UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Eléctrica

OWN-CONSUMPTION PV-SYSTEM FOR A COFFEE SHOP

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Valladolid, julio 2018

Table of Contents

List of figures

List of tables

NOMENCLATURE

PV	Photovoltaic
AC	Alternating Current
DC	Direct Current
kW	Kilowatt
MW	Megawatt
GW	Gigawatt
kWh	Kilowatt hour
kWp	Kilowatt peak
MWp	Megawatt peak
V	Voltage
A	Amperes
STC	Standard Test Conditions
DMS	Degrees, Minutes and Seconds
MPPT	Maximum Power Point Tracking
IRENA	International Renewable Energy Agency
EPIA	European Photovoltaic Industry Association

Abstract

Solar energy is becoming popular for building integrated applications. Based on this, the idea of my thesis is to design of an own-consumption photovoltaic system for a coffee shop located in Valladolid, Spain. Grid connected photovoltaic system is simulated using the PVsyst V6.62 software. There will be a comparison among numerous of simulations to find the most ideal power for the coffee shop and the optimal tilt for the PV modules in order to bring back the maximum savings for the owner. In summary, the coffee shop consumes approximately 99116 kWh per year. The user's need is covered by both the PV system and the grid. In one year, the PV system will generate 57.7 MWh, including 45.3 MWh is supplied to the user and 12.3 MWh is the excess energy will be injected to the grid. The lack of energy is taken from the grid with 53.8 MWh. The PV system comprises 96 PV modules, together with one triphased inverter connected to a grid. Performance ratio of the system is about 87.07% due to several losses from irradiation, PV modules, inverter, wirings, etc. The economical evaluation, the pros and cons when using the own-consumption photovoltaic system is also suggested in this study.

1. INTRODUCTION

1.1. Renewable Energy

As the world progresses towards sustainability, our attention has turned to the eternal sources of green energy surging around us in nature – such as sunlight, wind, rain, tides, waves, and geothermal heat [9]. According to renewable capacity statistics report of the International Renewable Energy Agency (IRENA), at the end of 2017, global renewable generation capacity amounted to 2,179 GW. Hydro accounted for the largest share of the global total, with an installed capacity of 1,152 GW. Wind and solar energy accounted for most of the remainder, with capacities of 514 GW and 397 GW respectively. Other renewables included 109 GW of bioenergy, 13 GW of geothermal energy and 500 MW of marine energy (tide, wave and ocean energy) [6].

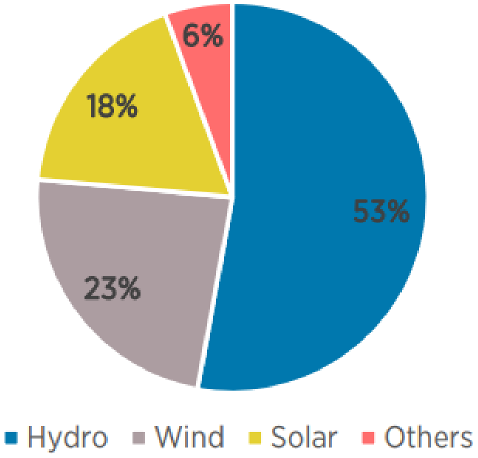


Figure 1. Renewable generation capacity by energy source

During 2017, renewable generation capacity increased by 167 GW, as shown in figure 2. Solar energy took first place with a capacity increase of 94 GW, followed by wind energy with an increase of 47 GW. Hydropower and bioenergy capacities increased by 21 GW and 5 GW, respectively. Geothermal energy increased by just under 1 GW [6].

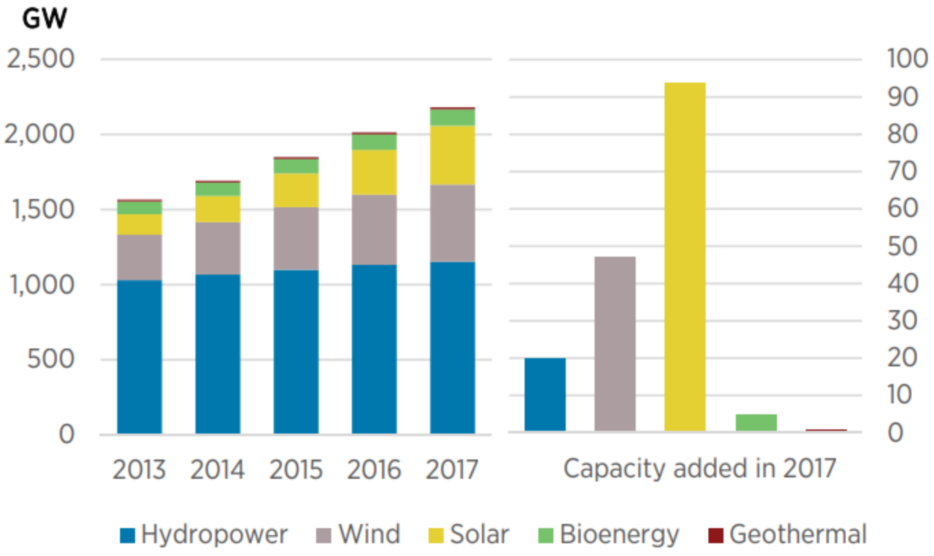


Figure 2. Capacity growth among renewable energies from 2013 to 2017

1.2. Solar Energy

Solar energy is the most readily available form of energy. Radiant light and heat from the sun that is harnessed using technologies such as solar heating, photovoltaics, concentrated solar power, concentrator photovoltaics, solar architecture and artificial photosynthesis [4]. Depending on how they capture and convert it into solar power, its technologies are characterized as either active or passive. The use of photovoltaic systems, concentrated solar power and solar water heating are consider as active solar techniques to harness the energy. On the other hand, orienting a building to the sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air are included in passive solar techniques. There are huge benefits in developing inexhaustible, affordable and clean solar energy technologies. Solar energy as an inexhaustible, indigenous and mostly import-independent resource has several advantages. These include enhanced sustainability, reduced pollution, lowered the costs of mitigating global warming and fossil fuel.

Solar energy in Spain

Spain is one of the top ten countries by solar photovoltaics installed capacity and the first country for concentrated solar power in the world. The solar market in Spain accounted for nearly 5% of the global PV market. In recent years the growth has slowed down significantly compared to rest of Europe. This decrease in growth is blamed for the end of all subsidies to solar energy in 2012 as a result of a wider economic review by the Spanish government. According to the European Photovoltaic Industry Association (EPIA), Spain's national target for solar capacity is 8,367 MW by 2020.

With more than 5GW already installed, the EPIA estimates that Spain only needs to increase 400MW per year to reach the necessary target. The EPIA also estimates that Spain should be able to add over 1500 MW of solar energy every year. As indicated by IRENA, Spain has an objective to meet 3% of total energy demand from solar by 2020. The report goes to say that Spain has a target to generate 38% of its electricity from renewable energy by 2020. However, by 2011, Spain already surpassed that target and more than 40% of its electricity was being generated through renewable energy in that year.

Spain has one of the highest levels of solar irradiance in Europe. With some regions receiving 2000 kWh per square metre annually, Southern Spain receives sunlight equivalent to Northern Africa making this part of the country particularly suitable PV deployment. According to EPIA, ground mounted solar farms account for about 80% of the total Spanish solar market and the rest of solar capacity is built for commercial and industrial use. Spain's residential solar market is only about 1% of the national solar market.

Castilla La Mancha is the largest regional market with about 1000 MW solar capacity installed, Andalucia is the second largest with over 800 MW. Other regions which have significant amount of solar installations include Castilla y Leon, La Comunidad Valenciana, Extremadura and Murcia. All four of these regions have more than 300 MW of installed capacity each [11].

1.3. Photovoltaic system

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaics. Components of a PV system are required depends on whether the system is connected to the electricity grid or whether it is designed as a stand-alone system [1]. The most important components are:

A mounting structure is used to fix the modules and to direct them towards the sun.

Energy storage is a vital part of stand-alone systems because it assures that the system can deliver electricity during the night and in periods of bad weather. Usually, batteries are used as energy storage units.

DC-DC converters are used to convert the module output, which will have a variable voltage depending on the time of the day and the weather conditions, to a fixed voltage output that e. g. can be used to charge a battery or that is used as input for an inverter in a grid-connected system.

Inverters are used in grid-connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid.

Cables are used to connect the different components of the PV system with each other and to the electrical load. It is important to choose cables of sufficient thickness in order to minimize resistive losses.

Even though not a part of the PV system itself, *the electric load*, i.e. all the electric appliances that are connected to it have to be taken into account during the planning phase. Further, it has to be considered whether the loads are AC or DC loads. The different components of a PV system are schematically presented in figure 3.

