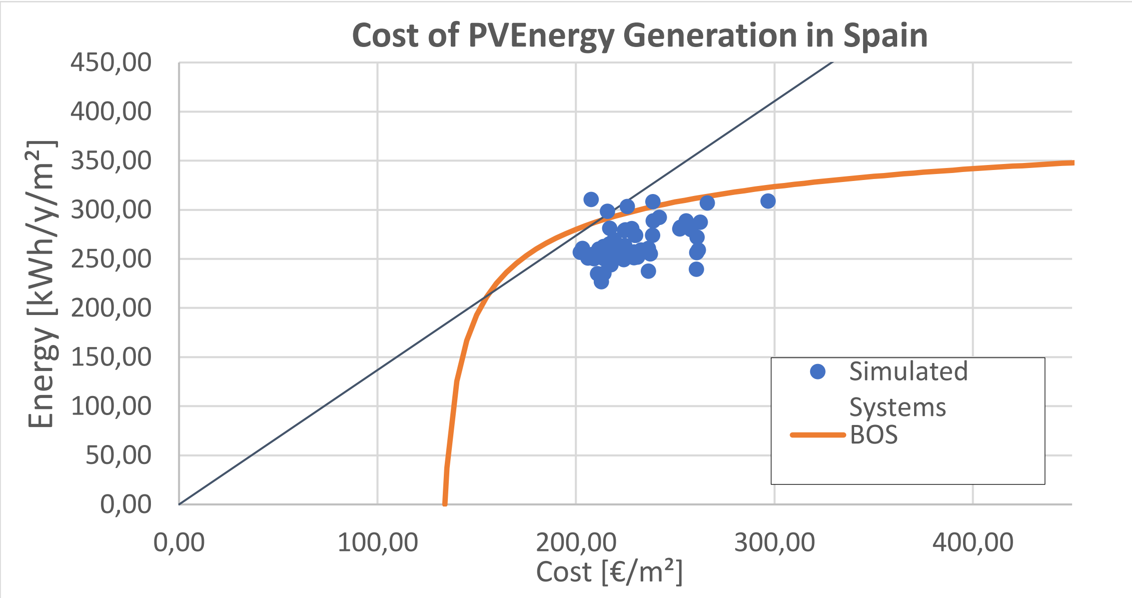
- Total Installed Power (kWp)
- Annual Energy Generation (kWh/Year)
- Module
- Pn [Wp]
- Number of Modules
- Inverter
- A [m²]
- Price [€]
- Module Cost [€/m²]
- Total Cost [€/m²]
- Energy Generated per area (kWh/Year/ m²)

The resulting table is attached from Annex 3 to Annex 7.

After simulating every module where it is forming an installation of a certain power, the oversizing has to be done maintaining the same inverter. The resulting table is the same as before, with the addition of:

- Oversized Power (Inverter Power*1.5)
- DC/AC ratio

Regarding to the BOS, it is possible to obtain the represent the energy generated every year per m² against to investment or total cost of installation.



3. ANALYSIS OF THE PERFOMANCE OF A PV SYSTEM IN CZECH REPUBLIC

The aim of this second part is simulating and analysing the performance of a photovoltaic installation for a household in Czech Republic. Furthermore, the optimization of the system is going to be object of study. Another important part of this part is obtaining the household consumption profile, which is really important for the analysis and optimization of the system. Finally, the water heaters installed in the house are also going to be analysed.

3.1. CHARACTERISTICS OF THE PV SYSTEM

First of all, it is necessary to describe the location of the already installed PV system. It is located in Revnice, Czech Republic, 30 km far away from Prague. Its coordinates are 49.9º N-14.2º E.

Regarding to the building where the installation is placed, it is a house with almost flat roof (1.73º) and the azimuth of the house is 173º. Its shape is irregular, formed by different modules. The house is surrounded by several trees which may project shadow to the roof.

The PV system is placed on the roof of the house, with its corresponding structure. The system characteristics are the next:

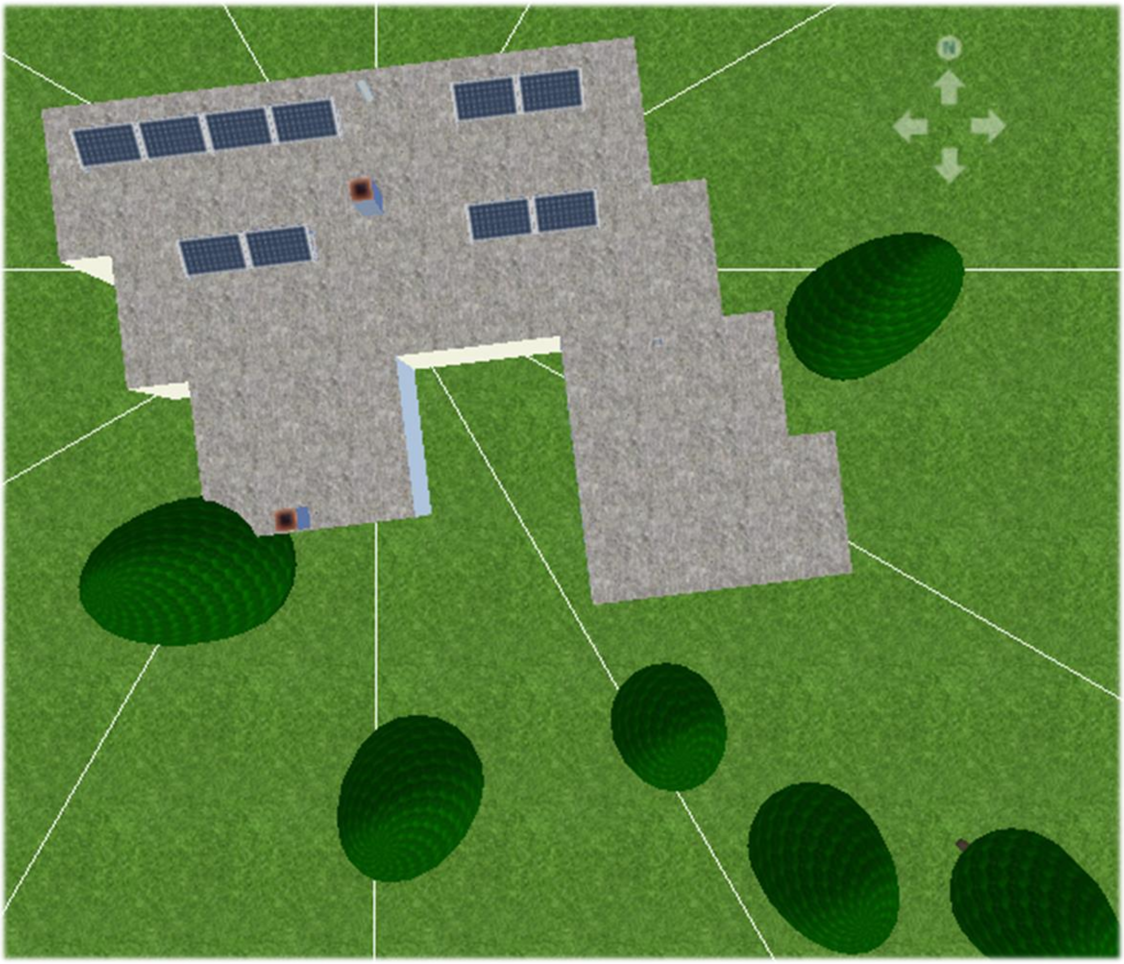
- The number of modules is up to 10.
- Every modules has a power of 325 Wp.
- The total power of the system is 3.25kWp.
- The azimuth of the modules is aligned with the azimuth of the house, resulting in 173º. This direction is between South and South-East
- The angle structure is 30º, facing the South – South-East. However, the real angle after discounting the slope of the roof is 28.2º.
- The inverter model is GoodWe 3000NS with a power of 3-kW.
- The system is not connected to any batteries.

The modules are manufactured by Jinko Solar. The specific model is JINKO SOLAR CHEETAH PERK JKM325M-60V. Some characteristics from it are presented below:

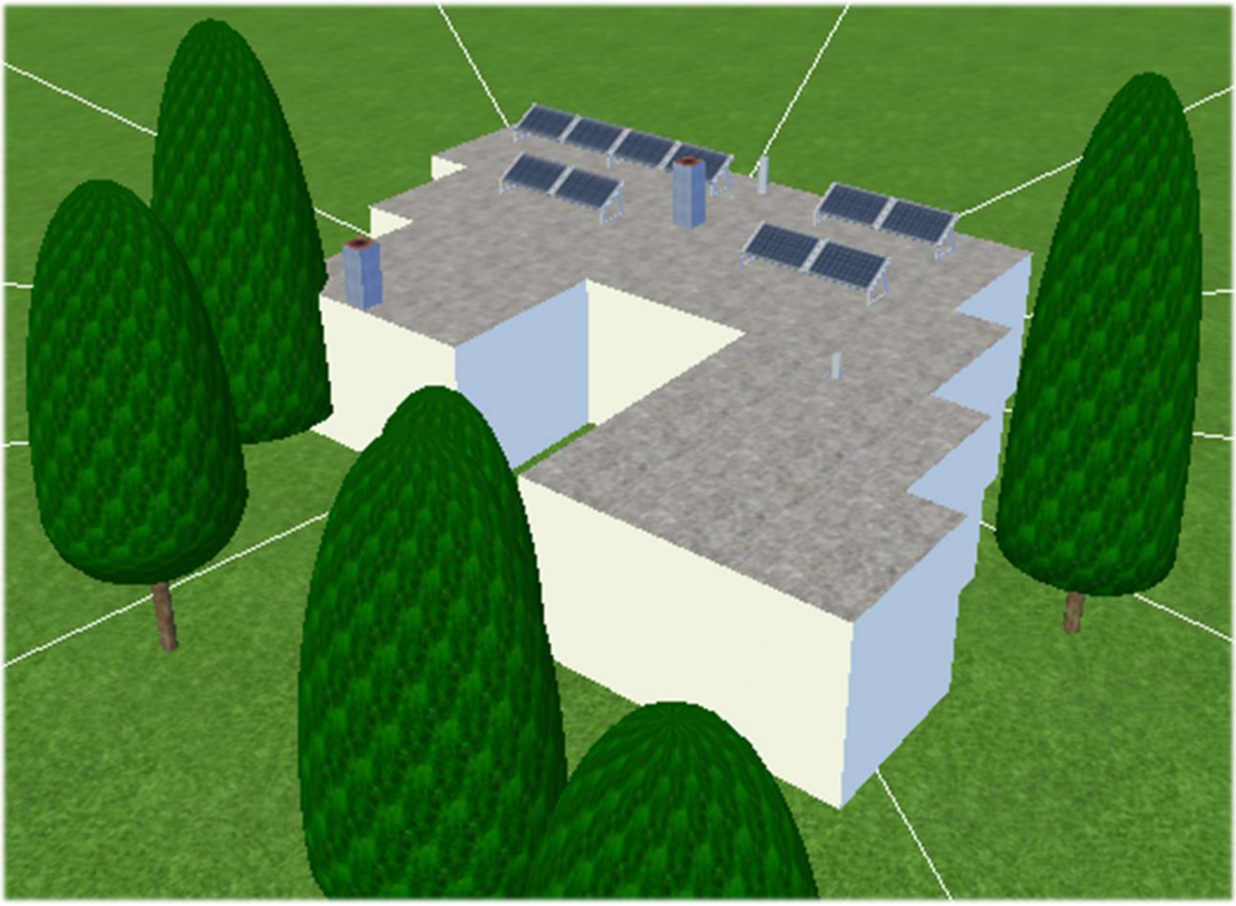
- Cell technology: monocrystalline
- POWER: 325 Wp
- EFFICIENCY: 19,48%
- OTHER CHARACTERISTICS
    - Voc: 41,2V
    - Isc: 10,2A
    - Vmp: 33,6V
    - Imp: 9,68A

2.2. DESIGN OF THE PV SYSTEM

Once all the characteristics of the PV system has been explained, the installation has to be implemented into the software PV*SOL. First of all, it is necessary to create the 3D house design into the PV*SOL tab called "3-D Visualization". With this software it is possible to draw the house dimensions and to create a virtual model of the house, after measuring in person every length of the house composition. Also, every distance between the trees and the house was also measured. The resulting design of the house with the PV modules place with their conditions is the following one:



It is also important to consider the shading elements, such as the trees, the chimneys and the pipes. It was also necessary to measure the height of every element and its placement respect to the house. In the next image, it is possible to observe the house in another perspective, this time with a 3D visualization:



3.3. SIMULATION RESULTS

After implementing the design of the house and the PV system into PV*SOL, the simulation of the performance of the installation can be done. As the system has no batteries, there is no need to modify anything else. The step to obtain the results of the simulation is pressing the corresponding button. Finally the results of the performance are obtained below:

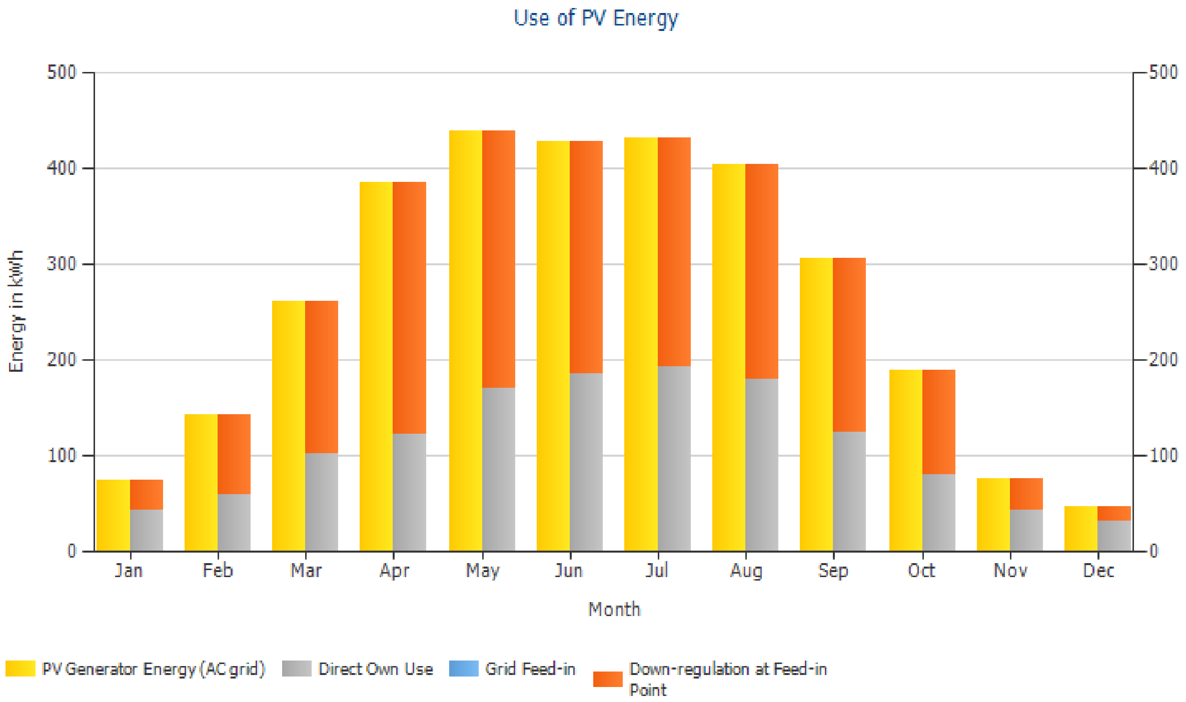
PV System		
PV Generator Output	3,3	kWp
Spec. Annual Yield	978,24	kWh/kWp
Performance Ratio (PR)	81,8	%
Yield Reduction due to Shading	4,0	%/Year
PV Generator Energy (AC grid)	3.179	kWh/Year
Own Consumption	1.328	kWh/Year
Grid Feed-in	0	kWh/Year
Down-regulation at Feed-in Point	1.851	kWh/Year
Own Power Consumption	41,8	%
CO_2 Emissions avoided	797	kg / year
Appliances		
Appliances	3.988	kWh/Year
Standby Consumption (Inverter)	7	kWh/Year
Total Consumption	3.995	kWh/Year
covered by PV power	1.328	kWh/Year
covered by grid	2.667	kWh/Year

Parameters to be highlighted are the *PV Generator Energy (AC grid),* which is the value of the total energy produced during the year after being converted from DC to AC by the inverter and whose value is 3,179 kWh/year; *Total consumption,* which represents the total consumption for the whole year of the home appliances. It is necessary to indicate that the profile consumption has also been obtained in this project and it is going to be explained in a following part.