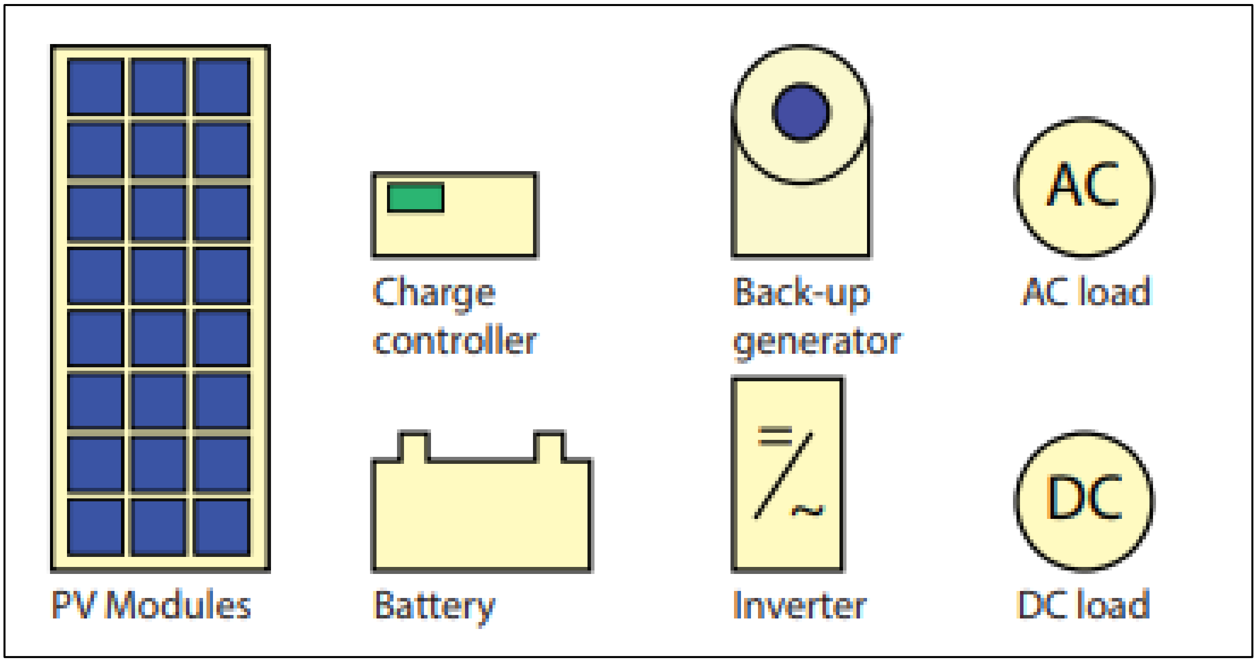


Figure 3. A schematic of the different components of a PV

1.4. Type of PV systems

Depending on the system configuration, we can distinguish three main types of PV systems: stand-alone, grid-connected, and hybrid. The basic PV system principles and elements remain the same. Systems are adapted to meet particular requirements by varying the type and quantity of the basic elements. A modular system design allows easy expansion, when power demands change [1].

Stand-alone PV System

Stand-alone systems, for an energetic point of view, are isolated from the rest of the world, therefore, they can be used for locations that are not fitted with an electricity distribution system. Stand-alone systems may depend only on solar power. The fundamental parts of these systems are PV panel, regulator, battery bank, inverter and load (DC or/and AC). The function of regulator is to switch off the PV modules when battery is fully charged and switch off the load to prevent the battery from being dischared below a certain limit. Besides, the battery must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather [1]. Figure 4 shows schematically examples of stand-alone systems; (a) a simple DC PV system without a battery and (b) a large PV system with both DC and AC loads.

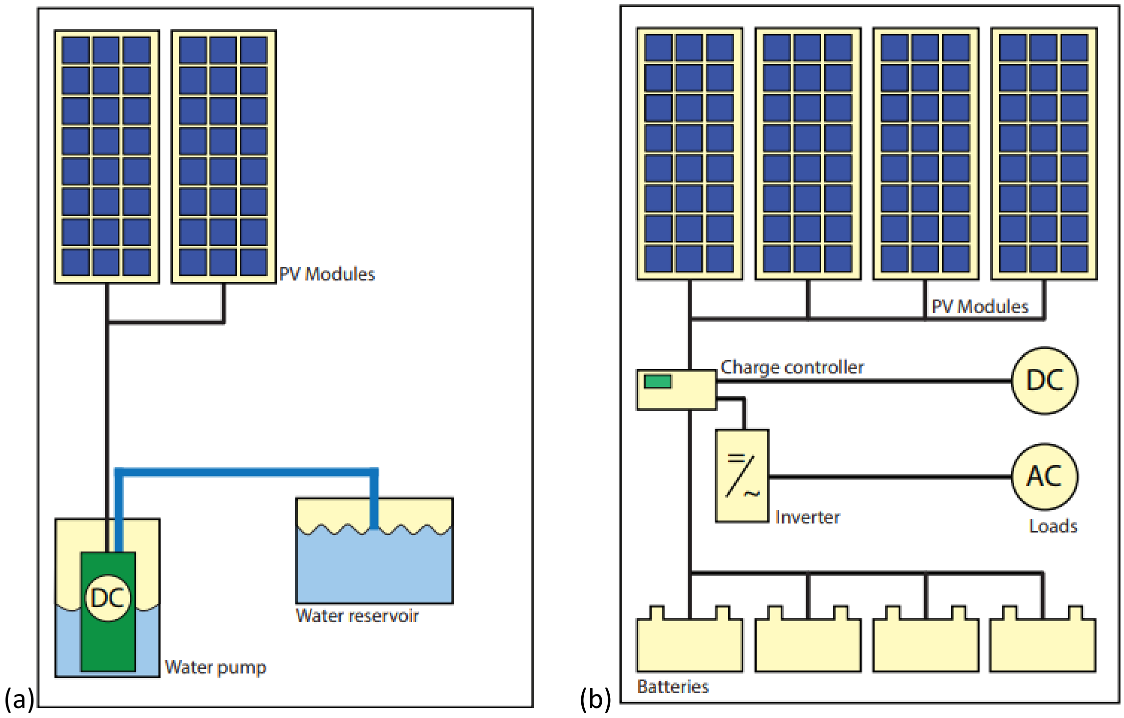


Figure 4. Schematic representation of (a) a simple DC PV system to power a water pump with no energy storage and (b) a complex PV system including batteries, power conditioners, and both DC and AC loads.

Grid-connected PV system

Grid-connected PV system is electricity generating solar PV system that is connected to the utility grid, they are becoming popular for building integrated applications. This system is made up of PV panel, inverter, grid and protections (DC and AC). As illustrated in figure 5, energy gathered by photovoltaic solar panels, intended for delivery to a power grid via an inverter, which convert the DC input voltage from the PV to AC voltage for the grid [1].

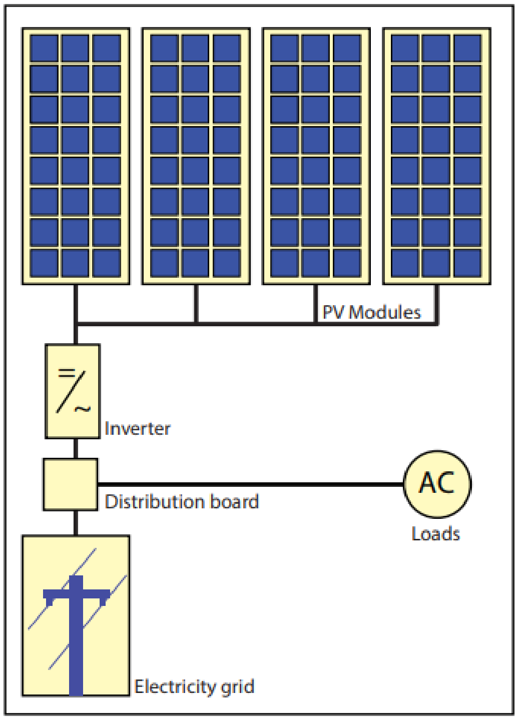


Figure 5. Schematic representation of a grid-connected PV

In small systems as they are installed in residential homes, the inverter is connected to the distribution board, from where the PV-generated power is transferred into the electricity grid or to AC appliances in the house. These systems do not need the batteries because the grid acts as a buffer into that an oversupply of PV electricity is transported while the grid also supplies the house with electricity in times of insufficient PV power generation. Large PV fields act as power stations from that all the generated PV electricity is directly transported to the electricity grid. They can reach peak powers of up to several hundreds of MWp [1].

Own-consumption PV systems

Own-consumption is a type of the combination between stand-alone PV system and grid-connected PV systems. The main goal of own-consumption PV systems is to supply energy to the load. Energy that your PV system produces will go first into your home to power any electrical devices which are running. If your solar system produces more energy than your household can consume at a given moment (e.g. if you're not home), the excess solar is automatically sent back into the grid [3]. On the contrary, the lack energy will be taken from the grid and you have to purchase for that energy to the electricity retailer. The fundamental parts of these systems are PV panel, inverter, protections (DC and AC), grid and load.

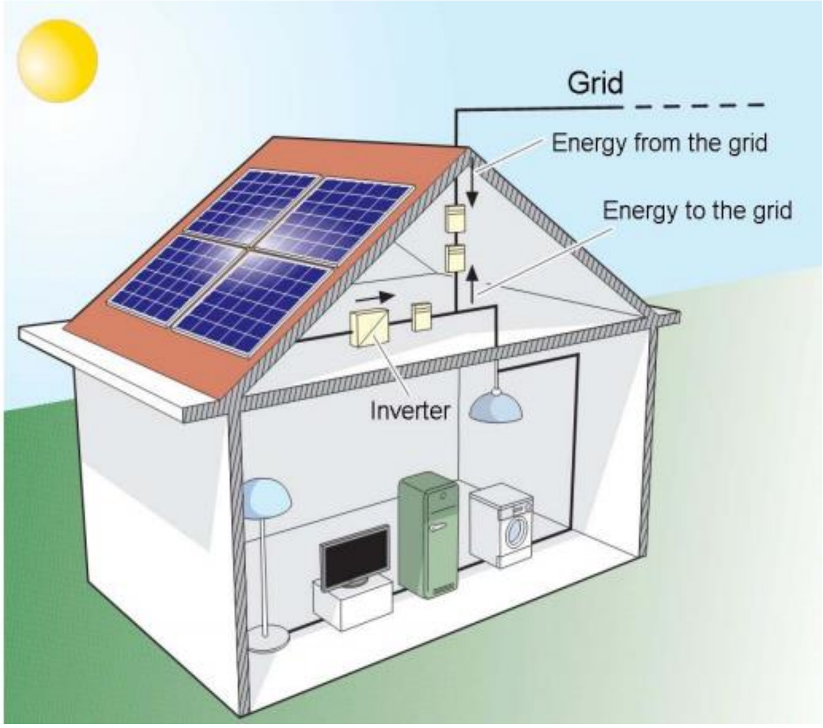


Figure 6. Schematic of own-consumption PV system

Hybrid systems

A hybrid system is the combination of PV modules and a complementary method of electricity generation such as a diesel, gas or wind generator. In order to optimize the different methods of electricity generation, hybrid systems typically require more sophisticated controls than stand-alone or grid-connected PV systems. By having other sources to charge your battery bank you can be assured that during bad weather for a significant amount of time it will not discharge your batteries beyond their desired capacity. For example, in the case of an PV/diesel system, the diesel engine must be started when the battery reaches a given discharge level and stopped again when battery reaches an adequate state of charge. The back-up generator can be used to recharge batteries only or to supply the load as well [1].