Moreover, it is important to remark that full energy production cannot be used because sometimes the production is higher that the consumption. The total amount of PV energy produced used for home appliances is 1,328 kWh/year, which represents the 42% of the total PV energy produced. So the remaining percentage (58%) should be sold to the grid, but this installation is set up to prevent this from occurring. Instead of going to the grid, the excess of PV energy must go to the water boiler for heating the biggest amount of water possible.

As it was said, only 1,328 kWh/year of the total 3,998 kWh/year (33%) consumed by the home appliances are covered by the PV system, so the rest of the consumption must be covered by grid. The aim of this project is rising this ratio and optimizing the system, so this issue will be attended again.

The following plots show how the PV energy is distributed month by month and also how the consumption is covered.



This plot shows that the amount of PV energy produced in summer is more than 4 times the energy produced in winter. However, in summer more than the half of energy produced is regulated at the feed-in point, because is energy which is not consumed by the home appliances, so this means it is kind of wasted energy. This happening occurs because during the day the Sun energy is high, so the production is bigger than the consumption.

In the other hand, during the winter most of the energy produced is consumed by the home appliances because the solar radiation is less during this time of the year and consequently the production of PV energy is low. Nevertheless, some winter days are sunny and the production can be higher than the consumption, this being the reason of why not all the energy produced is consumed by the appliances.

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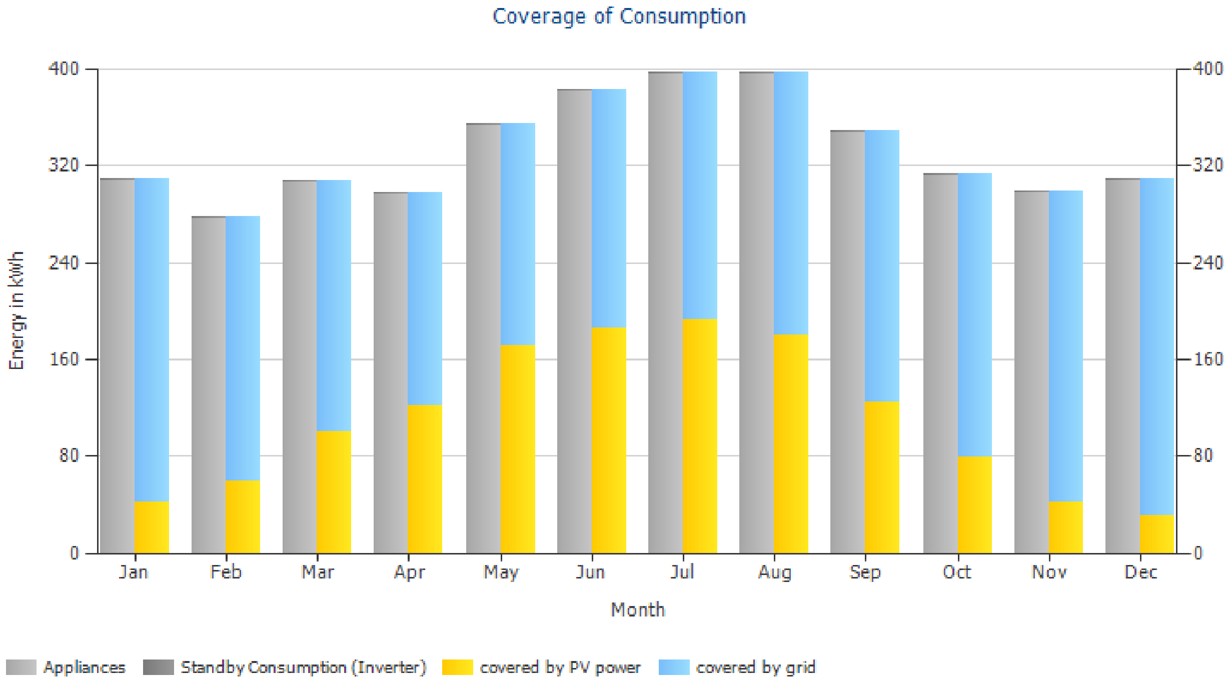


With respect to this graph, it shows the consumption covered by PV energy and the consumption covered by grid. In summer, around or slightly above the half of the appliances consumption can be covered by PV the energy and the rest of the consumption is covered by grid. In winter is so different, less than a quarter of the consumption is covered by PV energy and almost all the consumption must be covered by grid.

Furthermore, the PV system can register by the inverter the quantity of real energy that is produced by the modules. The software *Semsportal* provides this information on its website, so it is possible to download it. In the following table, there is a comparison between the produced energy estimated by the simulation of PV*SOL and the actual produced energy during the last months, between December 2019 and June 2020. The software *Semsportal* was registered in December, so the data starts on this date.

MONTH	SIMULATED ENERGY (kWh)	REAL ENERGY (kWh)	DIFFERENCE (kWh)	DIFFERENCE (%)
JANUARY	73,8	7,9	-65,9	-89,30
FEBRUARY	143,6	54,4	-89,2	-62,12
MARCH	263,7	289,9	26,2	9,94
APRIL	385,4	410,8	25,4	6,59
MAY	433,6	385,6	-48	-11,07
JUNE	420,8	342,5	-78,3	-18,61
JULY	424,4	NO DATA	NO DATA	NO DATA
AUGUST	399,2	NO DATA	NO DATA	NO DATA
SEPTEMBER	307,7	NO DATA	NO DATA	NO DATA
OCTOBER	190,5	NO DATA	NO DATA	NO DATA
NOVEMBER	74,5	NO DATA	NO DATA	NO DATA
DECEMBER	45,1	16,5	-28,6	-63,41

Between July and November there is still no data, but it will possible to complete this table at the end of the year 2020. It is also important to mention that some days of December, January and February the PV system was not working, probably because the energy was not enough for the inverter to turn on. If the actual energy data is compared with the simulated one, some differences can be found and explained basically by the weather. For example, during the spring earliest spring months (March and April) there were plenty of sunny and dry days, so the real production was higher than the energy estimated by the software. Conversely, during the latest spring months, the produced energy was lower than the estimated energy because the weather was cloudy and wet during the days of this months.

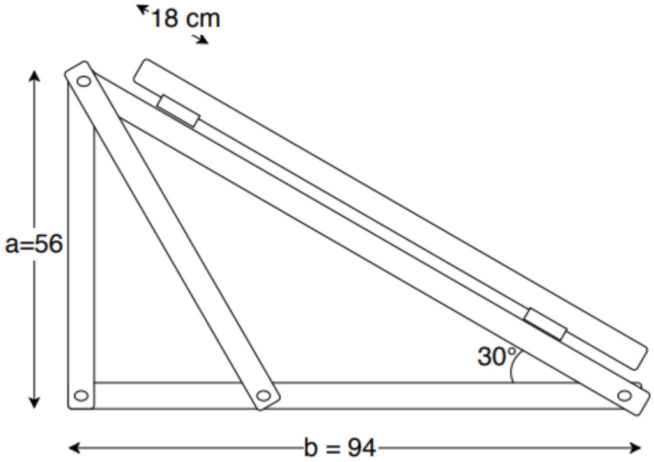
4. SYSTEM OPTIMIZATION

The aim of this part is finding other configurations for the system which provides a higher PV energy production, mostly in the winter months. This is an important issue because currently the produced energy during winter months is too few compared to the consumption. For this reason, it would be profitable to find other configuration for the PV system which increases the PV production during this months.

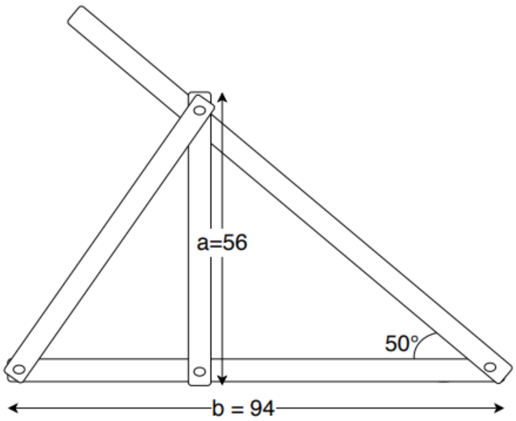
4.1. OPTIMIZATION PROPOSALS

In this section, various system configuration proposals to optimize it are going to be exposed and explained. This configurations are going to be focused on the following changes:

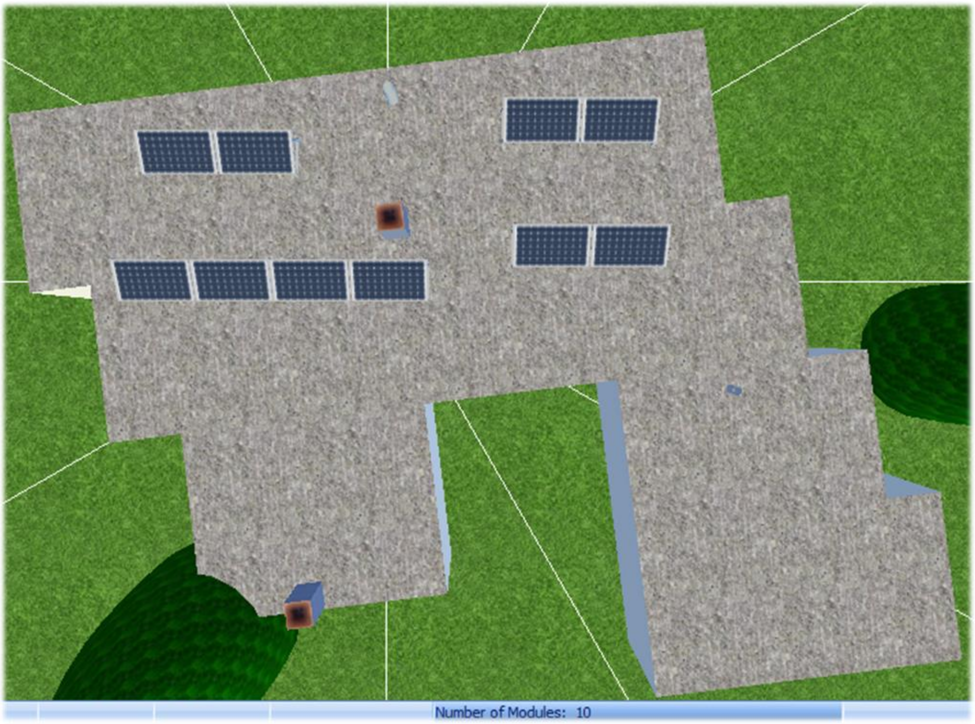
I. **Changing module position**: the modules can be moved along the structure where they are placed. For this proposal, the module is going to be moved up 18 cm along the supporting triangle.



II. **Changing the inclination angle of the structure**. According to the current mounting configuration, the structure forms an angle of 30º. If the bar “a” change its position with the bar on its right, keeping the bars “a” and “b” perpendicular, the new angle will be 50º. With this mounting, only this angle can be tried, nevertheless, other angles will be also simulated.



III. **Changing modules azimuth.** The azimuth of the modules will be changed too. According to the PV theory, the most profitable azimuth is 180º, facing the south. However, if there are shading elements, this assertion might change. The mounting of the modules is aligned with the azimuth of the house, in other words, the azimuth of the mounting is 173º. So, using the simulation, the current azimuth will be compared with the 180º one.



IV. **System Oversizing by adding more modules**. It is also interesting to check how much energy is possible to gain oversizing the system until the limit of 150%. This proposal is mainly focused on rising the produced energy during the winter months.

4.2. OPTIMIZATION RESULTS

As it was exposed before, different configurations for the PV system will be simulated in PV*SOL to check if they are profitable enough to change the current configuration. In this first batch, the proposals tried are going to be:

1. Shifting the module 18 cm upper along the mounting.
2. Changing the structure angle to 50º.
3. Changing the structure angle to the theoretical optimum angle. It is obtained by this ecuation: Angle β opt(º)=3,7+0,69*LATITUDE = 38.14º
4. Changing the azimuth to 180º.

CONFIGURATION	NUMBER OF MODULES	POWER (kWp)	AZIMUTH (º)	ANGLE (º)	ENERGY GENERATED (kWh/y)	DIFFERENCE (KWh/y)	DIFFERENCE (%)
CURRENT	10	3,25	173	30	3179	0	0
18CM UPPER	10	3,25	173	30	3192	13	0,41
CHANGING ANGLE	10	3,25	173	50	3094	-85	-2,67
CHANGING AZIMUTH	10	3,25	180	30	3170	-9	-0,28
ANGLE OPT	10	3,25	173	38,14	3174	-5	-0,16

The table shows that the differences in terms of total produced energy are narrow. Only in the proposal of shifting the modules upper 18 cm it is possible to observe gains in the total energy, although quite insignificant, with a value of 13 kWh/year (0.41%). The average consumption of a house during a day is about 10 kWh.

The other proposals related to change the angle and the azimuth not only fail to increase the total energy produced, but also reduce it. According to this data, the worst option should be the one which purposes changing the angle to 50º, because the losses are about 85 KWh/y. However, it is also important to compare the energy produced month by month because the aim of the project is increasing the energy produced during winter months.

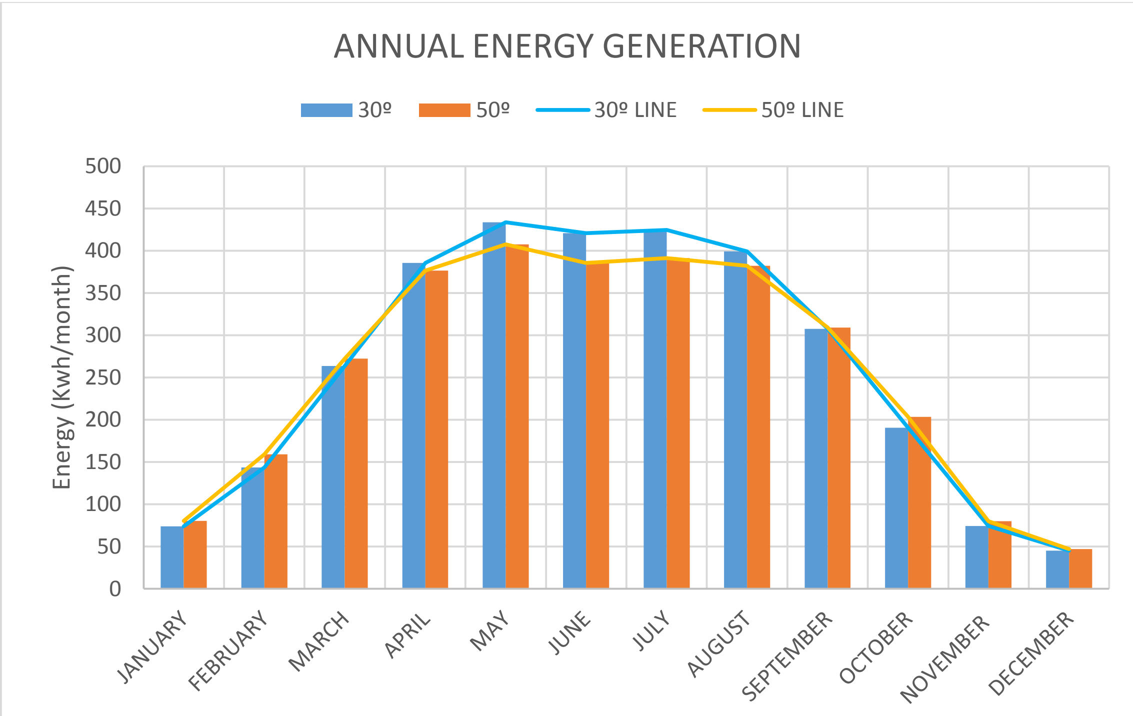
To decide if these proposal are worthwhile or provide enough benefit, some rules were established.

1. **Rising 18 cm the modules:** if the effect produced in the total energy is higher than an increase of 5%, it should be kept.
2. **Changing the azimuth:** if the effect produced in the total energy is higher than an increase of 5%, it should be kept.
3. **Changing the angle:** if the effect produced in winter months energy is higher than an increase of 10% and lower than a decrease of 20% in summer months, it should be kept.

According to these rules, shifting the modules position and changing the azimuth should be discarded. With respect to the proposal of changing the mounting angle, it is necessary to check the generated energy month by month in order to make a decision. In the following table, the two proposals related with changing the angle are going to be analysed in a monthly way.

SIMULATED ENERGY	30º	50º	DIFFERENCE (kWh)	DIFFERENCE (%)
JANUARY	73,8	80,6	6,8	9,21
FEBRUARY	143,6	159	15,4	10,72
MARCH	263,7	272,3	8,6	3,26
APRIL	385,4	376,5	-8,9	-2,31
MAY	433,6	407,7	-25,9	-5,97
JUNE	420,8	385,4	-35,4	-8,41

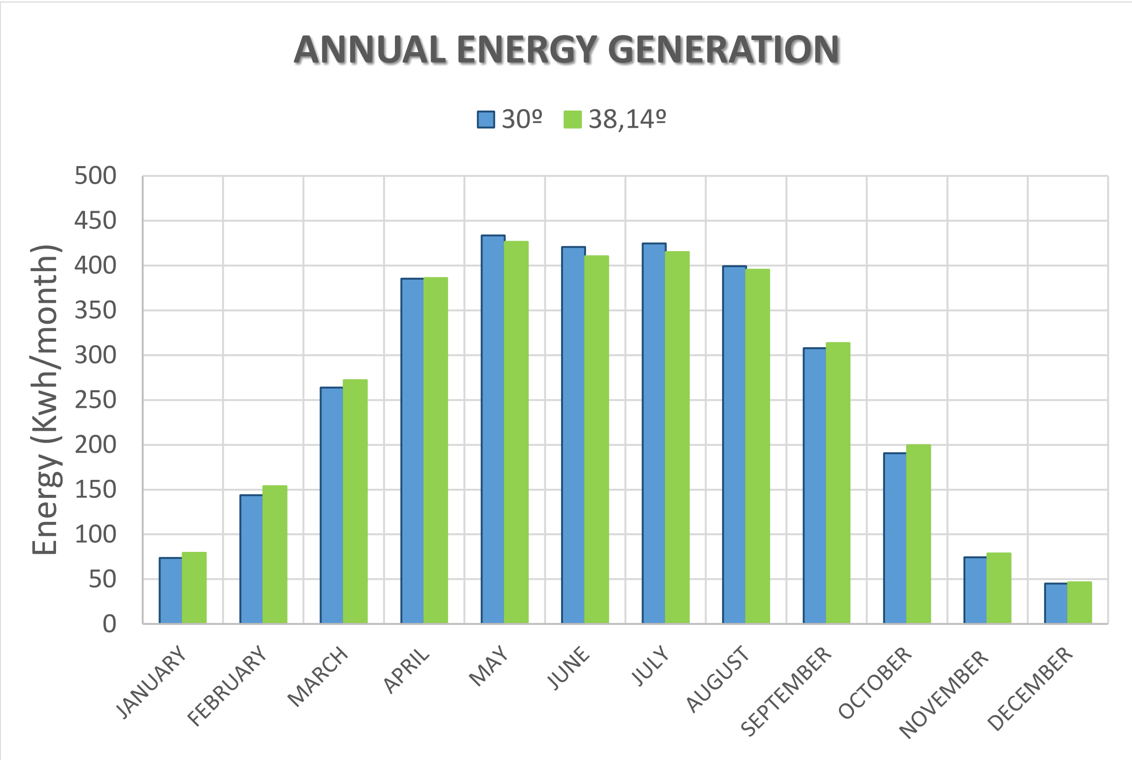
JULY	424,4	391,3	-33,1	-7,80
AUGUST	399,2	382,2	-17	-4,26
SEPTEMBER	307,7	309	1,3	0,42
OCTOBER	190,5	203,3	12,8	6,72
NOVEMBER	74,5	80	5,5	7,38
DECEMBER	45,1	47,2	2,1	4,66



The plot and the table show that the difference between both angles is not very remarkable. Regarding to winter months, it is observable that the gain during January and February is around 10%. However, if the KWh/y values are checked, this difference is only around 7kWh in January and 15 kWh in February. In December the difference is extremely little, only 2 kWh more in the whole month. This result concludes that the main problem in winter is the small amount of sun radiation, because the few hours of light and the cloudy weather.

With respect to the summer months, the loss of PV energy in comparison with the 30º angle system is below 35 kWh/month, or in percent terms is below 10%. Nevertheless, the most important issue was the gain during the winter, which is not profitable enough to make the decision in favour of change.

SIMULATED ENERGY	30º	38,14º	DIFFERENCE (kWh)	DIFFERENCE (%)
JANUARY	73,8	79,4	5,6	7,59
FEBRUARY	143,6	153,8	10,2	7,10
MARCH	263,7	272,1	8,4	3,19
APRIL	385,4	385,9	0,5	0,13
MAY	433,6	426,4	-7,2	-1,66
JUNE	420,8	410,2	-10,6	-2,52
JULY	424,4	414,9	-9,5	-2,24
AUGUST	399,2	395,3	-3,9	-0,98
SEPTEMBER	307,7	313,6	5,9	1,92
OCTOBER	190,5	199,6	9,1	4,78
NOVEMBER	74,5	78,8	4,3	5,77
DECEMBER	45,1	46,5	1,4	3,10



In this case, the differences between both configurations either in winter or in summer are even less remarkable. With the optimal angle, the gains are obtained during between the equinoxes, in other words, between September and March. But again, the difference is too small for the change. In winter months, the gain is maximum in February, around 10 kWh which. This value is similar to the consumption of a day.

Therefore, according to these results, the conclusion of this analysis is that it is not worth or profitable enough making any changes in this installation related to shifting the position of the modules, varying the azimuth or changing the mounting angle.

4.3. SYSTEM OVERSIZING

After figuring out that the system cannot get significantly optimized by varying the azimuth, changing the mounting angle or shifting the position of the modules, the next analysis must be calculating if adding some extra modules to oversizing the system would be profitable.

The aim of oversizing the system is just adding some extra module until reach 150% of the capacity of the inverter. This means that the inverter must be maintained and oversized its nominal capacity with more modules. Nevertheless, the modules usually never work at their nominal capacity because of situations such as low irradiation during winter months, moisture on their surface or losses because bad configuration. For these reasons is interesting to oversize the system and make better use of the inverter capacity.

By checking the current situation, the system has the following configuration:

<u>CURRENT INSTALLATION</u>

- NUMBER OF MODULES: 10
- POWER: 3,25 kWp
- INVERTER POWER: 3 kW
- ACTUAL OVERSIZING: 108,33%

<u>OVERSIZED CONFIGURATION</u>

- NUMBER OF MODULES: 14
- INSTALLATION POWER: 4,55 kWp
- INVERTER POWER: 3 kW
- OVERSIZING: 151,6%

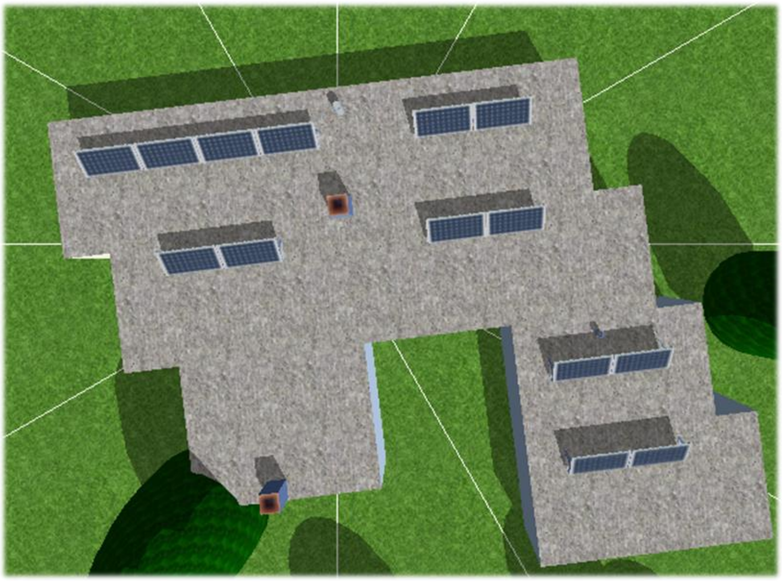
By adding 4 modules to the PV installation, the system pass from an oversized value of 108% to 151%. This value is really close to the oversizing limit. Nevertheless, it is also important to determine the precise placement of the modules in order to achieve the largest amount of PV energy. This requirement is induced because the presence of shading elements, mostly trees, pipes and chimneys.

4.3.1. EXTRA MODULES BEST PLACEMENT

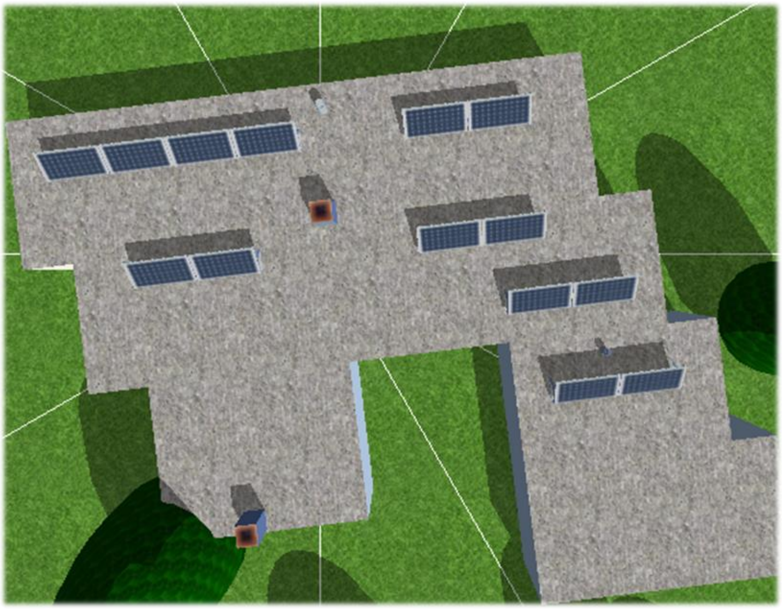
The objective of adding some extra modules is not increasing the total energy produced along the year, but to maximize the energy produced during winter months. For this reason, the **mounting angle selected is 50º**. Moreover, it is necessary to take into account that the placements are limited by space and building structures.

By the software PV*SOL, several simulations with different placements for the extra modules were run. After discarding the ones with the worst values of energy thrown, the four best placements are:

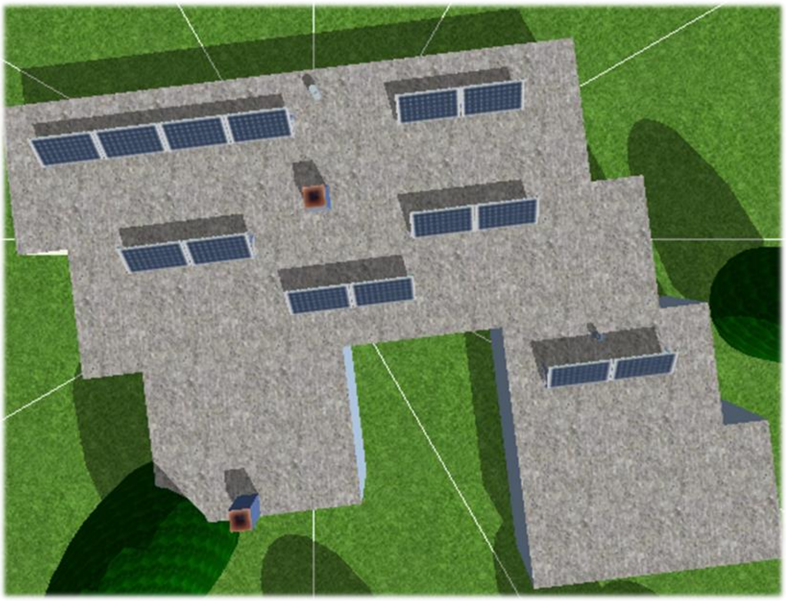
1. Two modules added on South-East surface.



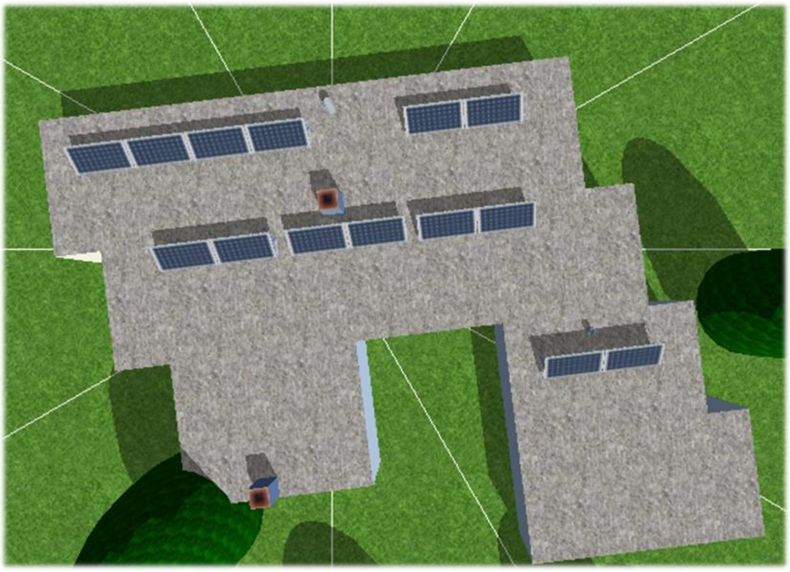
2. One module on the East surface and another one on the South-East surface.



3. One module on South surface and another one on the South-East surface.



4. One module integrated in the south modules row and another one on the South-East surface.

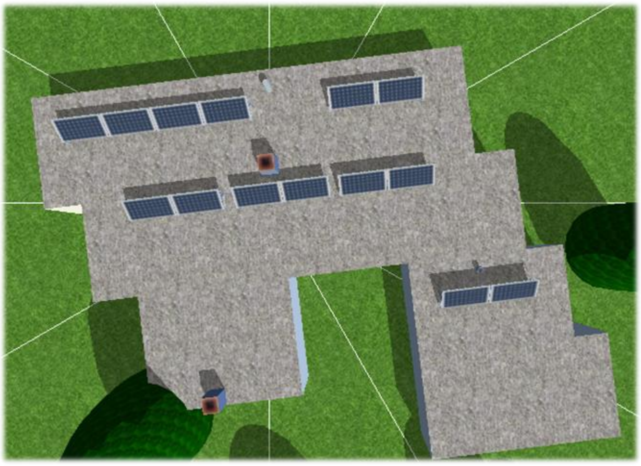


4.3.2. OVERSIZING RESULTS

In the following table, the results obtained after the simulations for the 4 placements chosen are presented below:

CONFIGURATION	POSITION	NUMBER OF MODULES	POWER (kWp)	AZIMUT (º)	ANGLE (º)	ENERGY GENERATED (kWh/y)	DIFFERENCE (kWh)	DIFFERENCE (%)
ACTUAL	0	10	3,25	173	30	3179	0	0
4mod SOUTH-EASTx2	1	14	4,55	173	50	3937	758	23,84
4mod EAST-SE	2	14	4,55	173	50	3921	742	23,34
4mod SE & SOUTH	3	14	4,55	173	50	3941	762	23,97
4mod SE & Row(S)	4	14	4,55	173	50	3966	787	24,76

According to these results, the best placement for adding 4 extra modules in order to oversize the system is the fourth one.



With this configuration, most of the shadows are avoided, so this explain the reason why the energy obtained is bigger. Nevertheless, this difference is not very significant respecting to the other configurations. However, this could be the cheapest in terms of placing the modules because there is already a mounting line at the second row. In conclusion, the placement chosen for adding 4 extra modules should be the fourth option.