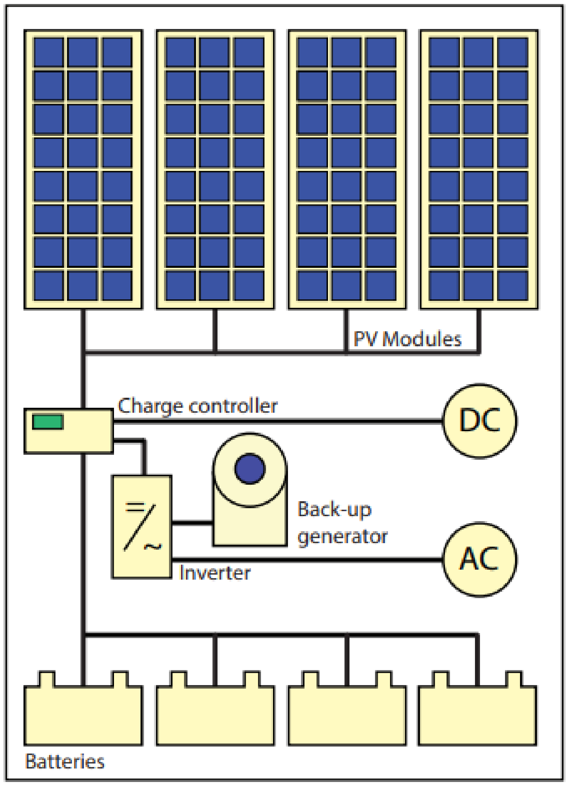


Figure 7. Schematic representation of a hybrid PV system that has a diesel generator as alternative electricity source

2. OBJECTIVE

2.1. Objective

The aim of this project is to size an own-consumption PV system for a coffee shop located in Valladolid. As Spain is one of the European countries with the most hours of sunshine, the shop can take advantages of the PV system since nearly all the appliances in the coffee shop consume most energy during the day. This coffee shop is based on Granier patisserie shop in Valladolid. It opens from 8:00.a.m to 22:00 p.m from Monday to Friday and from 8:00.a.m to 14:00.p.m on the weekend.

To do the sizing, own-consumption is going to be the master key since as less electricity we will be sold to the grid, as better will be for the shop economy. Assuming that the area to design this PV system is unlimited, this coffee shop is in the corner of the big building, hence, we can use the top of the building to place the PV panels.

2.2. Limitation

The data achieved to do the simulations is related to the consumption of the coffee in this thesis maybe doesn’t match perfectly with the restaurant consumption in reality. Anyway is only an approximation based on the observation of appliances in a coffee shop and it is supposed to be enough to this issue.

Achieving the meteorological data from another source different that the one PVSYST provide can give as some differences about the real measures. Is this case, the data source is from PVGIS and not from any meteorological station located in the surroundings. Finally, the simulations carried out through PVSYST are quite different from the ones that we could obtain in the reality due to limitations of the program, and certain approximations within it.

3. METHODOLOGY

3.1. Location

The coffee shop is located in Valladolid, a province of Northwest, Spain, in the central part of the autonomous community of Castilla y León. The DMS latitude and longitude coordinates for Valladolid are 41°39'36" North, 4°43'5" West and 704m above sea level.

Figure 8. Location of the systems study

3.2. User’s Loads

The electrical appliances in a coffee shop including:

Table 1. User's loads of the coffee shop

No.	Appliances	Number of devices	Power (W)
1	LED	30	7
2	Touchscreen Pos Computer	1	55
3	DELL Inspiron 3268 Desktop PC	1	150
4	Receipt machine	1	58
5	Telephone	1	9
6	Sound system EIS HST-540-2YCT	4	50
7	Camera surveillance	4	4
8	Air-conditioner Fujitsu	1	10000
9	Air conditioner Techna	1	316
10	Mobile charger	2	10
11	Laptop charger	2	65
12	Wifi modem	1	24
13	Vaccum cleaner	1	1600
14	Coffee blender	1	100
15	Coffee maker	1	2200

16	Blender	1	1800
17	Electricity hand whisk	1	180
18	Hot chocolate machine HC02A	1	1680
19	Microwave	2	800
20	Infrico served counter	1	1340
21	Infrico BMGN 1470F	1	550
22	Infrico AGB 701 BT CR	2	1402

These appliances operate depend on each season for 52 weeks in one years. Assuming this PV systems design is for the year 2018, the winter begins from week 1 to week 20, followed by the summer starts from week 21 to week 44, then the winter comes back again from week 45 to week 52. We also have specific holidays on January 1st (New Year's day) and on May 1st (International worker’s day). The three long breaks is on Easter holiday (week 14), summer holiday (week 32) and Christmas holiday (week 52). The difference between summer and winter is the air-conditioner is turned off in the winter while all the appliances mentioned above are used in the summer. However, several devices always on even in holidays are telephone, camera surveillance, the three Infrico refrigerators.

3.3. PVsyst

PVsyst V6.62 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid PV systems, and includes extensive meteo and PV systems components databases, as well as general solar energy tools. [3] The PVsyst software allows its user to accurately analyze different configurations and to evaluate the results and identify the best possible solution. There are four main parts of the program:

“Preliminary design” provides a quick evaluation of the potentials and possible constraints of a project in a given situation.

“Project design” is the main part of the software and is used for the complete study of a project. It involves the choice of meteorological data, system design, shading studies, losses determination, and economic evaluation. The simulation is performed over a full year in hourly steps and provides a complete report and many additional results.

“Databases” includes the climatic data management which consists of monthly and hourly data, synthetic generation of hourly values and importing external data. The databases contain also the definitions of all the components involved in the PV installations like modules, inverters, batteries, etc.

“Tools” provides some additional tools to quickly estimate and visualize the behavior of a solar installation. It also contains a dedicated set of tools that allows measured data of existing solar installations to be imported for a close comparison to the simulation.

In this study, the “Grid- connected” system in the “Project design” part is chosen to size the own-consumption PV system for the coffee shop.

3.4. Description of the simulation

3.4.1. Site and Meteo

Although PVSYST has a large meteorological database to which we can add data from other stations, the locations we are going to study (Valladolid, Spain) are not available, so the data will be imported into the software meteo database.