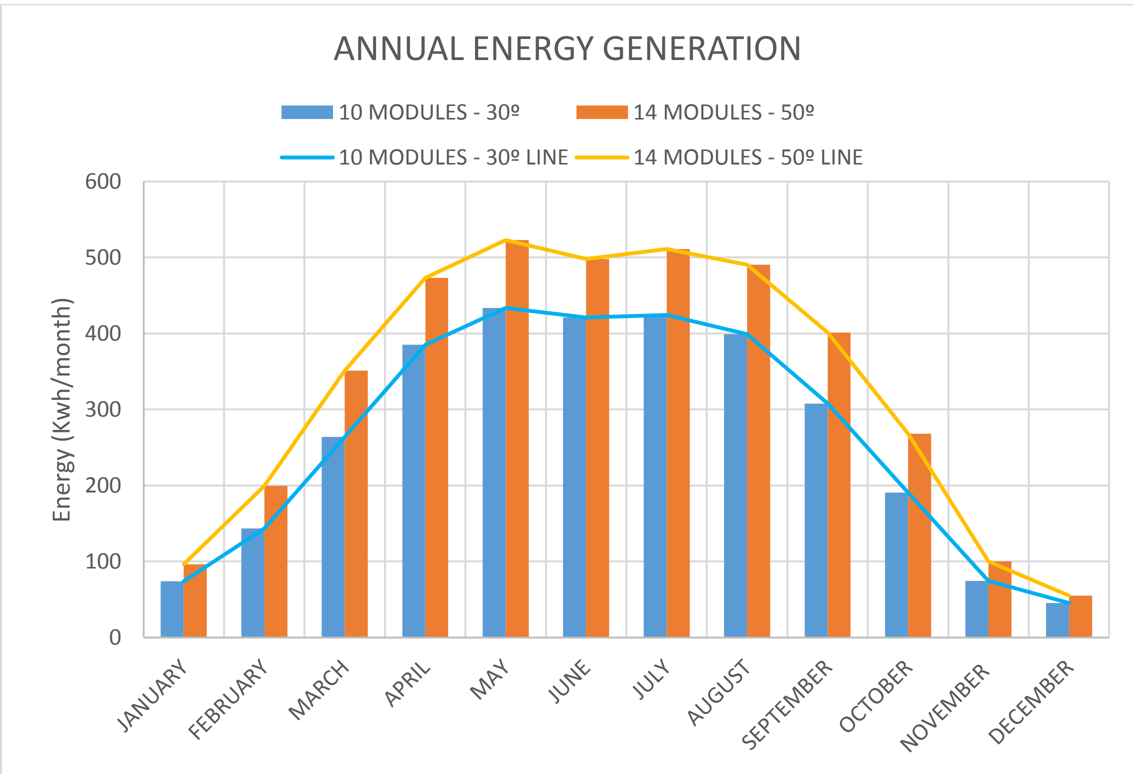
The next step has to be making a comparison between the monthly energy comparison obtained by this configuration and the current one. The configuration with 10 modules and a 50º mounting structure is also going to be presented. The results obtained are:

SIMULATED ENERGY	10 MODULES	10 MODULES	14 MODULES	DIFFERENCE (kWh)	DIFFERENCE (%)
	30º	50º	50º		
JANUARY	73,8	80,6	96,3	22,5	30,49
FEBRUARY	143,6	159	199,3	55,7	38,79
MARCH	263,7	272,3	350,9	87,2	33,07

APRIL	385,4	376,5	473,1	87,7	22,76
MAY	433,6	407,7	523,1	89,5	20,64
JUNE	420,8	385,4	497,9	77,1	18,32
JULY	424,4	391,3	511,1	86,7	20,43
AUGUST	399,2	382,2	490,5	91,3	22,87
SEPTEMBER	307,7	309	401,2	93,5	30,39
OCTOBER	190,5	203,3	268	77,5	40,68
NOVEMBER	74,5	80	100,2	25,7	34,50
DECEMBER	45,1	47,2	54,8	9,7	21,51
TOTAL	3179	3094	3966		

According to these values, the annual energy obtained differs in 800 kWh/year. Nonetheless, the important values are the winter months. In January, the gains are around 22 kWh (30%), in February 55 kWh (39%) and in March 87 kWh (33%). In the other hand, during October the gains are around 78 kWh (40%), in November 25 kWh (35%) and in December 10 kWh (22%).

As it is shown, during December the gains are really small (20%) even though the system is configured with 50º mounting structure, which is more appropriate for winter months. In January and November the gain is around 20 kWh, which starts to be a significant value. And in February, March and October, the gains are quite remarkable, ranging between a value of 50 and 80 kWh.



At the end, the benefit of adding 4 extra modules is not very clear for the months of December and January. However, the gains obtained for the rest of the months are more significant.

It is possible to conclude that obtaining more PV energy during winter months is an arduous task, mostly during December and January. This can be explained by the shortening of daylight and the cloudy weather. The location, or rather, the latitude of Czech Republic will never allow to produce a considerable amount of PV energy during these months and the only solutions would be adding modules almost infinitely until reaching the energy required for covering the consumption, although this would not be obviously economically profitable.

To summarize, adding 4 modules could be interesting for this installation, although the energy produced in winter does not increase too much. Nevertheless, the few amount of money that has to be invested for adding 4 extra modules as the most of the installation parts are already established is a reason enough for being favourable to this proposal. More energy will be obtained along the year and the consumption will be more covered by this energy than with the previous configuration. Moreover, in summer will be a gain of energy because adding 4 modules compensates changing the mounting angle from 30º to 50º.

5. CONSUMPTION PROFILE

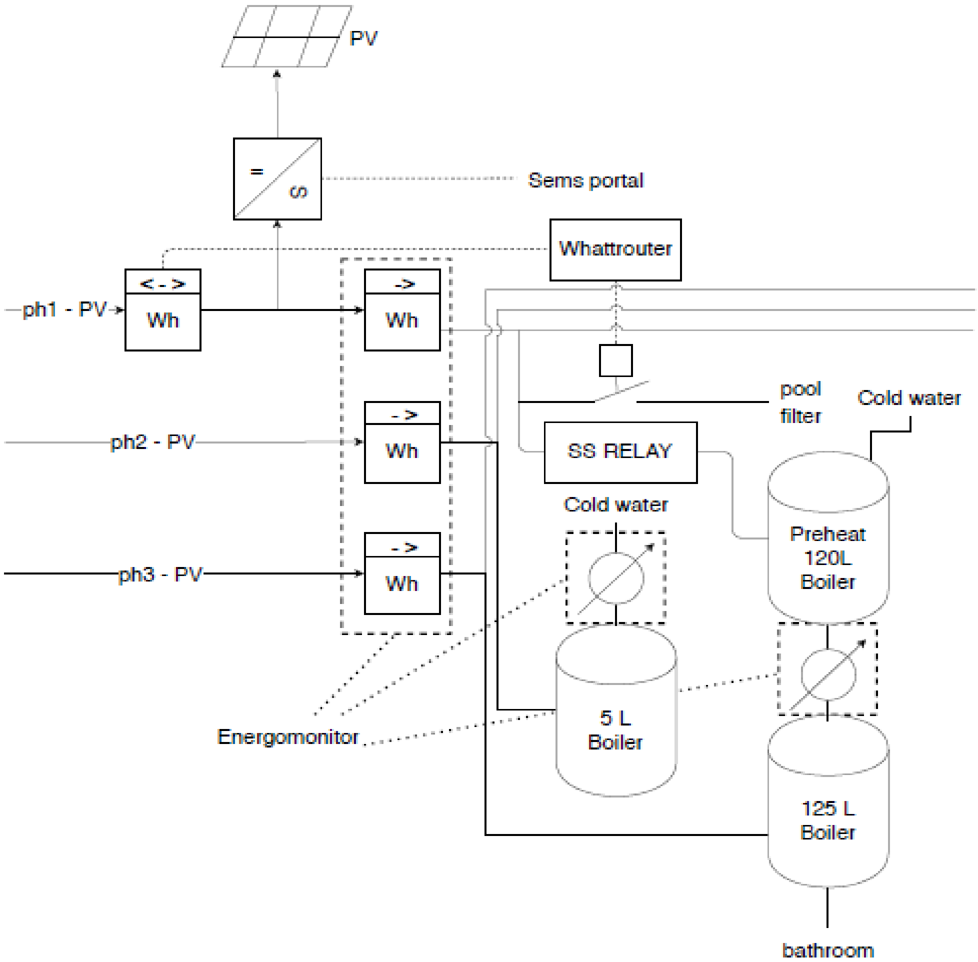
The aim of this part is determining the consumption profile of Mr. Holovsky´s house consumption without taking into account the water heating for the bathroom. The reason why the consumption profile is obtained by this way is to compare the energy consumed by the electrical system with the PV energy generated by the modules. With the comparison, the objective is to obtain the daily excess of energy which is not used neither for consumption nor for selling to grid. The low feed-in tariff in Czech Republic results in that selling energy to the grid is not a profitable option.

In the other hand, this excess of energy is wasted if it is not given a use. In some cases, mostly in self-consumption installations, this excess of energy is stored in batteries. In this case, the owner of this installation did not want to neither store the energy in batteries nor sell it to the grid. So the solution reached was to use the excess of energy for heating water. This option is similar to storing electrical energy in batteries, but in this case the energy stored is not electrical but thermal.

5.1. TOOLS

For obtaining the consumption profile, there are several tools available for helping in this purpose. These tools are the following ones:

1. ENERGOMONITOR: is a website which compiles the data related to the house electrical consumption. For obtaining this data, it is necessary to install wattmeters in every phase of the installation.
2. SEMSPORTAL: is a website where it is possible to obtain the data related to the PV energy produced by the modules of the PV system. It is necessary to connect the inverter, which provides the data, to the website.
3. PV SOL: with this possible it is possible to simulate the energy generation along the year, obtained by minutely values.
4. INSTALLATION SCHEME: it is useful for understanding the distribution of the installation.



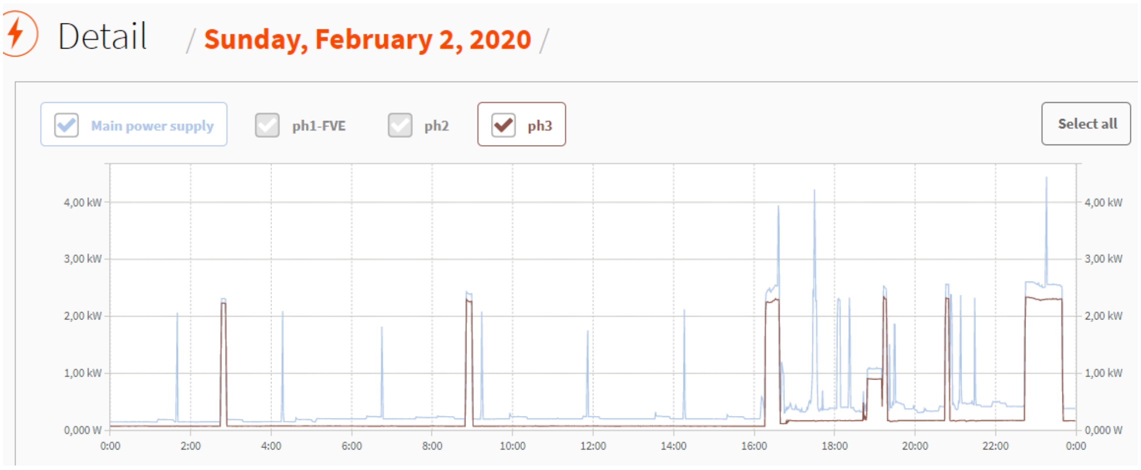
Among the characteristics of the installation that can be distinguished, the following stand out:

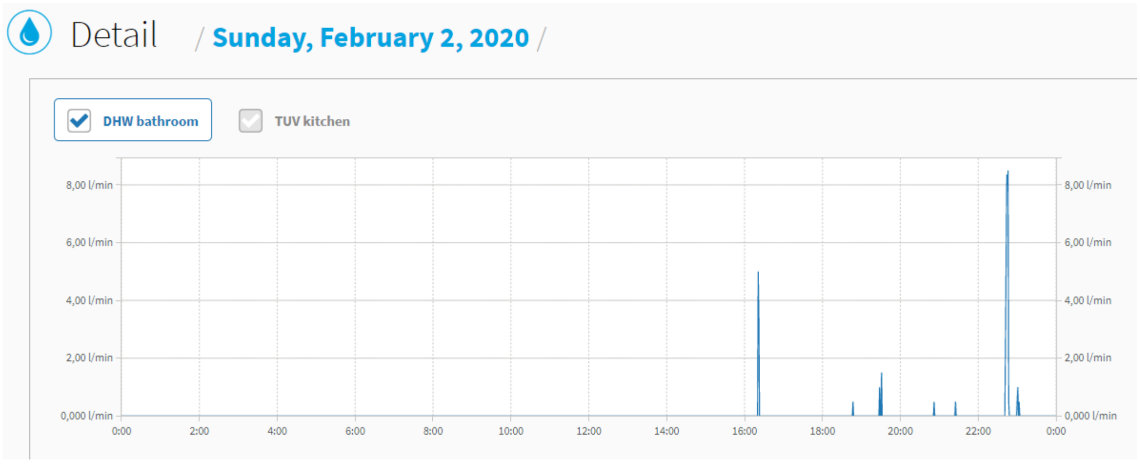
- 3 phases
- PV system connected to 1st phase
- Inverter connected to SemsPortal
- 120l preheater boiler and other appliances connected to 1st phase
- 125l heater connected to 3rd phase
- 5l boiler for the kitchen is connected to 2nd phase
- Pool filtration is connected to 1st phase.
- There is a flowmeter before the 5L boiler and 125L boiler.
- The wattmeters and flowmeters are connected to Energomonitor.
- There is a relay before the 120L preheater which allows to change the power for the heating depending on the PV energy available.

5.2. PROCEDURE FOR OBTAINING THE CONSUMPTION PROFILE

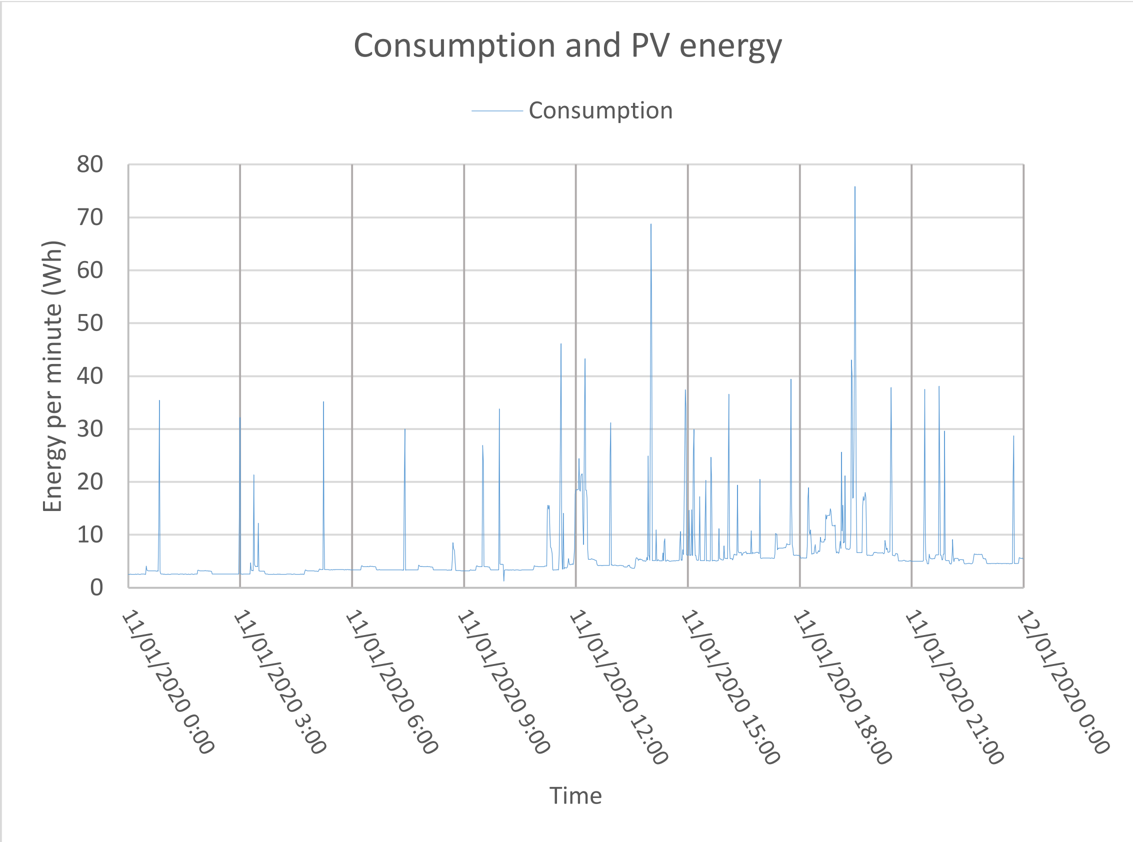
The procedure to obtain the house consumption profile without taking into account the water heating is divided into the following steps:

1. Search for days when PV system did not work: 14th January -14th February.
2. Find these days in Energomonitor and download the minutely file.
3. Determine in which moments there is water heating, which is determined by two situations:
    a. After hot water consumption (energomonitor).
    b. Consumption peak of 2kw power in phase-3.
4. Enter the data to minutely consumption excel file.
5. Substract water heating value from the total consumption value (minutely).