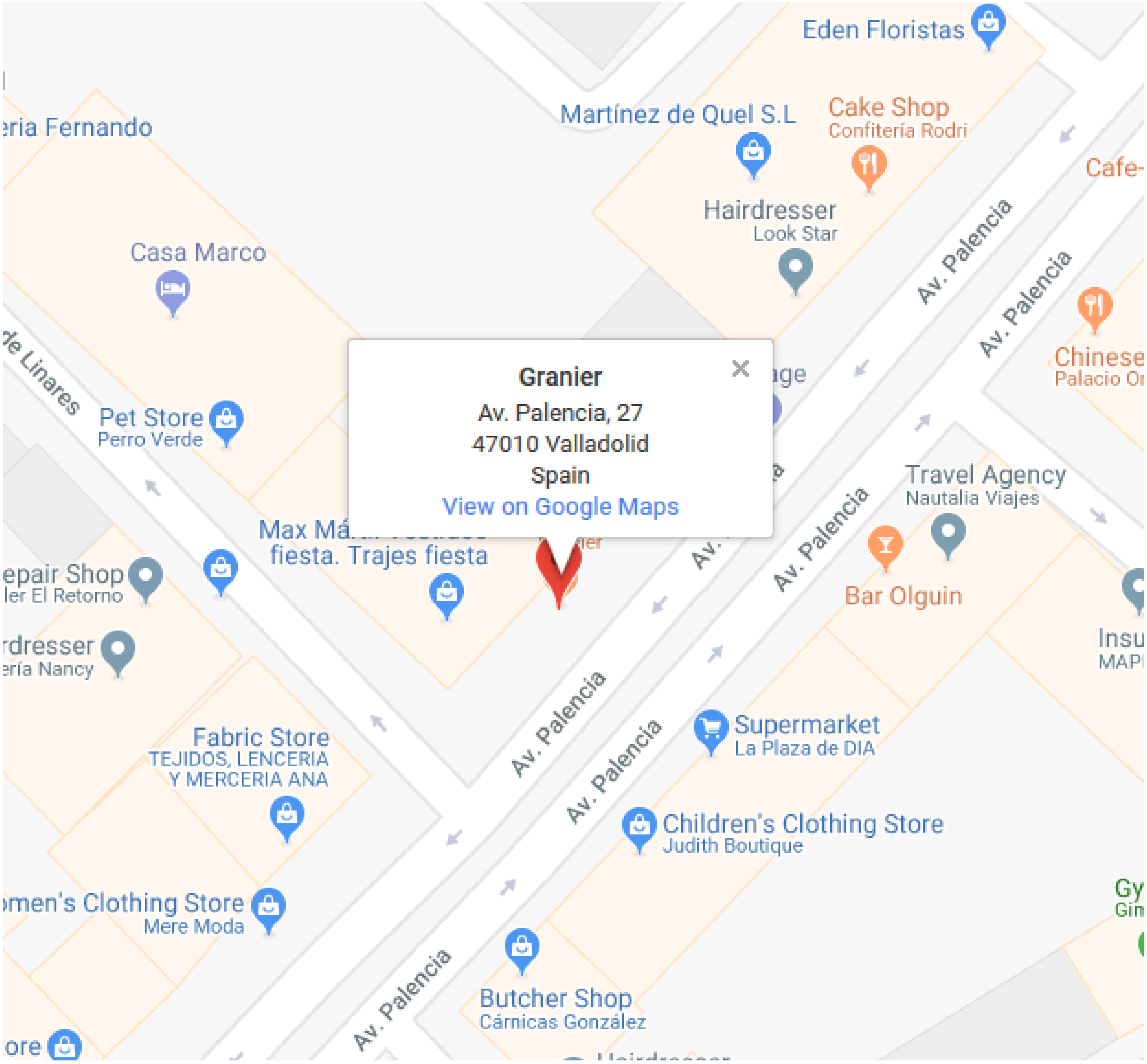


Figure 9. Location of the coffee shop

By going to PVGIS Europe page, we obtain a GoogleMap-like tool for choosing the exactly location we want. The coffee shop is located on Avenida De Palencia, Valladolid, Spain. It lies on 41°39'36" North, 4°43'5" West, 704 m above the sea. On the right dialog, select the "Monthly Radiation" tab, and check the following variables to be imported: Horizontal Irradiation, Dif. / Global radiation and Daily Average Temperature. The result is shown in table 2.

Table 2. PVGIS mean values for Valladolid

Month	**H_h**	**D/G**	**T_{24h}**
Jan	1730	0.55	4.2
Feb	2870	0.43	4.5
Mar	4340	0.43	7.8
Apr	5200	0.42	11.3
May	6420	0.37	14.8
Jun	7390	0.31	19.2
Jul	7780	0.23	22.8
Aug	6800	0.24	22.6
Sep	5190	0.29	18.7
Oct	3460	0.39	13.7
Nov	2120	0.48	8.1
Dec	1630	0.51	4.5
Year	4590	0.35	12.7

Hh: Irradiation horizontal plane (Wh/m2/day)

D/G: Ratio of diffuse to global irradiation (-)

T24h: 24 hour average of temperature (°C)

3.4.2. Orientation

The direction of the solar panels will face to the south. Normally, we will choose "yearly irradiation yield, then adjust the tilt until "Loss By Respect to Optimum" equal to 0.0% and the "Global on collector plane" is the most optimal. In this case, we first have the tilt 37° with highest "Global on collector plane" is 1877 kWh/m2.

However, my target is to design the own-consumption PV system that the energy taken from the grid will be at the lowest to reduce the money buying energy from electrical company. Hence, the optimal tilt of the solar panels must both provide the maximum output power and take as less electricity from the grid as possible over the year. Several tilts are going to be tested 15º, 20°, 25°, 30°, 35°, 45º, then we will compared the results with the first tilt 37°. The azimuth will be set at 0º and the modules are fixed so no tracking is used.

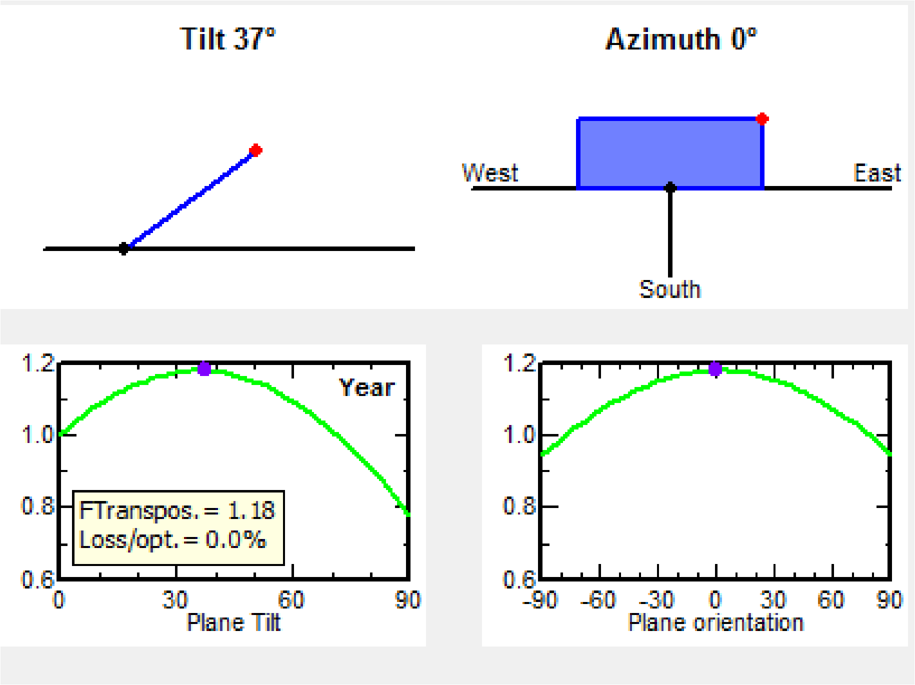


Figure 10. Orientation of the solar modules: tilt 37°

3.4.3. User's Needs

The energy requirements of the coffee shop during the year are necessary to carry out the simulations and properly analysis. Through the user's loads profile of the coffee shop, we can calculate the energy consumption of the coffee shop and how much energy we need to cover it in order to avoid oversizing or under sizing of the system because it can lead to increase the cost of the system [10]. The consumption of this restaurant has been calculated in all the hour of the year including 8760 values which is equivalent with 8760 hours over a year period: from January 1, 2018 to December 31, 2018. The hourly distribution of the energy load for a given day is shown in figure 11.

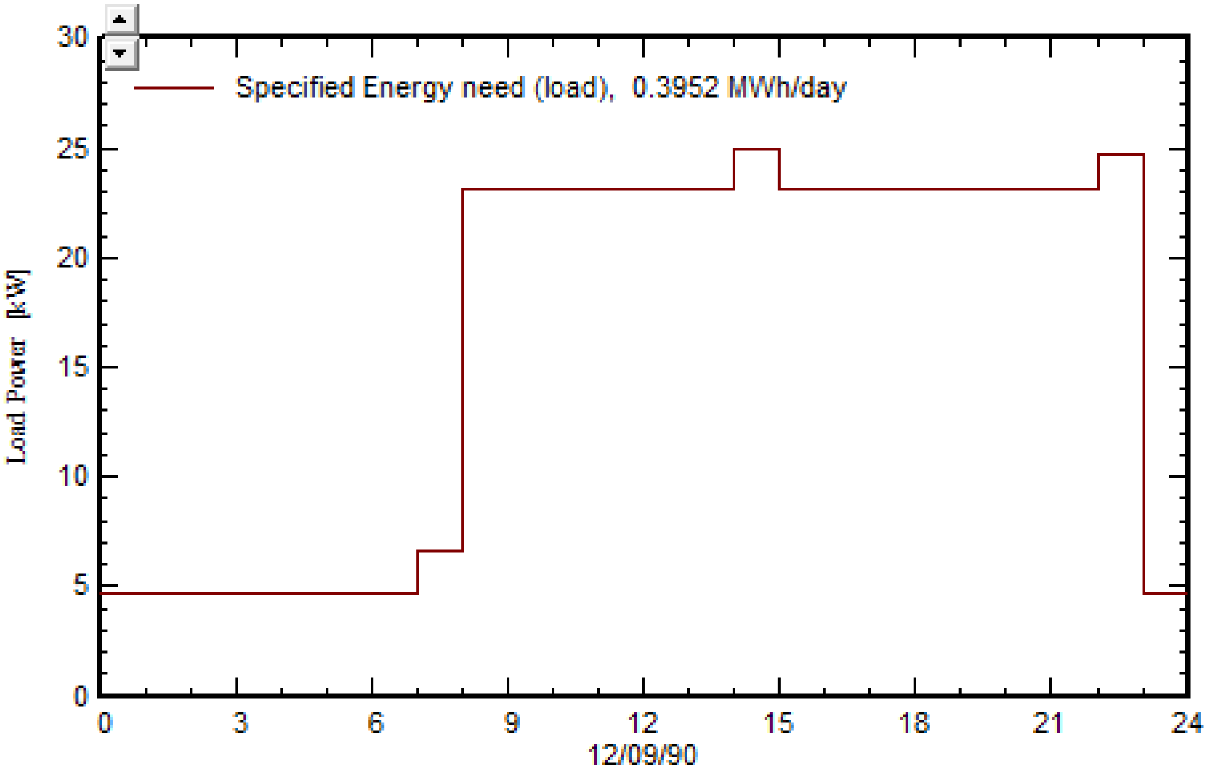


Figure 11. Hourly distribution of the energy need for a given day of the coffee shop

Table 3. Specified energy needed for each month of the coffee shop

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
6779	6185	6837	5844	8316	10497	10892	9371	10346	11043	7119	5889	99116

Table 3 illustrated the monthly distribution of the loads in the coffee shop need for in a year. In general, the annual electricity demand for this coffee shop is about 99116 kWh. It can be seen that October is the month this shop has the highest power consumption with 11043 kWh. In contrast, on December, this shop consumes the least energy, with only 5889 kWh. The energy consumption is bigger during the summer because of the two air-conditioner are used. From May to October are the duration the coffee shop needs the highest PV production.