In this image, it is possible to observe that when the water consumption matches with the heating. Just after consuming hot water from the 125L heater of the bathroom, there is a 2Kwp energy consumption, which means that there is a water heating.

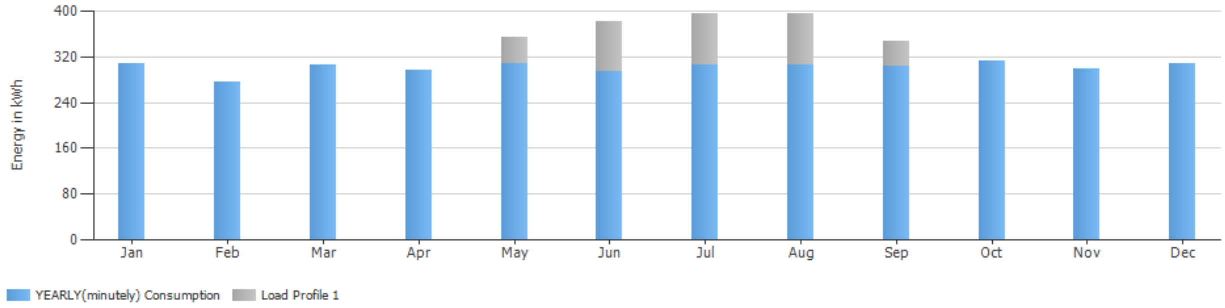


Once all the steps explained before are done, the profile of the consumption should have a shape like this, with variations depending on the day. Moreover, a monthly consumption profile was also obtained in order to find similarities between the consumption of the same day of the week. It is going to be attached in the annex.

For obtaining the annual consumption profile, there is one final step. Between 14th of January and 14th of February there is 1 month data. However, only 4 weeks were taken for building the consumption profile. The reason of this is to make it symmetrical weekly, in other words, to have the same numbers of week days than a normal year.

Finally, this 4 weeks or 28 days are copied until completing the 365 days of year, always with minutely values. After obtaining the annual consumption profile, it is going to be implemented to PV*SOL by csv. file, which is the format this software accepts. To end the profile, it is necessary to add the pool filtration during the summer months, which is available in PV*SOL.

NAME	ENERGY IN KWH
YEARLY(minutely) Consumption	3628
Load Profile 1	360

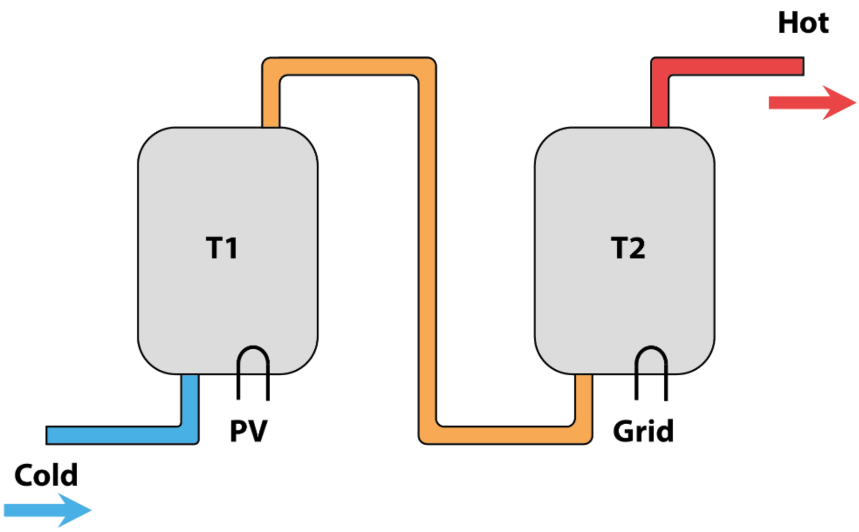


6. WATER HEATERS AND ENERGY STORAGE

6.1. CURRENT CONFIGURATION

In this section, the current configuration in the house for heating the water is going to be explained. The water heating system consist of two different boiler, the first one is connected to the PV modules, it has a capacity of 120 L and it is used for pre-heating; the second one is connected only to grid, its capacity is 125 L and it heats water for supplying to the bathroom.

The cold water enter through the first heater and it gets heated there with PV energy. In the second heater there is always hot water available and when there is a hot water consumption, new water enters to this one from the previous heater. Sometimes, this water will be hot enough because it has been heated in this first heater. Other times, the water will not have enough temperature because a lack of PV energy, and the second heater will need to heat the water until it reaches the right temperature. So in ideal conditions, the temperature of the first heater (T1) will be higher than the temperature of the second heater. This premise is supposed to counteract losses due to isolation.



The heaters have a power of 2kW and this involves that their consumption is approximately 35 Wh per minute. Nevertheless, with the relay installed, it is possible to modify this power and to adapt the heating to the excess of energy available

However, describing the performance of this configuration is quite complex. There are some priorities which try to approach the system to a better optimization.

1. The first and most important one is that **PV energy usage has to be maximized**. The aim of this project is to use as much excess of PV energy as possible by heating water. For this reason, the water of the first heater has to be cold in the morning, for being heated during the day.

2. The second premise is that **hot water** has to be **available** for the consumption of the **day**. Usually, the most of the hot water consumption is made during the morning, in the evening and at night before midnight. So hot water in the second heater has to be prepared for its usage.

3. The third priority is **backup heating at night**, because during the night the consumption is in low tariff and it is possible to save money. Nevertheless, this priority is the least important of the three, and the aim project is about not saving money, it is about saving energy, wasting as less PV energy as possible and giving it a usage.

6.2. OBJECTIVE

The objective of installing two water heaters is giving a usage to the excess of PV energy generated by the modules. When the consumption is totally covered by PV energy, the modules are still generating more energy but it cannot be used anymore by the appliances. There are three solutions for giving a use to this energy:

- Selling the energy to the grid: the excess of energy produced is sold to the main grid and it flows through the voltage grid as the energy produced in power plants. It is possible to receive money for the sale of the energy, although the price of kWh received as money for selling the energy is very low in Czech Republic.

- Storing the energy in batteries: this is the most common solution for isolated and self-consumption installations. The energy stored in the batteries is consumed later by the home appliances. However, is neither a cheap nor environmental-friendly solution.
- Heating water as a way of storing energy: the excess of energy is used for heating water as a thermal storage. Is a cheap and sustainable solution

This system is configured to use the excess of PV energy for heating water, so in the following paragraph, the reasons why this option was selected are going to be explained:

REASONS:

- Does not use batteries.
- Gives a usage to the excess of energy.
- Wastes the less amount of energy.

ADVANTAGES:

- Easy way of storing energy and instantly usage.
- No chemical or polluting material required.
- Big thermal inertia and specific heat of water.
- It can be used for house heating.

DISADVANTAGES:

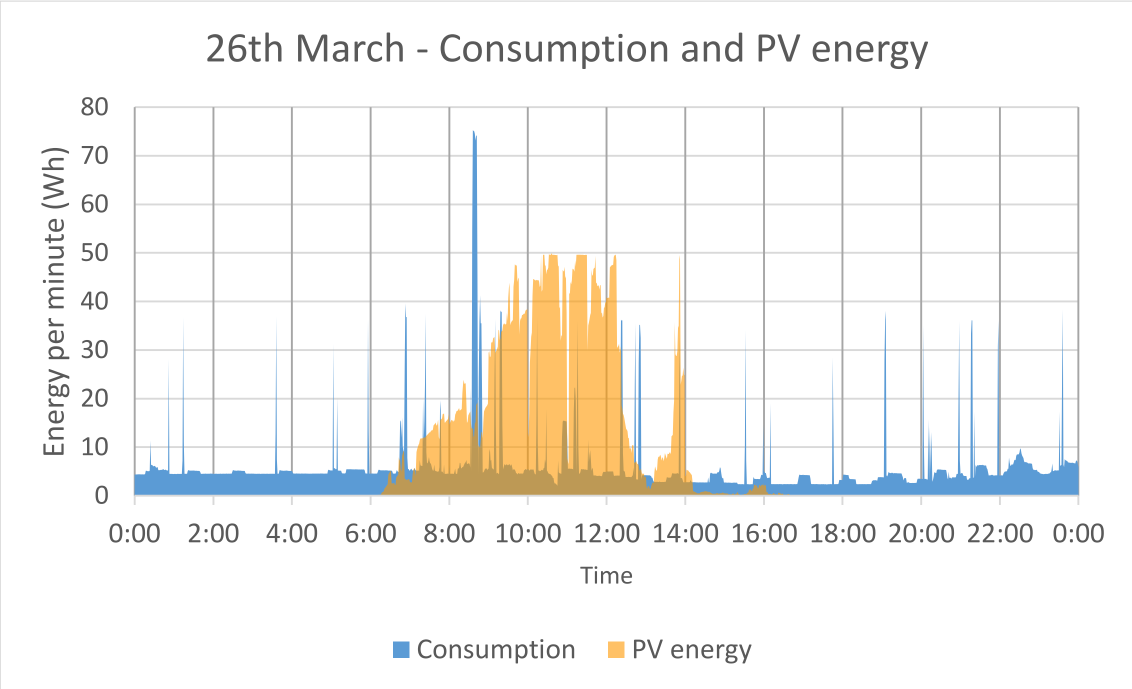
- The excess of energy can only be used for heating water.
- Part of the energy will be lost.
- There are losses.

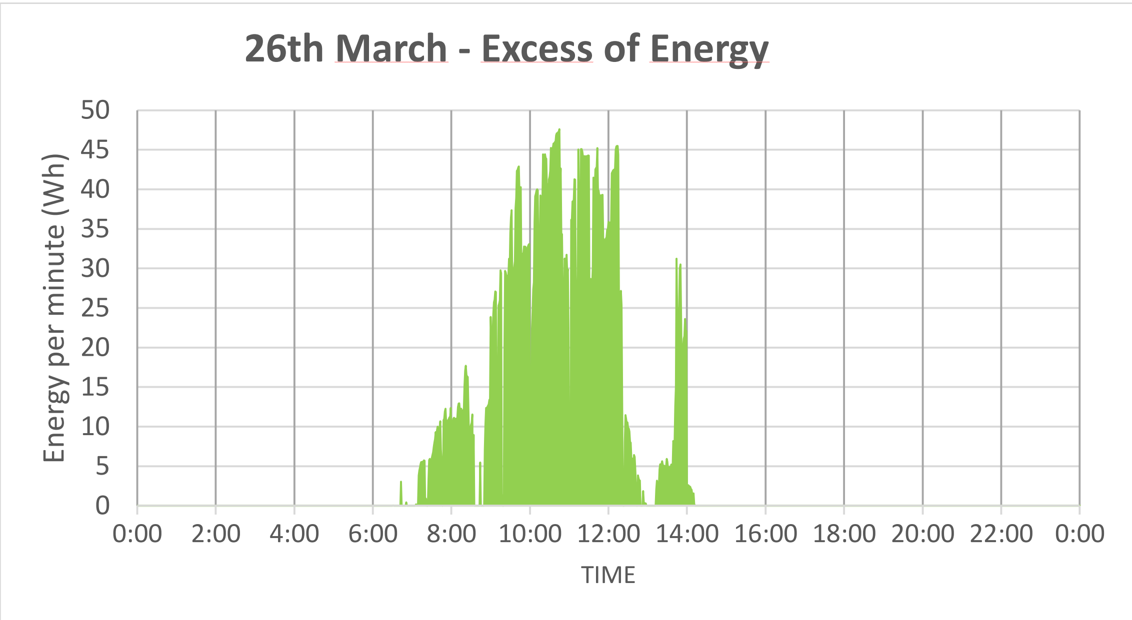
6.3. HOW TO OBTAIN THE EXCESS OF ENERGY

The procedure followed for obtaining the excess of PV energy of this system has the following steps:

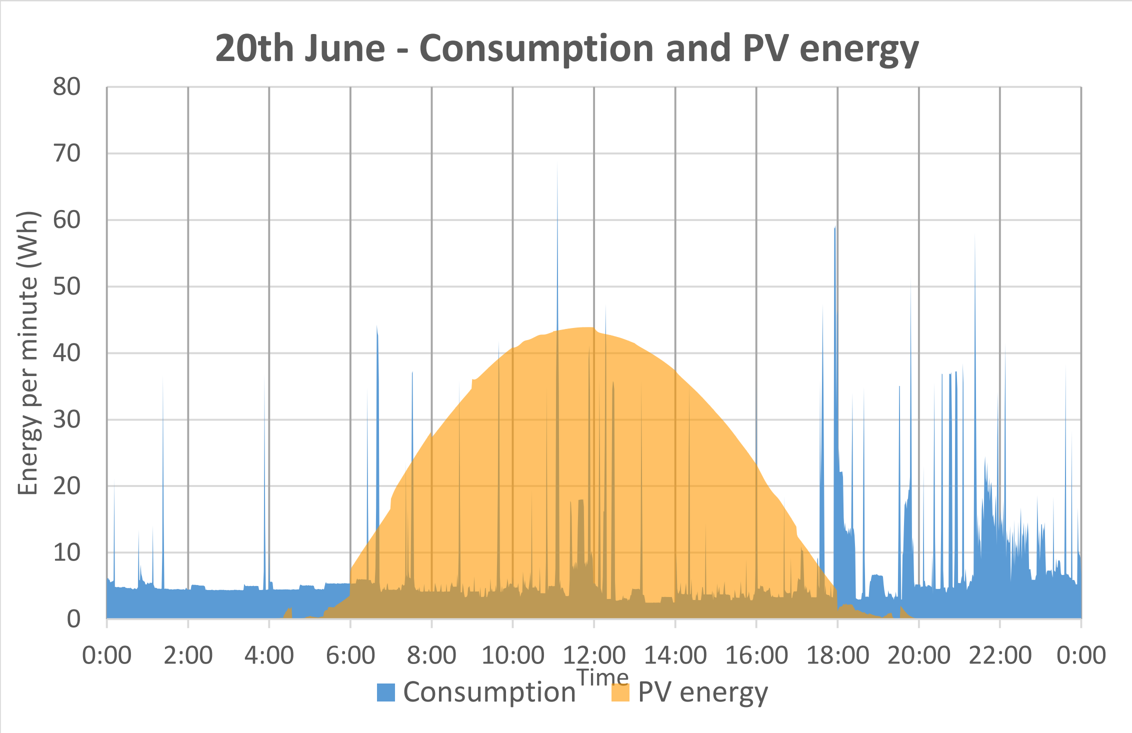
1. **Obtain PV energy minutely profile for the full year by PV*SOL**: when the house design and PV system are simulated in PV*SOL, it is possible to obtain a excel file with the PV energy minutely data along the whole year of the PV energy produced by the system.
2. **Implement it to consumption profile excel file:** after obtaining the PV energy data of the system, it has to be introduced in the consumption profile created in a excel file before
3. **Calculate the resulting excess of energy profile:** for concluding the obtaining of the excess of energy profile, the final step is subtracting the PV energy and the consumption. If and only if the minute PV energy is higher than the minute consumption, there will be excess of energy.

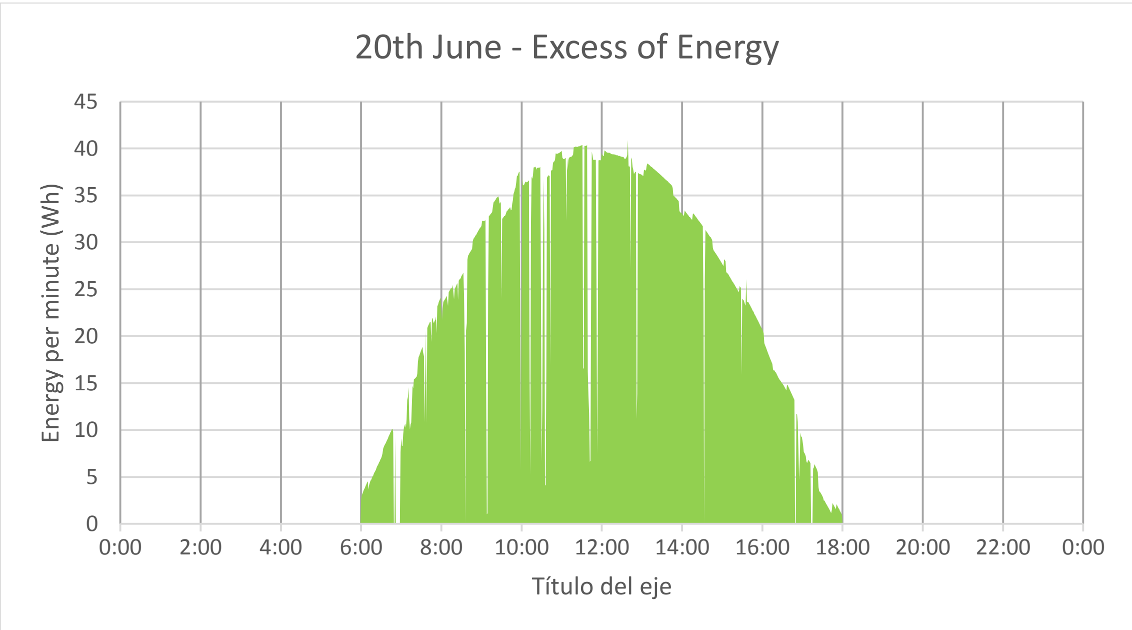
In the following graphs, the comparison between the consumption profile and the PV energy for some representative days is going to be plotted.





As it can be seen, for the 26th of March there is quite solar energy and it is higher than consumption the most of the time between the morning and the afternoon. This means that there is also quite excess if energy, which can be used to heat water. However, after 2pm there is no excess of energy anymore, and the consumption neither gets covered by the PV energy. The green area means the amount of excess energy available in that day and it can be used for heating water.





This day is a good example for a sunny summer day in Czech Republic. There is remarkable solar energy from 6 am to 6pm, and the most of the time the PV energy is covering the consumption, except some peaks. The amount of excess of energy for heating water in a typical sunny summer, as we can see, is quite large.

6.4. WATER STORING

Finally, the aim is to compare the excess of energy with the water heating demand. This analysis is going to be simplify to the monthly data for only making an idea about the quantity of energy is being considered.

For a more accurate analysis, a lot variables should be taken into consideration, such as the power capacity and isolation of the heaters, the thermal properties of the water, the heating speed, the water consumption, etc.

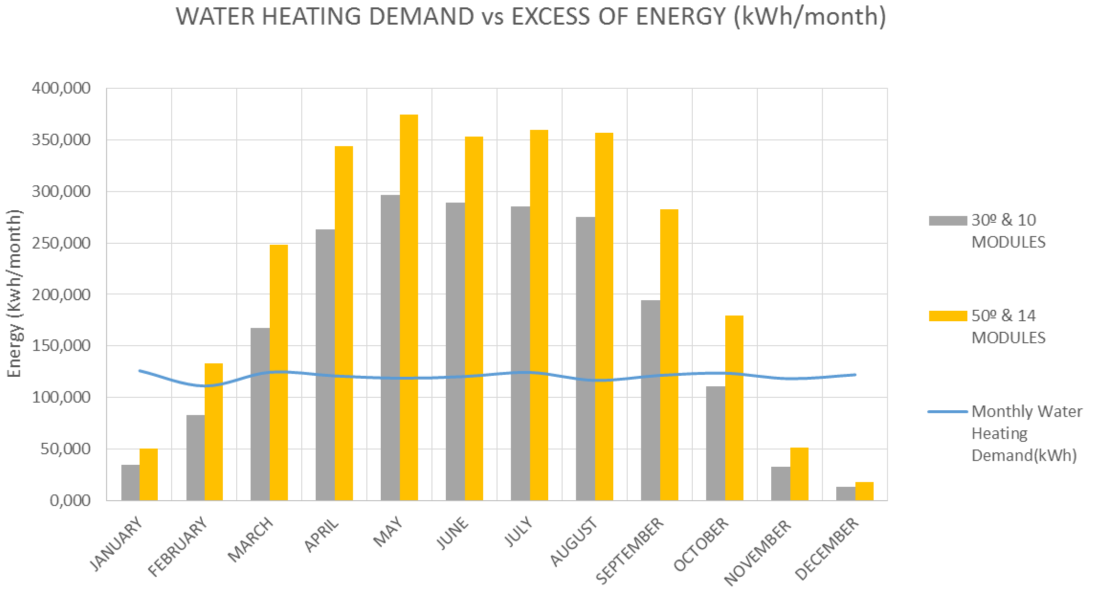
For this analysis, the procedure followed was:

- Calculating the daily excess of energy and the daily heating demand.
- Grouping daily values into monthly values.
- Comparing both values for the current configuration and optimized configuration.

The values of the excess of energy obtained for the current 10 modules-30º configuration and the optimized 14 modules-50º proposal are going to be compared between them and with the water heating demand. The results are shown in the following table and graph:

MONTH	Monthly Water Heating Demand (kWh)	30º & 10 MODULES	50º & 14 MODULES	DIFFERENCE (kWh)	DIFFERENCE (%)
		Monthly Excess Energy (kWh)	Monthly Excess Energy (kWh)		
JANUARY	125,93	34,094	49,830	15,736	31,58
FEBRUARY	111,09	82,978	132,618	49,640	37,43
MARCH	124,495	167,026	247,870	80,844	32,62
APRIL	120,96	262,941	343,855	80,915	23,53
MAY	118,65	296,683	375,053	78,370	20,90
JUNE	120,33	289,113	353,685	64,572	18,26
JULY	124,32	285,090	359,946	74,856	20,80
AUGUST	116,55	274,907	356,906	81,999	22,97

SEPTEMBER	121,485	194,827	282,406	87,579	31,01
OCTOBER	123,55	110,504	179,404	68,900	38,41
NOVEMBER	118,23	32,931	51,044	18,113	35,48
DECEMBER	122,01	12,671	17,823	5,151	28,90



As the table and the graph show, the excess of energy follows a similar pattern to the PV energy graph. The most remarkable difference between both configurations is noticed during summer months, when it is not required.

During the winter, the difference in percent on the excess of energy available in perceptible, but in terms of concrete values, the excess of energy among winter months has few importance. From February to October, the excess of energy becomes more significant, so for the months near to the equinoxes, this energy could be profitable.

The representation of the monthly water heating demand in kWh is the set of energy used throughout the month to heat water. However, this energy is not distributed proportionally in every day because the consumption of hot water varies depending on the day.

This clarification entails that the excess of energy produced during a certain could not be used, because if there is no water consumption that day or the consumption is slight, the excess of energy cannot be used for heating water.

For this reason, this graph is merely for making an idea about how much energy is available for being stored in a thermal way, by heating water. The quantity of energy that can be really used depends mainly on the capacity of the boiler and the hot water consumption.

7. CONCLUSIONS

This part is going to summarize the main ideas, solutions and conclusions that this project has reached. The main subject of the conclusions is related to the analysis of the performance of the PV system, focusing on system optimization.

First of all, the current configuration of the system is not the optimal for winter months. The amount of PV energy produced through these months supplies less than 20% of the consumption. Most of consumption is covered by grid. The only good point that can be said about winter months energy is that few of it is wasted.

Although during summer months the total energy produced is higher than the consumption, the amount of PV energy used for covering the consumption is around 50% and the other half of the energy produced is available like excess, because the energy is down-regulated at feed-in point. Furthermore, the appliances consumption is half covered (50%) by PV energy and half covered (50%) by grid. This is because although the PV energy generated during the day is almost always higher than the consumption, during the night the consumption has to be covered by grid.

Regarding to the optimization proposals, the simulations run about the different system configurations provide as a conclusion that changing the angle, shifting the position of the modules or varying the azimuth do not induce to an energy boost during winter months, which is the main goal of the project.

Nevertheless, the project has also concluded that oversizing the system by adding 4 modules more might be profitable in general terms. Because of the main installation is already done, the addition of modules will only suppose the cost of them and their mounting structure, which is affordable and amortizable in few time.

Furthermore, all the already-installed 10 modules and the new 4 ones will be mounted at an angle of 50º, in order to maximize the energy production during winter months, which was the aim of the project.

ANNEXES

ANNEX 1. POLYCRYSTALLINE MODULES MARKET SURVEY FOR PV MODULES IN SPAIN

		Module	Pn [Wp]	η [%]	η (cal)[%]	h [mm]	w [mm]	A [m²]	Price [€]	Module Cost [€/m²]	Datapoint [€/m²]
POLLYCRYSTALLINE	FOREIGN	Eldora 200P GRAND SERIES	220	15,13	13,47	1650	990	1,63	149,99	91,82	323,37
		Ecosolar 250W 24V	250	15,40	15,40	1640	990	1,62	122,90	75,70	307,25
		Red Solar RED260-60P-260W	260	16,00	15,98	1640	992	1,63	136,48	83,89	315,44
		Jinko JKM 265 60P	265	16,19	16,19	1650	992	1,64	137,11	83,77	315,32
		Canadian Solar CSI CS6K-270P	270	16,50	16,50	1650	992	1,64	123,00	75,15	306,70
		GCL - P6/60 270Wp	270	16,60	16,60	1640	992	1,63	155,00	95,27	326,83
		Talesun TT660P	270	16,50	16,50	1650	992	1,64	129,12	78,89	310,44
		Canadian Solar CSI CS6K-275P	275	16,80	16,80	1650	992	1,64	143,49	87,66	319,22
		AstroNova CHSM6610P 275W	275	16,90	16,86	1648	990	1,63	169,00	103,58	335,14
		Sharp NDAK275	275	16,90	16,90	1640	992	1,63	153,90	94,60	326,15
		Trina Solar TSM-275 PD05	275	16,80	16,80	1650	992	1,64	135,00	82,48	314,03
		Bauer Energy BSP275P	275	16,92	16,92	1640	991	1,63	131,76	81,07	312,62

		Jinko Solar Eagle 60P-275	275	16,80	16,80	1650	992	1,64	126,00	76,98	308,53
		Trina Solar TSM280-PE05H	280	16,90	16,85	1675	992	1,66	129,00	77,64	309,19
		Akcome SK6610P-5BB 280W	280	17,20	17,21	1640	992	1,63	109,00	67,00	298,55
		Axitec AC-280P/60S	280	17,21	17,21	1640	992	1,63	135,00	82,98	314,53
		Eco Solar 280W AltoRendimiento	280	17,21	17,21	1640	992	1,63	124,90	76,77	308,32
		Peimar SG280P	280	17,21	17,21	1640	992	1,63	111,18	68,34	299,89
		Amerisolar AS-6P30	280	17,21	17,21	1640	992	1,63	121,00	74,38	305,93
		Bauer Energy BSP280P	280	17,10	17,14	1650	990	1,63	131,08	80,24	311,80
		Red Solar RED280-60P	280	17,25	17,25	1640	990	1,62	128,41	79,09	310,64
		Red Solar RED280-120P	280	17,10	17,09	1652	992	1,64	154,00	93,97	325,52
		Red Solar SRP-280-BPB	280	16,86	16,86	1674	992	1,66	128,41	77,33	308,88
		Yingli YL280P-29B	280	17,10	17,11	1650	992	1,64	117,98	72,08	303,63
		Canadian Solar CS6K-280P	280	17,11	17,11	1650	992	1,64	162,00	98,97	330,53
		Rec Solar TwinPeak 2 285	285	17,10	17,07	1675	997	1,67	156,84	93,92	325,47
		Canadian Solar CS3K-285	285	17,15	17,15	1675	992	1,66	141,00	84,86	316,41
		Canadian Solar CS3K-290	290	17,45	17,45	1675	992	1,66	143,00	86,06	317,61
		AmeriSolar AS-6P-320W	320	16,49	16,46	1960	992	1,94	160,00	82,29	313,84
		Waaree Aditya WS-320	320	16,49	16,49	1960	990	1,94	246,10	126,83	358,38

		Ecosolar 320W 24V	320	16,50	16,46	1960	992	1,94	146,00	75,09	306,64
		CSUN 320-72P	320	16,52	16,53	1956	990	1,94	247,55	127,84	359,39
		SHARP NDAH 325 72P	325	16,70	16,72	1960	992	1,94	164,29	84,50	316,05
		Canadian Solar CS6U-325P	325	16,72	16,72	1960	992	1,94	166,74	85,76	317,31
		Jinko Eagle JKM325PP-72	325	16,80	16,75	1956	992	1,94	175,00	90,19	321,74
		AXIPower AC-330P/72S 330Wp	330	17,01	17,01	1956	992	1,94	185,00	95,34	326,90
		Red Solar RED330-72P	330	17,10	17,09	1950	990	1,93	133,00	68,89	300,45
		Red Solar RED330-144P	330	16,67	16,67	1996	992	1,98	122,57	61,90	293,46
		SunTech STP330 - 24/Vfw	330	17,00	16,97	1960	992	1,94	159,04	81,80	313,35
		Axitec AC-330P/156-72S	330	17,01	17,00	1957	992	1,94	152,00	78,30	309,85
		Akcome SK6612P- 330W	330	17,00	17,00	1957	992	1,94	121,00	62,33	293,88
		Sharp ND-AF330C	330	17,23	17,00	1960	992	1,94	144,54	74,34	305,89
		Talesun TP672P-330W	330	17,00	17,00	1960	990	1,94	155,28	80,02	311,58
		Ja Solar JAP72S01 -330	330	16,99	17,00	1960	991	1,94	155,79	80,21	311,76
		Sharp ND-AH330H	330	17,00	17,00	1960	992	1,94	159,00	81,78	313,33
		GCL -P6/72	330	17,00	17,01	1956	992	1,94	199,00	102,56	334,11
		Canadian Solar Max Power CS6U-335P	335	17,23	17,23	1960	992	1,94	135,00	69,43	300,99

		Yingli YL335P-35B	335	17,20	17,23	1960	992	1,94	188,76	97,08	328,63
		Red Solar SRP-335-BPA-HV	335	16,92	16,92	1996	992	1,98	122,57	61,90	293,46
		Era Solar ESPMC335	335	17,20	17,26	1956	992	1,94	156,30	80,55	312,10
		AmeriSolar AS-6P-335W	335	17,26	17,26	1956	992	1,94	147,04	75,78	307,33
		Jinko Solar Eagle72P-V 335	335	17,26	17,26	1956	992	1,94	145,00	74,73	306,28
		Canadian Solar CS6U-335P	335	17,23	17,23	1960	992	1,94	199,65	102,68	334,24
		Trina Solar Tallmax TSM-PE15H	340	16,70	16,73	2024	1004	2,03	139,00	68,40	299,95
		Era Solar ESPMC 340	340	17,50	17,52	1956	992	1,94	149,30	76,94	308,50
		Ecosolar 340W 24V	340	17,52	17,52	1956	992	1,94	156,30	80,55	312,10
		AmeriSolar AS-6P-340W	340	17,52	17,49	1960	992	1,94	157,30	80,90	312,45
		Trina Solar TSM340-PE14H	340	17,14	17,14	2000	992	1,98	157,30	79,28	310,84
		Canadian Solar KuMax CS3U-345P	345	17,39	17,39	2000	992	1,98	180,00	90,73	322,28
		Canadian Solar KuMax CS6U-345P	345	17,39	17,39	2000	992	1,98	185,00	93,25	324,80
		Trina Solar TSM350-PE15H	350	17,40	17,40	2004	1004	2,01	121,58	60,43	291,98
		Canadian Solar CS3U-350 KuMax	350	17,64	17,64	2000	992	1,98	190,00	95,77	327,32
		Canadian Solar CS3W-400P HiKu	400	18,11	18,11	2108	1048	2,21	183,60	83,11	314,66
		Canadian Solar CS3W-405P	405	18,33	18,33	2108	1048	2,21	199,88	90,48	322,03
		LG NeON 2 Bifacial 395NT2-A5	514	24,30	24,32	2064	1024	2,11	345,00	163,23	394,79