3.4.4. Systems

- Enter planned power

The user’s needs must be covered, these energy must be provided by both the PV system and the grid. The PV energy is supplied to the user, the lack of energy is taken from the grid and the excess of energy is injected into the grid.

The greater the power, the less energy we have to buy from the electrical company but the more energy is injected into the grid also. The PV energy is cheaper than the electrical company energy. However, since the injected energy is given as a present to the electrical company, this energy is considered as a loss of money to the coffee shop. Therefore, we need to find the optimal power for our coffee shop, which means the power that produces the maximum savings in comparison with the situation of no PV system.

The "enter planned power" is the power that PV system provided for one hour. In this part, we will test the powers range from 5 kWp to 100 kWp, each one is the number divisible by 5. From there we will find the gap which can bring the maximum saving in order to continue to narrow the gap among these power.

After that, we draw the curve between "Savings" and "Power" to find the highest point of this curve, which shows the balancing between the power requirement and the economic reason.

- PV modules and Inverter

In the first case, I choose PV module and the inverter with small power. It is just a small step in order to vary the power of the system and to observe small changes among many enter planned powers. From there we can choose the ideal power for our system.

Table 4. First PV Module Specifications

PV modules	**Parameter**
Manufacturer	Gista
Model name	GS5 M36-105W
Technology used	Si-mono
Nominal Power	105 Wp
Module area	0.639 m2
Efficiency	16.43%

Table 5. First Inverter Specifications

Inverter	**Parameter**
Manufacture	Enecsys
Model	SMI-200 / VDE
MPP Voltage range	27-45V
Nominal PV Power	0.19 kW
Efficiency	94.37%

3.4.5. Horizon

This term simulates the horizon line letting us know how much useful radiation is available in the system. The red line that appears in the window corresponds to obstacles around the solar field meanwhile the blue line represents the auto-shading due to the modules. As bigger is the tilt, as bigger will be this line. In this project, no auto-shading will be considered.

3.4.6. Near Shadings

This term considers the shadow generated over the panels due to close objects like buildings, trees, and fence. In this case, there is no shadowing effect assumed.

3.5. Economical Evaluation

- Investment

Table 6. Cost of installation an own-consumption PV system

Components	**Money**
Panels	1.00 €/Wp
Inverter	0.70 €/Wp
Supports/ Integration	0.12 €/Wp
Settings, wiring,etc.	0.50€ / Wp
Gross investments (without taxes)	2.32 €/Wp

- Financing

Taxes (21%)	0.49 €/ Wp
Gross investment (including taxes)	2.81 €/ Wp
Total yearly cost	0.11 €/ WP

We have the cost of the installation connected to the network is 2320 €/kW. On average, a lifespan of a PV system is 25 years, now we calculate the money spent on buying PV system per year:

$$(1)\ \text{Money spent PV system/year} = \frac{\text{PV cost per kW} * \text{Enter planned power}}{25}$$

Since the result of the simulation of PVsyst only has 4 defined variables : Energy injected to grid, available energy at inverter output, Energy need of the user (Load) and energy supplied to the use, we have to calculate one more important missing is the energy taken from the grid.

Energy taken from grid = E load – E user

Consulted from the electrical company in the market, it cost about 0.15 € for each kWh we take from the grid. Assuming that if we have no energy to provide to the coffee shop and we have to buy total energy from the grid, the money we have to pay is:

$$(2)\ \text{Money spent buying energy electrical company} = \text{Electrical company kWh cost} \times \text{Energy taken from grid}$$

= 99116 * 0.15 = 14867.36 € (3)

From the enter planned powered 5kW and more, we continue to calculate the money spent on buying the PV system and the money to buy energy taken from the grid from the electrical company each year.

Finally, to find the money we can save for each year, take (3) - [(1)+(2)] to get the results:

$$\text{Savings} = 14867.36 - (\text{Money spent PV system/year} + \text{Money buying energy electrical company})$$

4. RESULT

In this chapter the simulations of several scenarios are made through the software PVSYST and some results are exposed. These results will determine the best power, the optimal tilt and the ideal PV module together with the inverter for the PV system we will establish for this thesis.

4.1. Optimal enter planned powered

Table 7. The optimum enter planned power for the PV system

Total						Economical evaluation		
PV Power kWp	E_Grid kW	EOutInv kW	E Load kW	E User kW	E taken grid kW	Money spent PV system/ year	Money spent buying energy electrical company	Savings
0	0.00	0.00	99115.75	0.00	99115.75	0.00	14867.36	0.00
5	0.00	7899.31	99115.75	7899.31	91216.44	464.00	13682.47	720.90
10	186.28	15798.62	99115.75	15612.34	83503.41	928.00	12525.51	1413.85
15	689.83	23697.95	99115.75	23008.11	76107.64	1392.00	11416.15	2059.22
20	1935.87	31268.11	99115.75	29332.25	69783.50	1856.00	10467.52	2543.84
25	4197.46	39167.43	99115.75	34969.97	64145.78	2320.00	9621.87	2925.49
30	7084.99	47066.72	99115.75	39981.75	59134.00	2784.00	8870.10	3213.26
34	10264.35	53320.36	99115.75	43056.01	56059.74	3155.20	8408.96	3303.20
34.5	10859.66	54307.76	99115.75	43448.10	55667.65	3201.60	8350.15	3315.61
35	11265.39	54966.07	99115.75	43700.67	55415.08	3248.00	8312.26	3307.10
35.5	11679.77	55624.31	99115.75	43944.55	55171.20	3294.40	8275.68	3297.28
36	12312.79	56611.72	99115.75	44298.94	54816.81	3340.80	8222.52	3304.04
37	13178.23	57928.29	99115.75	44750.05	54365.70	3433.60	8154.85	3278.91
38	14291.13	59573.96	99115.75	45282.83	53832.92	3526.40	8074.94	3266.02
39	15442.91	61219.67	99115.75	45776.77	53338.98	3619.20	8000.85	3247.32
40	16635.81	62865.37	99115.75	46229.56	52886.19	3712.00	7932.93	3222.43
45	22751.76	70764.67	99115.75	48012.91	51102.84	4176.00	7665.43	3025.94
50	29024.28	78334.85	99115.75	49310.56	49805.19	4640.00	7470.78	2756.58
55	35858.95	86234.16	99115.75	50375.20	48740.55	5104.00	7311.08	2452.28
60	42928.79	94133.48	99115.75	51204.70	47911.05	5568.00	7186.66	2112.71
65	50167.71	102032.80	99115.75	51865.09	47250.66	6032.00	7087.60	1747.76
70	57537.86	109932.08	99115.75	52394.22	46721.53	6496.00	7008.23	1363.13
75	64681.90	117502.28	99115.75	52820.38	46295.37	6960.00	6944.31	963.06
80	72209.03	125401.57	99115.75	53192.55	45923.20	7424.00	6888.48	554.88
85	79789.68	133300.91	99115.75	53511.22	45604.52	7888.00	6840.68	138.68
90	87406.12	141200.21	99115.75	53794.09	45321.66	8352.00	6798.25	-282.89
95	95048.49	149099.56	99115.75	54051.07	45064.68	8816.00	6759.70	-708.34
100	102398.12	156669.71	99115.75	54271.58	44844.16	9280.00	6726.62	-1139.26

E_Grid	Energy injected to grid	E user	Energy supplied to the user
E OutInv	Energy output of the inverter	E taken grid	Energy taken from grid
E Load	Energy need of the user (Load)		