	SPANISH	Iberian Solar IBS 270 60P	270	16,60	16,55	1645	992	1,63	127,12	77,90	309,45
		ATERSA ULTRA A-270P	270	16,56	16,58	1645	990	1,63	144,00	88,42	319,97
		Eleksol SUN- 60P 270W	270	16,63	16,63	1640	990	1,62	145,00	89,31	320,86
		IBERIAN IBS 280 60P	280	17,16	17,16	1645	992	1,63	130,25	79,82	311,37
		ATERSA A-280P GS	280	17,20	17,19	1645	990	1,63	111,28	68,33	299,88
		Eleksol SUN- 60P 280W	280	17,25	17,25	1640	990	1,62	145,20	89,43	320,98
		IBERIAN IBS 310 72P	310	15,98	15,98	1956	992	1,94	141,64	73,00	304,55
		ATERSA ULTRA A-315P	315	16,20	16,19	1965	990	1,95	190,58	97,97	329,52
		Eleksol SUN 72P 330W	330	17,10	17,09	1950	990	1,93	181,50	94,02	325,57
		Atersa A-330P GSE	330	17,01	17,01	1956	992	1,94	141,50	72,92	304,48
		IBERIAN IBS 330 72P	330	17,01	17,01	1956	992	1,94	148,90	76,74	308,29

ANNEX 2. MONOCRYSTALLINE MODULES MARKET SURVEY FOR PV MODULES IN SPAIN

		Module	Pn [Wp]	η [%]	η (calc.) [%]	h [mm]	w [mm]	A [m²]	Price [€]	Module Cost [€/m²]	Module Cost [€/Wp]	Datapoint [€/m²]
MONOCRYSTALINE	FOREIGN	Red Solar CSUN200-60M	200	16,16	16,16	1250	990	1,24	159,20	128,65	0,80	262,59
		Red Solar RED210-72M	210	16,45	16,45	1580	808	1,28	139,71	109,44	0,67	243,38
		Almaden M60-280W	280	17,00	17,02	1662	990	1,65	209,00	127,02	0,75	260,97
		Longi LR6-60-285M	285	17,43	17,43	1650	991	1,64	139,60	85,37	0,49	219,32
		Canadian Solar - CS6K-290MS	290	18,02	17,72	1650	992	1,64	177,00	108,14	0,61	242,08
		Sharp NURC300	300	18,30	18,25	1660	990	1,64	209,00	127,18	0,70	261,12
		Canadian Solar CS3K-300MS	300	18,05	18,05	1675	992	1,66	174,00	104,72	0,58	238,66
		ECO DELTA ECO-300M-60 Black PERC	300	18,30	18,33	1650	992	1,64	157,30	96,10	0,52	230,05
		Candian Solar CS6K-300M	300	18,63	18,33	1650	992	1,64	203,00	124,02	0,68	257,97
		Seraphin SRP-310-E01B-60M	310	18,94	18,94	1650	992	1,64	199,00	121,58	0,64	255,53
		Akcome SK6610M- 310W	310	19,10	19,05	1640	992	1,63	130,00	79,91	0,42	213,85
		Longi LR6-60-310M	310	18,94	18,94	1650	992	1,64	210,81	128,79	0,68	262,74
		Era Solar ESPSC 310	310	19,16	18,98	1650	990	1,63	133,78	81,90	0,43	215,84
		Trina Solar Honey Black TSM-DD06M	315	18,50	18,48	1698	1004	1,70	179,00	105,00	0,57	238,94
		Jinko Solar Cheetah HC60M 335	335	19,85	19,85	1684	1002	1,69	159,00	94,23	0,47	228,18
		Canadian Solar CS1H-MS335MB	335	19,86	19,86	1700	992	1,69	223,00	132,23	0,67	266,18

		LG NeON 340N1C-A5	340	19,80	19,85	1686	1016	1,71	279,09	162,93	0,82	296,87
		Sharp NUAH370	370	19,10	19,07	1956	992	1,94	230,48	118,78	0,62	252,73
		Red Solar SRP-335-BPA-HV	375	19,33	19,33	1956	992	1,94	165,45	85,27	0,44	219,21
		Akcome SK6612M 375W	375	19,30	19,32	1957	992	1,94	159,00	81,90	0,42	215,85
		AXIPremium AC-380MH/72S 380Wp	380	19,15	19,15	2000	992	1,98	235,00	118,45	0,62	252,39
		Sunrise SR-M672390HL	390	19,38	19,38	2008	1002	2,01	183,06	90,98	0,47	224,93
		Red Solar SR-M672400HL	400	19,89	19,88	2008	1002	2,01	182,00	90,46	0,46	224,40
		Red Solar SRP-400-BMA-HV	400	19,81	19,81	2015	1002	2,02	177,80	88,06	0,44	222,01
		Era Solar ESPSC 400	400	19,16	20,17	1979	1002	1,98	210,55	106,18	0,53	240,13
		Seraphin Blade 400w	400	19,81	19,81	2015	1002	2,02	189,00	93,61	0,47	227,56
		Jinko Solar Cheetah HC72M 400	400	19,88	19,88	2008	1002	2,01	185,00	91,95	0,46	225,89
		Ja Solar JAM72S10	405	20,40	20,18	2015	996	2,01	210,55	104,91	0,52	238,86
	SPANISH	ATERSA A-310M GS	310	19,09	19,09	1640	990	1,62	156,30	96,27	0,50	230,21
		Eleksol SUN-60M PERC 300W	310	19,09	19,09	1640	990	1,62	157,30	96,88	0,51	230,83
		GM LLEGC-M-PERC 315	315	19,10	19,07	1665	992	1,65	139,00	84,16	0,44	218,10
		ATERSA A-360M GS	360	18,55	18,55	1960	990	1,94	164,33	84,69	0,46	218,64
		ATERSA A-370M OPTIMUM GS	370	19,07	19,07	1956	992	1,94	148,83	76,70	0,40	210,65
		ATERSA A-390M OPTIMUM GS	390	19,67	19,67	1979	1002	1,98	156,09	78,72	0,40	212,66
		GM LLEGC-M-PERC 399	400	19,80	19,81	2015	1002	2,02	179,00	88,66	0,45	222,60
		ELEKSOL SUN 78M-HF 445W	445	20,66	20,66	2150	1002	2,15	245,95	114,17	0,55	248,11

ANNEX 3: PV MODULES IN SPANISH MARKET SIMULATION: POLYCRYSTALLINE NON-OVERSIZED

	PV*SOL Simulations											
	Installed Power [kWp]	**Annual Power Generation [kWh/Year]**	**Module**	**Pn [Wp]**	**Number of Modules**	**Inverter**	**A [m²]**	**TOTAL A [m²]**	**Price [€]**	**Module Cost [€/m²]**	**Total Cost [€/m²]**	**Energy per Area [kWh/y/m²]**
POLICRYSTALINE	2,2	3331	AstroNova CHSM6610P 275W	275	8,00	Growatt 2000-S	1,63	13,05	169,00	103,58	237,53	255,21
	2,24	3287	Yingli YL280P-29B	280	8,00	Goodwe GW2000-NS	1,64	13,09	117,98	72,08	206,03	251,02
	2,31	3532	SunTech STP330 - 24/Vfw	330	7,00	Growatt 2000-S	1,94	13,61	159,04	81,80	215,74	259,51
	2,345	3430	Yingli YL335P-35B	335	7,00	Goodwe GW2000-NS	1,94	13,61	188,76	97,08	231,03	252,02
	2,385	3596	Jinko JKM 265 60P	265	9,00	Growatt 2000-S	1,64	14,73	137,11	83,77	217,71	244,11
	2,43	3687	Canadian Solar CSI CS6K-270P	270	9,00	Growatt 2000-S	1,64	14,73	123,00	75,15	209,09	250,29
	2,43	3681	GCL - P6/60 270Wp	270	9,00	Azzurro 2200TL	1,63	14,64	155,00	95,27	229,22	251,40
	2,475	3733	Sharp NDAK275	275	9,00	SolaX Power SL-TL2200	1,63	14,64	153,90	94,60	228,54	254,95
	2,475	3821	Trina Solar TSM-275 PD05	275	9,00	SolaX Power SL-TL2200	1,64	14,73	135,00	82,48	216,42	259,38
	2,52	3885	Axitec AC-280P/60S	280	9,00	Shenzen CP2K2TL	1,63	14,64	135,00	82,98	216,93	265,33
	2,52	3818	Canadian Solar CS6K-280P	280	9,00	Fronius Galvo 2.5-1	1,64	14,73	162,00	98,97	232,92	259,18

	2,56	4014	CSUN 320-72P	320	8,00	B&B Power SF2200TL	1,94	15,49	247,55	127,84	261,78	259,11
	2,61	3959	Canadian Solar CS3K-290	290	9,00	Fronius Galvo 2.5-1	1,66	14,95	143,00	86,06	220,01	264,74
	2,64	3655	Ja Solar JAP72S01 - 330	330	8,00	Schneider Xantrex GT 2,5-DE	1,94	15,54	155,79	80,21	214,15	235,22
	2,64	3959	Sharp ND-AF330C	330	8,00	Fronius Galvo 2.5-1	1,94	15,55	144,54	74,34	208,29	254,52
	2,64	3691	GCL -P6/72	330	8,00	Schneider Xantrex GT 2,5-DE	1,94	15,52	199,00	102,56	236,51	237,78
	2,7	3712	Talesun TT660P	270	10,00	Schneider Xantrex GT 2,5-DE	1,64	16,37	129,12	78,89	212,83	226,78
	2,72	3648	Era Solar ESPMC 340	340	8,00	Schneider Xantrex GT 2,5-DE	1,94	15,52	149,30	76,94	210,89	235,01
	2,75	4174	Jinko Solar Eagle 60P-275	275	10,00	Growatt 2000-S	1,64	16,37	126,00	76,98	210,93	255,01
	2,76	4185	Canadian Solar KuMax CS3U-345P	345	8,00	Fronius Galvo 2.5-1	1,98	15,87	180,00	90,73	224,67	263,67
	2,8	4181	Peimar SG280P	280	10,00	Fronius Galvo 2.5-1	1,63	16,27	111,18	68,34	202,29	256,99
	2,85	4309	Canadian Solar CS3K-285	285	10,00	Fronius Galvo 2.5-1	1,66	16,62	141,00	84,86	218,80	259,33
	2,88	4182	Waaree Aditya WS-320	320	9,00	Fronius Galvo 2.5-1	1,94	17,46	246,10	126,83	260,78	239,47
	2,925	4424	Canadian Solar CS6U-325P	325	9,00	Fronius Galvo 2.5-1	1,94	17,50	166,74	85,76	219,70	252,82

	2,925	4352	Jinko Eagle JKM325PP-72	325	9,00	Fronius Galvo 2.5-1	1,94	17,46	175,00	90,19	224,14	249,21
	2,97	4583	Akcome SK6612P-330W	330	9,00	SolaX Power SL-TL2800	1,64	14,76	121,00	73,78	207,73	310,50
	2,97	4589	Talesun TP672P-330W	330	9,00	SolaX Power SL-TL2800	1,94	17,46	155,28	80,02	213,97	262,78
	2,97	4595	Sharp ND-AH330H	330	9,00	SolaX Power SL-TL2800	1,94	17,50	159,00	81,78	215,72	262,59
	3,015	4561	Canadian Solar CS6U-335P	335	9,00	Fronius Galvo 2.5-1	1,94	17,50	135,00	69,43	203,38	260,65
	3,015	4455	Era Solar ESPMC335	335	9,00	SolaX Power SL-TL2800	1,94	17,46	156,30	80,55	214,50	255,11
	3,015	4561	Canadian Solar CS6U-335P	335	9,00	Fronius Galvo 2.5-1	1,94	17,50	199,65	102,68	236,63	260,65
	3,025	4576	Bauer Energy BSP275P	275	11,00	Enfinity-2800TL	1,63	17,88	131,76	81,07	215,02	255,96
	3,025	4577	Canadian Solar CSI CS6K-275P	275	11,00	Fronius Galvo 2.5-1	1,64	18,00	143,49	87,66	221,61	254,21
	3,08	4752	Trina Solar TSM280-PE05H	280	11,00	Sunways AT2700	1,66	18,28	129,00	77,64	211,58	259,99
	3,15	4892	Canadian Solar CS3U-350P KuMax	350	9,00	Kostal Piko 3.0 MP	1,98	17,86	190,00	95,77	229,71	273,97
	3,2	4970	Canadian Solar CS3W-400P HiKu	400	8,00	Kostal Piko 3.0 MP	2,21	17,67	183,60	83,11	217,05	281,21
	3,24	4933	Canadian Solar CS3W-405P	405	8,00	Fronius Galvo 3.0-1	2,21	17,67	199,88	90,48	224,42	279,12
	3,36	4910	Bauer Energy BSP280P	280	12,00	Kostal Piko 3.0 MP	1,63	19,60	131,08	80,24	214,19	250,48
	3,63	5490	AXIPower AC-330P/72S 330Wp	330	11,00	Schneider Conext TX 3300 NA	1,94	21,34	185,00	95,34	229,29	257,22

ANNEX 4: PV MODULES IN SPANISH MARKET SIMULATION: MONOCRYSTALLINE NON-OVERSIZED

	PV*SOL Simulations											
	Installed Power [kWp]	**Annual Power Generation [kWh/Year]**	**Module**	**Pn [Wp]**	**Number of Modules**	**Inverter**	**A [m²]**	**TOTAL A [m²]**	**Price [€]**	**Module Cost [€/m²]**	**Total Cost [€/m²]**	**Energy per Area [kWh/y/m²]**
MONOCRYSTALINE	2,4	3579	Sharp NURC300	300	8,00	Azzurro 2200TL	1,64	13,15	209,00	127,18	261,12	272,23
	2,52	3799	Almaden M60-280W	280	9,00	B&B Power SF2200TL	1,65	14,81	209,00	127,02	260,97	256,54
	2,52	3780	Seraphin SRP-315-E01B-60M	315	8,00	Shenzen CP2K2TL	1,64	13,09	199,00	121,58	255,53	288,67
	2,565	3969	Longi LR6-60-285M	285	9,00	B&B Power SF2200TL	1,64	14,72	139,60	85,37	219,32	269,70
	2,61	4308	Canadian Solar - CS6K-290MS	290	9,00	Schneider Xantrex GT 2,5-DE	1,64	14,73	177,00	108,14	242,08	292,44
	2,68	3794	Jinko Solar Cheetah HC60M 335	335	8,00	Schneider Xantrex GT 2,5-DE	1,69	13,50	159,00	94,23	228,18	281,06
	2,7	4098	Canadian Solar CS3K-300MS	300	9,00	Fronius Galvo 2.5-1	1,66	14,95	174,00	104,72	238,66	274,03
	2,7	4039	ECO DELTA ECO-300M-60 Black PERC	300	9,00	Fronius Galvo 2.5-2	1,64	14,73	157,30	96,10	230,05	274,18