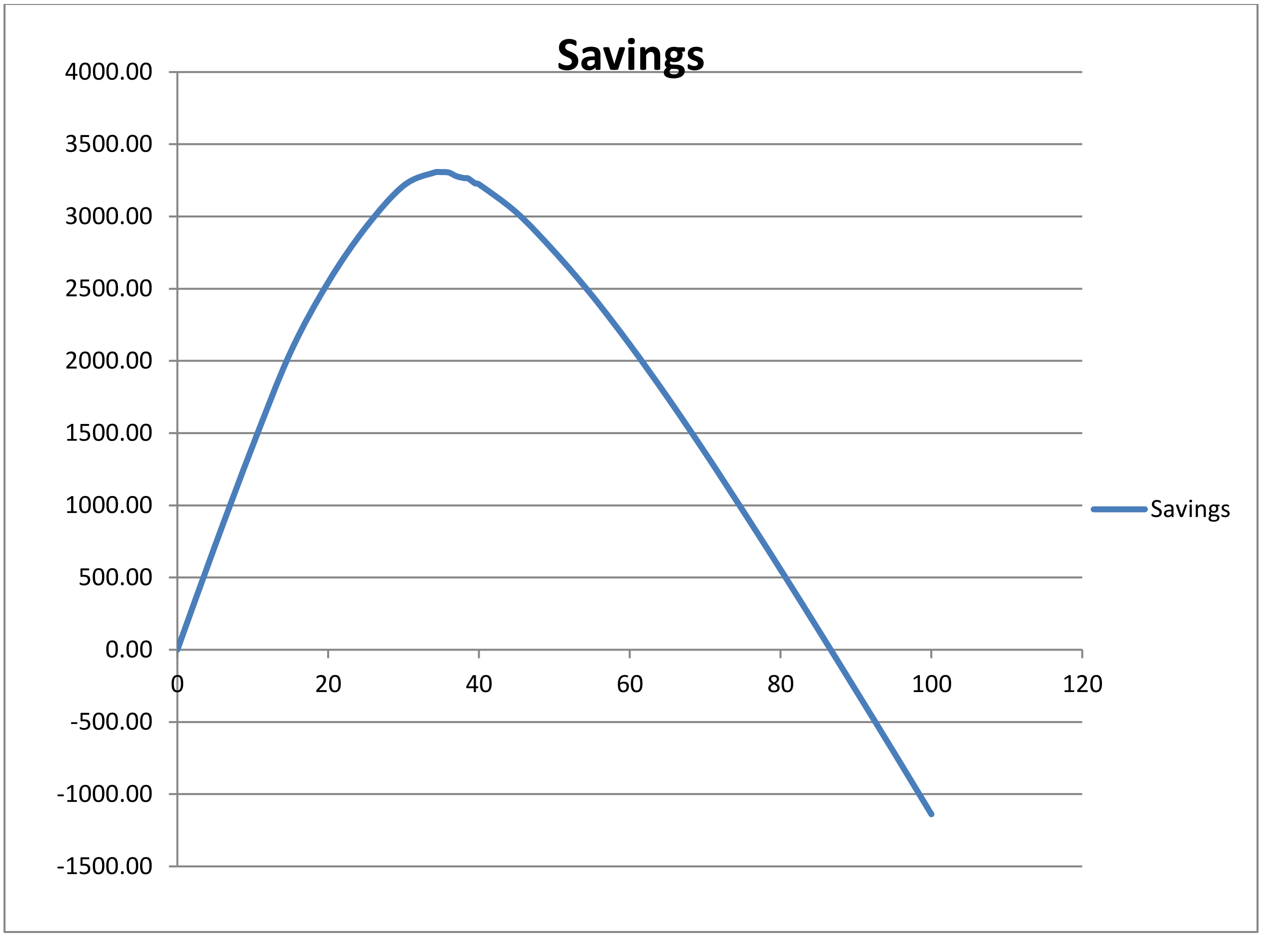


Figure 12. Chart shows the balance between "Powers" and "Savings"

The peak point between Power and Savings are 34.5 kWp. At this point, the energy it can provide can save the most money for the user with 3315.61 € every year. The savings will gradually decrease if we increase the “enter planned power” until 85 kW. If we continue to increase the power, the savings is a negative number.

4.2. Optimal tilt

Table 8. The optimum tilt for the PV system

Tilt	E_Grid kW	E OutInv kW	E Load kW	E User kW	E taken grid kW	Money spent PV system/ year	Money spent buying energy electrical company	Savings
15°	8969.82	52131.99	99115.75	43162.17	55953.58	3201.60	8393.04	3272.73
20°	9659.29	53179.00	99115.75	43519.70	55596.05	3201.60	8339.41	3326.36
25°	10215.91	53892.18	99115.75	43676.28	55439.46	3201.60	8315.92	3349.84
30°	10608.20	54279.18	99115.75	43670.97	55444.78	3201.60	8316.72	3349.04
37°	10859.66	54307.76	99115.75	43448.10	55667.65	3201.60	8350.15	3315.61
45°	10728.44	53627.37	99115.75	42898.94	56216.81	3201.60	8432.52	3233.24

E_Grid	Energy injected to grid
E OutInv	Energy output of the inverter
E Load	Energy need of the user (Load)
E user	Energy supplied to the user
E taken grid	Energy taken from grid

The optimal tilt must be the tilt that can meet the requirements for users and taken the least energy from grid to increase the saving. Take the enter planned powered 34.5 Wp, we continue the simulation with different tilts mentioned above: 15°,20°,25°,30°,45°. It can be seen from the table 8, the perfect tilt in this case is 25°. Compared to the tilt 37°, the energy we taken from grid now is decrease from 55667.65 to 55439.46. Besides, the money saving is increasing from 3315.61for tilt 37° to 3349.84 for tilt 25°.

4.3. Choosing PV modules and inverter

There are some weaknesses of the first PV module from Gista and inverter from Enecsys. First, the nominal PV power of 34.6 kWp need approximate 330 PV modules also requires a lot of area with 211 m2. Second, in the array design, the modules connecting in series is only possibly 2, which is so much smaller than the number of strings in parallel is 165. It would be better if we can minimize the strings in parallel compare to the number of modules in series of the PV system in order to reduce the cables sections and the heating transfer among them. Finally, both the old PV module and the inverter do not have quite high efficiency.

Therefore, I choose the new PV panels with higher power with better efficiency. In terms of the inverter, I increase higher voltage range to decrease the current, results in reducing the size of the cables and also their price. Compare to the old choice, they have higher efficiency and requires the less number of PV modules and also the area to install the PV system.

- PV modules

The new PV module is selected for this study is from “SunPower” manufacturer, parameters of proposed module is given in the table 9.

Table 9. Final PV module specifications

Specification	**Parameter**
Manufacturer	SunPower
Model name	SPR- X22-360-COM
Technology used	Si-mono
Nominal Power	360.0 Wp
Vmpp	59.52 V
Impp	6.05 A
Module area	1.631m2
Efficiency	22.07%

- Inverter

When enter planned power is under 10kW, we can choose monophased inverter, on the contrary, if it is higher than 10kW, we should choose the inverter uses multi-MPPT feature. The inverter used for this study is a triphased inverter from “Kaco new energy”, the specification of the inverter is shown in the table 10.

Table 10. Final Inverter Specifications

Specification	**Parameter**
Manufacture	Kaco new energy
Model	Powador 36 TL3 XL
MPP Voltage range	200-800V
Nominal PV Power	30 kW
Maximum PV Power	37.5 kW
Output side (AC grid)	Triphased
Efficiency	98%

The nominal AC power of the inverter is 30kW and I had adjusted the number of MPPT inputs are 3 inputs. By default, PVsyst assumes that an inverter with 3 MPPT inputs behaves as 3 identical inverters of a third the power. That is, each MPPT input will have a "nominal power" of a third the power of the full inverter. In this case, an inverter of 30 kW with 3 MPPT will behave as to 3 independent inverters of 10kW.

4.4. Design the array

From the simulation 96 PV modules are required and for the placement of the modules we will need about 157 m2 area. The number of strings should ideally be a multiple of the number of MPPT inputs. Since I choose the inverter with 3MPPT inputs, the number of strings should be the number divisible by 3. In this case, I choose 12 strings, then the modules in series will be 96/12 = 8 modules. Figure 13 shows the block diagram of the PV system input. Since we have 3 MPPT inputs, we will connect each 4 strings of PV modules to one MPPT input of the inverter.

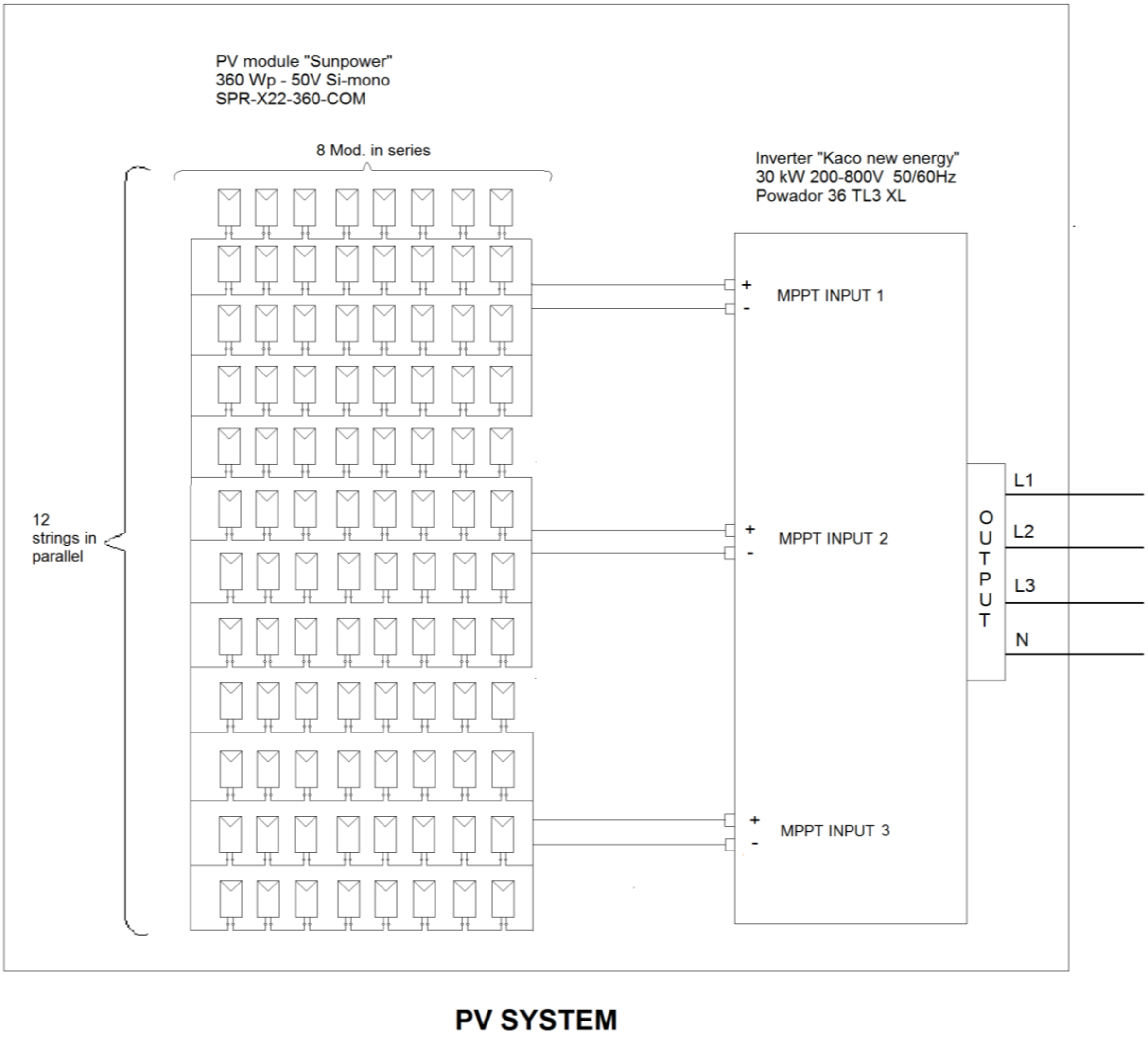


Figure 13. Block diagram of the PV system input

Figure 14 illustrates the diagram of the PV system output. An electricity meter box is a device that measures the amount of electric energy consumed by a coffee shop. They are typically calibrated in billing units, the most common one being the kilowatt hour (kWh). They are usually read once each billing period. Electric utilities use electric meters installed at customers' premises for billing purposes. However, the energy from the grid have to transfer in a long way to reach the meter box and it could cost us more money. Therefore, we will install it on the grid to reduce the cost.