	2,79	4233	Longi LR6-60-310M	310	9,00	Fronius Galvo 2.5-1	1,64	14,73	210,81	128,79	262,74	287,35
	2,88	4430	Trina Solar Honey Black TSM-DD06M	320	9,00	Fronius Galvo 2.5-1	1,70	15,34	179,00	105,00	238,94	288,73
	3	4635	Akcome SK6612M 375W	375	8,00	SolaX Power SL-TL2800	1,94	15,53	159,00	81,90	215,85	298,44
	3,015	4662	Canadian Solar CS1H-MS335MB	335	9,00	SolaX Power SL-TL2800	1,69	15,18	223,00	132,23	266,18	307,16
	3,06	4765	LG NeON 340N1C-A5	340	9,00	SolaX Power SL-TL2800	1,71	15,42	279,09	162,93	296,87	309,08
	3,12	4500	Sunrise SR-M672390HL	390	8,00	Sunways AT2700	2,01	16,10	183,06	90,98	224,93	279,57
	3,2	4882	Jinko Solar Cheetah HC72M 400	400	8,00	Riello UPS HP2800X	2,01	16,10	185,00	91,95	225,89	303,30
	3,24	4953	Ja Solar JAM72S10	405	8,00	Ingeteam Ingecon Sun3TL	2,01	16,06	210,55	104,91	238,86	308,49
	3,3	5042	Candian Solar CS6K-300M	300	11,00	Fronius Galvo 3.0-1	1,64	18,00	203,00	124,02	257,97	280,04
	3,33	4927	Sharp NUAH370	370	9,00	Fronius Primo 3.0-1	1,94	17,46	230,48	118,78	252,73	282,14
	3,42	5014	AXIPremium AC-380 MH/72S	380	9,00	Fronius Primo 3.0-1	1,98	17,86	235,00	118,45	252,39	280,80

ANNEX 5: PV MODULES IN SPANISH MARKET SIMULATION: POLYCRYSTALLINE OVERSIZED

	PV*SOL Oversizing Simulations														
	DC for 150% [kWp]	**Installed Power [kWp]**	**Annual Power Generation [kWh/Year]**	**Module**	**Pn [Wp]**	**Number of Modules**	**Inverter**	**Inverter Power [kW]**	**A [m²**	**TOTAL A [m²]**	**Price [€]**	**Module Cost [€/m²]**	**Total Cost [€/m²]**	**Energy per Area [€/m²]**	**DC/ AC**
POLICRYSTALINE	3,000	3,3	4497	AstroNova CHSM6610 P 275W	275	12,00	Growatt 2000-S	2	1,6 3	19,58	169,0 0	103,58	237,53	229,69	1,65
	3,000	3,3	4499	SunTech STP330 - 24/Vfw	330	10,00	Growatt 2000-S	2	1,9 4	19,44	159,0 4	81,80	215,74	231,39	1,65
	3,000	3,35	4251	Yingli YL335P-35B	335	10,00	Goodwe GW2000-NS	2	1,9 4	19,44	188,7 6	97,08	231,03	218,64	1,68
	3,000	3,36	4262	Yingli YL280P-29B	280	12,00	Goodwe GW2000-NS	2	1,6 4	19,64	117,9 8	72,08	206,03	216,99	1,68
	3,000	3,71	5349	Jinko Solar Eagle 60P-275	265	14,00	Growatt 2000-S	2	1,6 4	22,92	137,1 1	83,77	217,71	233,43	1,86
	3,000	3,78	4838	Canadian Solar CSI CS6K-270P	270	14,00	Growatt 2000-S	2	1,6 4	22,92	123,0 0	75,15	209,09	211,13	1,89
	3,300	3,78	4865	GCL - P6/60 270Wp	270	14,00	Azzurro 2200TL	2,2	1,6 3	22,78	155,0 0	95,27	229,22	213,60	1,72

	3,300	3,84	5279	CSUN 320-72P	320	12,00	B&B Power SF2200TL	2,2	1,94	23,24	247,55	127,84	261,78	227,18	1,75
	3,300	3,85	4915	Sharp NDAK275	275	14,00	SolaX Power SL-TL2200	2,2	1,63	22,78	153,90	94,60	228,54	215,79	1,75
	3,300	3,85	4968	Trina Solar TSM-275 PD05	275	14,00	SolaX Power SL-TL2200	2,2	1,64	22,92	135,00	82,48	216,42	216,80	1,75
	3,750	3,85	5933	Jinko Solar Eagle 60P-275	275	14,00	Fronius Galvo 2.5-1	2,5	1,64	22,92	126,00	76,98	210,93	258,91	1,54
	3,300	3,92	5249	Axitec AC-280P/60S	280	14,00	Shenzen CP2K2TL	2,2	1,63	22,78	135,00	82,98	216,93	230,46	1,78
	3,750	3,92	5543	Canadian Solar CSI CS6K-280P	280	14,00	Fronius Galvo 2.5-1	2,5	1,64	22,92	162,00	98,97	232,92	241,89	1,57
	3,750	3,96	4961	Ja Solar JAP72S01 - 330	330	12,00	Schneider Xantrex GT 2,5-DE	2,5	1,94	23,31	155,79	80,21	214,15	212,84	1,58
	3,750	3,96	5534	Sharp ND-AF330C	330	12,00	Fronius Galvo 2.5-1	2,5	1,94	23,33	144,54	74,34	208,29	237,19	1,58
	3,750	3,96	4925	GCL -P6/72	330	12,00	Schneider Xantrex GT 2,5-DE	2,5	1,94	23,28	199,00	102,56	236,51	211,52	1,58
	3,750	3,99	5579	Canadian Solar CS3K-285P	285	14,00	Fronius Galvo 2.5-1	2,5	1,66	23,26	141,00	84,86	218,80	239,83	1,60

	3,750	4,06	5650	Canadian Solar CS3K-290P	290	14,00	Fronius Galvo 2.5-1	2,5	1,66	23,26	143,00	86,06	220,01	242,88	1,62
	3,750	4,08	4810	Era Solar ESPMC 340	340	12,00	Schneider Xantrex GT 2,5-DE	2,5	1,94	23,28	149,30	76,94	210,89	206,58	1,63
	3,750	4,14	5712	Canadian Solar CS3U-345P KuMax	345	12,00	Fronius Galvo 2.5-1	2,5	1,98	23,81	180,00	90,73	224,67	239,92	1,66
	3,750	4,32	5173	Talesun TT660P	270	16,00	Schneider Xantrex GT 2,5-DE	2,5	1,64	26,19	129,12	78,89	212,83	197,53	1,73
	4,200	4,4	5915	Bauer Energy BSP275P	275	16,00	Enfinity-2800TL	2,8	1,63	26,00	131,76	81,07	215,02	227,47	1,57
	3,750	4,4	5919	Canadian Solar CSI CS6K-275P	275	16,00	Fronius Galvo 2.5-1	2,5	1,64	26,19	143,49	87,66	221,61	226,01	1,76
	3,750	4,48	5914	Peimar SG280P	280	16,00	Fronius Galvo 2.5-1	2,5	1,63	26,03	111,18	68,34	202,29	227,20	1,79
	3,750	4,48	5656	Waaree Aditya WS-320	320	14,00	Fronius Galvo 2.5-1	2,5	1,94	27,17	246,10	126,83	260,78	208,20	1,79
	4,050	4,48	6294	Trina Solar TSM280-PE05H	280	16,00	Sunways AT2700	2,7	1,66	26,59	129,00	77,64	211,58	236,74	1,66
	3,750	4,55	6015	Canadian Solar CS6U-325P	325	14,00	Fronius Galvo 2.5-1	2,5	1,94	27,22	166,74	85,76	219,70	220,97	1,82

	3,750	4,55	5931	Jinko Eagle JKM325PP-72	325	14,00	Fronius Galvo 2.5-1	2,5	1,94	27,16	175,00	90,19	224,14	218,33	1,82
	4,200	4,62	6220	Akcome SK6612P-330W	330	14,00	SolaX Power SL-TL2800	2,8	1,64	22,96	121,00	73,78	207,73	270,91	1,65
	4,200	4,62	6237	Talesun TP672P-330W	330	14,00	SolaX Power SL-TL2800	2,8	1,94	27,17	155,28	80,02	213,97	229,59	1,65
	4,200	4,62	6238	Sharp ND-AH330H	330	14,00	SolaX Power SL-TL2800	2,8	1,94	27,22	159,00	81,78	215,72	229,17	1,65
	3,750	4,69	6100	Canadian Solar CS6U-335P	335	14,00	Fronius Galvo 2.5-1	2,5	1,94	27,22	135,00	69,43	203,38	224,10	1,88
	4,200	4,69	5895	Era Solar ESPMC335	335	14,00	SolaX Power SL-TL2800	2,8	1,94	27,16	156,30	80,55	214,50	217,01	1,68
	4,500	4,8	6381	Canadian Solar CS3W-400P HiKu	400	12,00	Kostal Piko 3.0 MP	3	2,21	26,51	183,60	83,11	217,05	240,70	1,60
	4,500	4,86	6795	Canadian Solar CS3W-405P	405	12,00	Fronius Galvo 3.0-1	3	2,21	26,51	199,88	90,48	224,42	256,32	1,62
	4,500	4,9	6861	Canadian Solar CS3U-350P KuMax	350	14,00	Kostal Piko 3.0 MP	3	1,98	27,78	190,00	95,77	229,71	247,01	1,63

	4,500	5,04	6577	Bauer Energy BSP280P	280	18,00	Kostal Piko 3.0 MP	3	1,63	29,40	131,08	80,24	214,19	223,68	1,68
	4,950	5,28	7311	AXIPower AC-330P/72S 330Wp	330	16,00	Schneider Conext TX 3300 NA	3,3	1,94	31,05	185,00	95,34	229,29	235,49	1,60

ANNEX 6. PV MODULES IN SPANISH MARKET SIMULATION: MONOCRYSTALLINE OVERSIZED

	PV*SOL Oversizing Simulations														
	DC for 150% [kWp]	**Installed Power [kWp]**	**Annual Power Generation [kWh/Year]**	**Module**	**Pn [Wp]**	**Number of Modules**	**Inverter**	**Inverter Power [kW]**	**A [m²**	**TOTAL A [m²]**	**Price [€]**	**Module Cost [€/m²]**	**Total Cost [€/m²]**	**Energy per Area [€/m²]**	**DC/ AC**
MONOCRYSTALINE	3,300	3,6	4777	Sharp NURC300	300	12,00	Azzurro 2200TL	2,2	1,64	19,72	209,00	127,18	261,12	242,23	1,64
	3,300	3,78	5043	Seraphin SRP-315-E01B-60M	315	12,00	Shenzen CP2K2TL	2,2	1,64	19,64	199,00	121,58	255,53	256,75	1,72
	3,300	3,92	5127	Almaden M60-280W	280	14,00	B&B Power SF2200TL	2,2	1,65	23,04	209,00	127,02	260,97	222,57	1,78
	3,300	3,99	5287	Longi LR6-60-285M	285	14,00	B&B Power SF2200TL	2,2	1,64	22,89	139,60	85,37	219,32	230,95	1,81
	3,750	4,02	5025	Jinko Solar Cheetah HC60M 335	335	12,00	Schneider Xantrex GT 2,5-DE	2,5	1,69	20,25	159,00	94,23	228,18	248,17	1,61
	3,750	4,06	5071	Canadian Solar - CS6K-290MS	290	14,00	Schneider Xantrex GT 2,5-DE	2,5	1,64	22,92	177,00	108,14	242,08	221,29	1,62
	3,750	4,2	5757	Canadian Solar CS3K-300MS	300	14,00	Fronius Galvo 2.5-1	2,5	1,66	23,26	174,00	104,72	238,66	247,48	1,68

	3,750	4,2	5709	ECO DELTA ECO-300M-60 Black PERC	300	14,00	Fronius Galvo 2.5-1	2,5	1,64	22,92	157,30	96,10	230,05	249,14	1,68
	3,750	4,34	5842	Longi LR6-60-310M	310	14,00	Fronius Galvo 2.5-1	2,5	1,64	22,92	210,81	128,79	262,74	254,94	1,74
	3,750	4,48	6008	Trina Solar Honey Black TSM-DD06M	320	14,00	Fronius Galvo 2.5-1	2,5	1,70	23,87	179,00	105,00	238,94	251,73	1,79
	4,200	4,5	6136	Akcome SK6612M 375W	375	12,00	SolaX Power SL-TL2800	2,8	1,94	23,30	159,00	81,90	215,85	263,39	1,61
	4,050	4,68	5969	Sunrise SR-M672390HL	390	12,00	Sunways AT2700	2,7	2,01	24,14	183,06	90,98	224,93	247,22	1,73
	4,200	4,69	6255	Canadian Solar CS1H-MS335MB	335	14,00	SolaX Power SL-TL2800	2,8	1,69	23,61	223,00	132,23	266,18	264,93	1,68
	4,200	4,76	6339	LG NeON 340N1C-A5	340	14,00	SolaX Power SL-TL2800	2,8	1,71	23,98	279,09	162,93	296,87	264,33	1,70
	4,200	4,8	5639	Jinko Solar Cheetah HC72M 400	400	12,00	Riello UPS HP2800X	2,8	2,01	24,14	185,00	91,95	225,89	233,56	1,71
	4,500	4,8	6819	Candian Solar CS6K-300M	300	16,00	Fronius Galvo 3.0-1	3	1,64	26,19	203,00	124,02	257,97	260,38	1,60

	4,500	4,86	6589	Ja Solar JAM72S10	405	12,00	Ingeteam Ingecon Sun3TL	3	2,01	24,08	210,55	104,91	238,86	273,59	1,62
	4,500	5,18	6625	Sharp NUAH370	370	14,00	Fronius Primo 3.0-1	3	1,94	27,16	230,48	118,78	252,73	243,88	1,73
	4,500	5,32	6661	AXIPremium AC-380MH/72S 380Wp	380	14,00	Fronius Primo 3.0-1	3	1,98	27,78	235,00	118,45	252,39	239,81	1,77

ANNEX 7. TOTAL PV SYSTEM BUDGET: KITS+INSTALLATION/WHOLE BUDGET

TOTAL PV SYSTEM BUDGET				
	System Power [kWp]	**Company Name**	**Number of Modules**	**Total Price (€)**
KITS + INSTALLATION	1,98	Suministros de Sol	6	2375,00
	2,345	Revosolar	7	3506,00
	2,43	Suministros de Sol	9	2079,00
	2,5	AutoSolar	8	3442,70
	2,63	Solar Plak	11	3089,00
	2,68	Revosolar	8	3759,00
	2,97	Solar Plak	9	2514,13
	3	AutoSolar	9	3953,04
	3	AutoSolar	9	5193,41
	3	AutoSolar	9	4293,56
	3	AutoSolar	9	4715,32
	3	AutoSolar	9	4830,90
	3	MerkaSolar	12	4295,50
	3	TiendaSolar	8	2952,86
	3	DSP Solar	7	2745,00
	3,015	Revosolar	9	4331,00
	3,24	Suministros de Sol	12	2439,00
	3,3	MerkaSolar	10	4035,58
	3,3	TiendaSolar	12	2170,74
	3,3	Suministros de Sol	10	2795,00
	3,33	DSP Solar	9	2368,00

	3,35	Revosolar	10	4771,00
	3,36	Suministros de Sol	12	2870,00
	3,685	Revosolar	11	5070,00
	3,96	Solar Plak	12	3325,00
	4	AutoSolar	10	5091,20
	4	MerkaSolar	16	5314,14
	4	DSP Solar	10	3699,00
	4,025	Revosolar	12	5321,00
	4,29	TiendaSolar	13	3602,76
	4,355	Revosolar	13	5921,00
	4,62	Solar Plak	14	3832,00
	4,65	AutoSolar	15	5208,62
	4,69	Revosolar	14	6394,00
	4,8	AutoSolar	12	5575,62
	4,86	Suministros de Sol	18	3320,00
	4,96	AutoSolar	16	5827,13
	5,025	Revosolar	15	6350,00
	5,1	AutoSolar	15	5891,57
	5,28	Solar Plak	16	4065,00
Whole Budget	3,02	Cero Grados Sur	9	7250,00
	3,2	Cobaltiq Group	8	5808,00
	4,08	Otovo	14	6780,00
	4,6	Albasolar	14	6072,00
	3,06	AutoSolar	9	4360,00
	2,8	Atersa	9	5350,00
	2,52	Escala Solar	8	5489,00
	3,35	Soty Solar	10	6000,00
	3,36	Sol Sureste	12	5640,00

ANNEX 8. FOUR WEEKS COMSUMPTION PROFILE COMPARISON