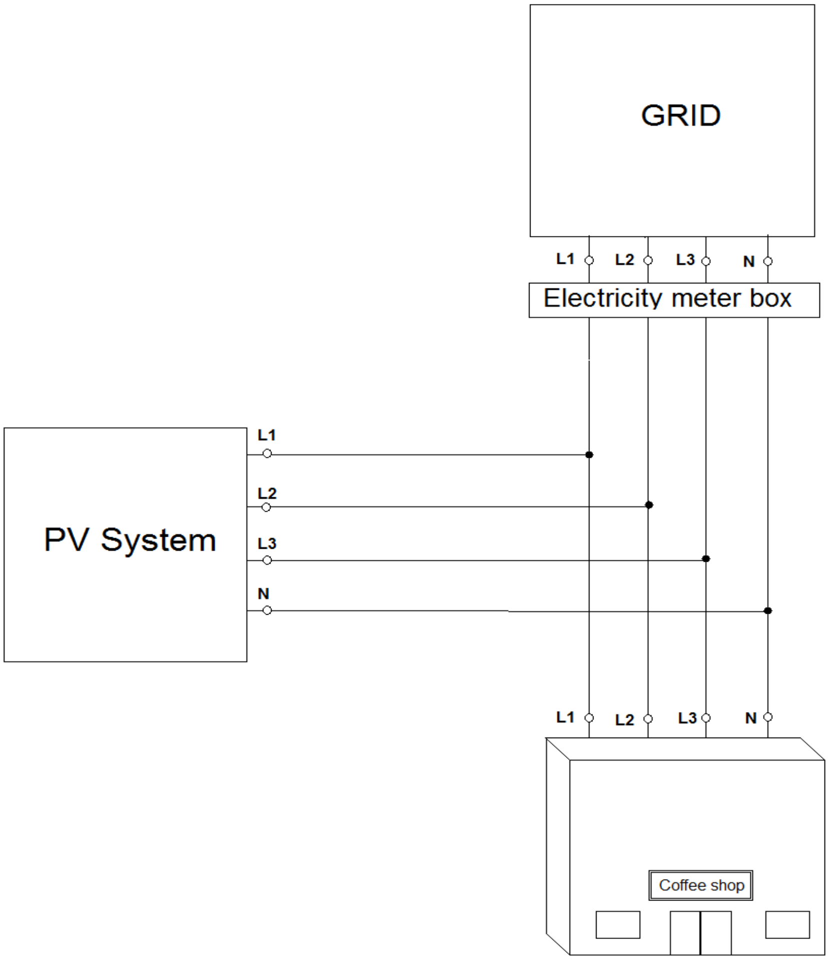


Figure 14. Block diagram of the PV system output

- Temperature Effect

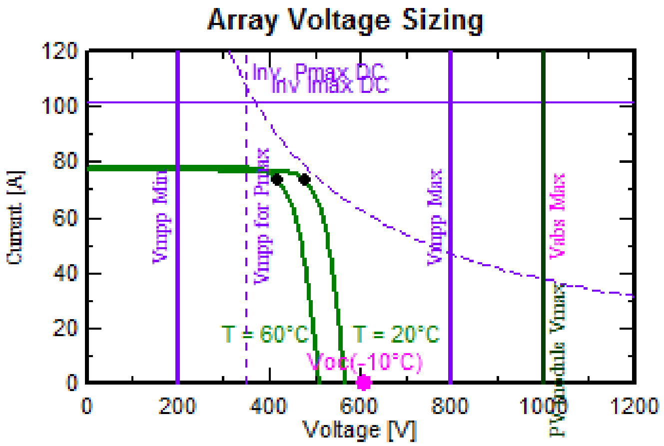


Figure 15. PV Array Voltage-Current Characteristics

The output of the PV system depends upon the received solar radiation and temperature. Figure 15 shows the voltage-current diagram of the photovoltaic module. At the 60°C temperature maximum power point voltage will be 420 V whereas at the 20°C temperature maximum point voltage will be 478 V.

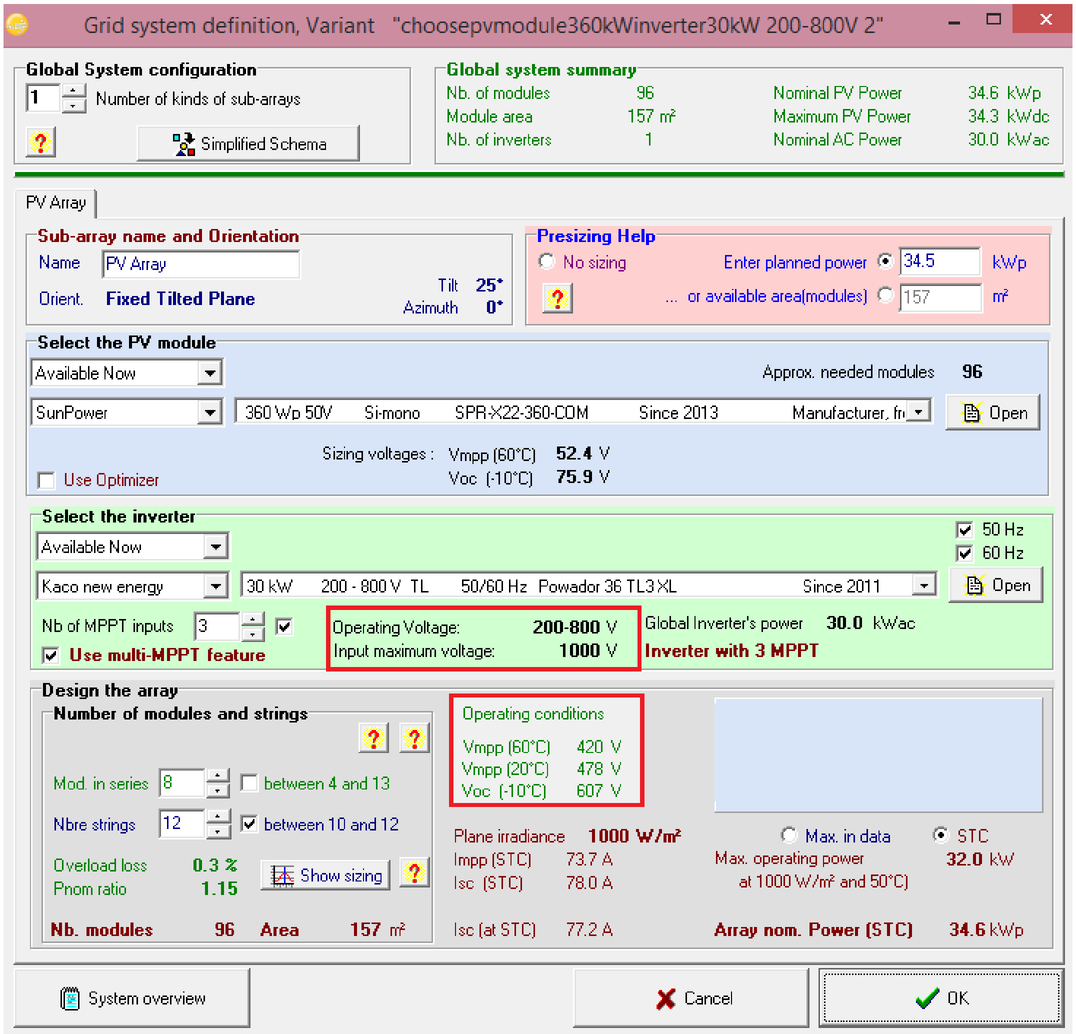
- Power Sizing Characteristics

Table 11. Power sizing characteristics

PV Array, Pnom (STC)	34.6 kWp
PV Array, Pmax (50°C)	34.3 kWdc
Inverters, Pnom (AC)	30.0 kWac

The inverters providers recommend a PNom array limit or a fixed Pnom ratio, usually of the order of 1.0 to 1.1. In practice these criteria lead to Pnom Ratio of the order of 1.1 to 1.2 for most well-oriented systems. In this case study:

Pnom Ratio = (Pnom(Array) / Pnom (Inv) = 34.6kWp /30kW(AC) = 1.15.



Grid system definition, Variant "choosepvmodule360kWinverter30kW 200-800V 2"

Global System configuration

1 Number of kinds of sub-arrays

Global system summary

Nb. of modules	96	Nominal PV Power	34.6 kWp
Module area	157 m²	Maximum PV Power	34.3 kWdc
Nb. of inverters	1	Nominal AC Power	30.0 kWac

Sub-array name and Orientation

Name: PV Array

Orient.: Fixed Tilted Plane — Tilt 25° — Azimuth 0°

Presizing Help

○ No sizing — Enter planned power ● 34.5 kWp — ... or available area(modules) ○ 157 m²

Select the PV module

Available Now — Approx. needed modules 96

SunPower — 360 Wp 50V Si-mono SPR-X22-360-COM Since 2013 Manufacturer, fr

☐ Use Optimizer

Sizing voltages : Vmpp (60°C) 52.4 V — Voc (-10°C) 75.9 V

Select the inverter

Available Now — ☑ 50 Hz ☑ 60 Hz

Kaco new energy — 30 kW 200 - 800 V TL 50/60 Hz Powador 36 TL3 XL Since 2011

Nb of MPPT inputs 3 ☑

☑ Use multi-MPPT feature

Operating Voltage: 200-800 V

Input maximum voltage: 1000 V

Global Inverter's power 30.0 kWac

Inverter with 3 MPPT

Design the array

Number of modules and strings

Mod. in series 8 ☐ between 4 and 13

Nbre strings 12 ☑ between 10 and 12

Overload loss 0.3 %

Pnom ratio 1.15

Nb. modules 96 — Area 157 m²

Operating conditions

Vmpp (60°C) 420 V

Vmpp (20°C) 478 V

Voc (-10°C) 607 V

Plane irradiance 1000 W/m²

Impp (STC) 73.7 A

Isc (STC) 78.0 A

Isc (at STC) 77.2 A

○ Max. in data ● STC

Max. operating power at 1000 W/m² and 50°C) 32.0 kW

Array nom. Power (STC) 34.6 kWp

Figure 16. Conditions in the array design

The choice for the number of modules in series/parallel meets the following requirements:

The minimum array voltage in worst temperature conditions (60°C) is under the inverter's voltage range for MPPT: 420V< 800V.

The maximum array voltage in worst temperature conditions (20°C) is not above the inverter's voltage range for MPPT: 478 >200V.

The maximum array voltage in open circuit (Voc at -10°C in Europe) does not exceed the absolute maximum voltage at the input of the inverter: 607V < 1000V.

The maximum array voltage in open circuit (Voc at -10°C in Europe) should not exceed the allowed system voltage specified for the PV module: 607V < 1000V.

4.5. Economical study

- **Comparison**

Table 12. Comparision the economy between the first and the second choice of PV module and inverter

PV module	**E_Grid**	**E OutInv**	**E Load**	**E User**	**E taken grid**	**Money spent PV system/ year**	**Money spent buying energy electrical company**	**Savings**
The 1st PV module and inverter	10215.91	53892.18	99115.75	43676.28	55439.46	3201.60	8315.92	3349.84
The 2nd PV module and inverter	12328.41	57664.40	99115.75	45336.00	53779.75	3201.60	8066.96	3598.80

E_Grid	Energy injected to grid
E OutInv	Energy output of the inverter
E Load	Energy need of the user (Load)
E user	Energy supplied to the user
E taken grid	Energy taken from grid

In comparison with the first choice of PV module and inverter, the second selection help decreasing the money we have to buy from electrical company, from 8315.92€ to 8066.96 € /year. Consequently, the savings is also increased from 3349.84 € to 3598.8 € /year.

Assuming that the price of electrical we have to buy annually does not increase in 25 years, the savings we can have in 25 years is 3598.8×25 = 89970 €.This price is not including any taxes.

- **Simulation results**

Table 13. Investment calculation of PV system

Components	Units	Money/unit	Total
PV modules (Pnom = 360W)	96	360€/ unit	34,560 €
Supports / Integration	96	43€/module	4,147 €
Inverter (1 unit of 30.0 kW)	1	24192€/unit	24,192 €
Settings, wirings			17,280 €
Gross investment (without taxes)			80,179 €

Table 14. Financial calculation of PV system

Taxes on investment (VAT)	Rate 21%	16,838 €
Gross investment (including taxes)		97,017 €
Annuities (Loan 0.0 % over 25 years)		3881 € /year
Total yearly cost		3881 € /year

In one year, the PV system can produce 57,700 kWh (including energy supplied to user and energy injected to grid), hence, the total energy it can produce in 25 years is:

25 × 57,700 MWh = 1,442,500 kWh.

If the VAT tax is not counted when buying PV system, the total investment in 25 years is 80,179 €, so the money for each kWh my PV system produces is:

80,179 / 1,442,500 = 0.555 € ⇔ 5.55 c€/ kWh.

This price is about a third of the price we buy electricity from electrical company (15 c€/ kWh).

Assuming no tax is counted, in one year, we have to pay:

Money spent PV system/ year + Savings

= 3201.60 +3598.80 = 6800.40 €/ year

From table 13, PV system cost in 25 years without VAT tax is 80179 €.

Therefore, the years we have to spent money is

$$\frac{80179}{6800.40} = 11.79 \text{ years}$$

⇨ The number of years we start to have benefit from PV system is:

25 – 11.79 = 13,21 years.

5. DISCUSSION

5.1. Balances and main results

Table 15. Balances and main results of PV system

	GlobHor kWh/m1	**DiffHor** kWh/m2	**T Amb** °C	**GlobInc** kWh/m2	**GlobEff** kWh/m2	**E Load** MWh	**E User** MWh	**E_Grid** MWh
January	53.6	29.50	4.20	78.6	77.6	6.78	2.025	0.475
February	80.4	34.60	4.50	109.7	108.6	6.18	2.414	1.040
March	134.5	57.90	7.80	162.3	160.6	6.84	3.310	1.700
April	156.0	65.50	11.30	169.7	167.5	5.84	3.007	2.138
May	199.0	73.60	14.80	202.3	199.6	8.32	4.223	1.827
June	221.7	68.70	19.20	217.2	214.4	10.50	5.698	0.696
July	241.2	55.50	22.80	241.4	238.5	10.89	6.129	0.859
August	210.8	50.60	22.60	228.2	225.6	9.37	5.054	1.573
September	155.7	45.20	18.70	188.1	186.1	10.35	5.000	0.574
October	107.3	41.80	13.70	144.8	143.3	11.04	4.256	0.172
November	63.6	30.50	8.10	94.4	93.4	7.12	2.401	0.566
December	50.5	25.80	4.50	79.6	78.7	5.89	1.820	0.708
Year	1674.3	579.20	12.73	1916.2	1894.00	99.12	45.336	12.328

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	E Load	Energy need of the user (Load)
T Amb	Ambient Temperature	E User	Energy supplied to the user
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid

Balances and main results are shown in table 15. The computed values of each variable mentioned in balances and main results were obtained in terms of monthly and yearly values. For the study location, annual global irradiance on horizontal plane is 1674.3 kWh/ m2. The global incident energy on annual basis on the collector without optical corrections and effective global irradiance after optical losses are 1916.2 kWh/ m2 and 1894 kWh/ m2, respectively. With this effective irradiance, 45.336 MWh from the output of the inverter are supplied to user annually and 12.328 MWh are injected to grid.

5.2.Normalized productions and Performance Ratio

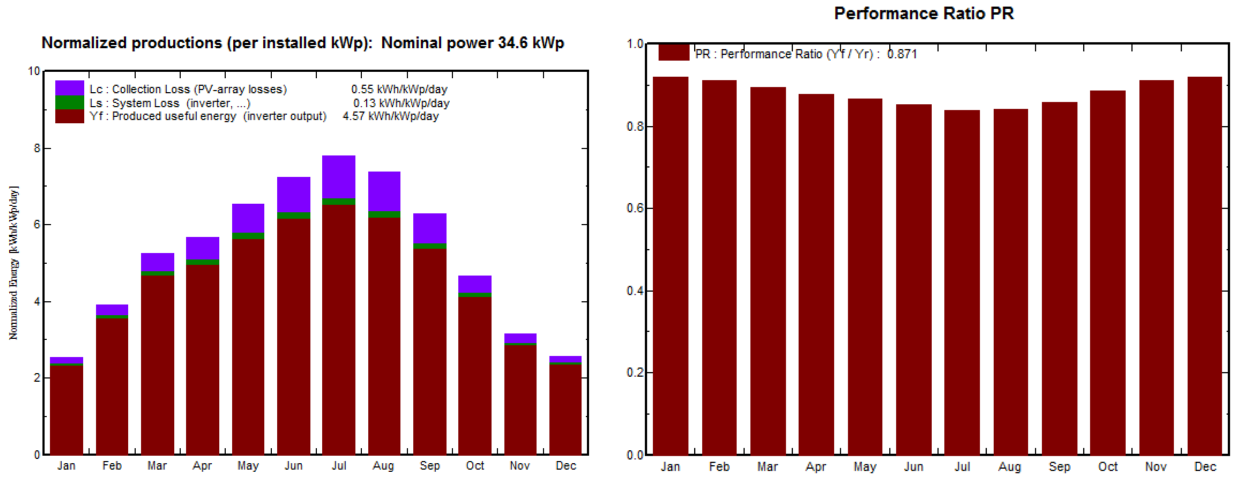


Figure 17. Normalized productions and Performance Ratio

Normalized productions are standardized variables for assessing the PV system performance, as illustrated in Figure 17. The collection losses by PV array (Lc) and the system loss due to the inverter (Ls) are 0.55 kWh/kWp/day and 0.13 kWh/kWp/day, respectively. Besides, Yf is the produced useful energy with 4.57 kWh/kWp/day.

The performance ratio informs you as to how energy efficient and reliable your PV plant is. The closer the PR value determined for a PV plant approaches 100 %, the more efficiently the respective PV plant is operating. In real life, a value of 100 % cannot be achieved, as unavoidable losses always arise with the operation of the PV plant (e.g. thermal loss due to heating of the PV modules). High-performance PV plants can however reach a performance ratio of up to 80 % [7].

$$\mathrm{PR} = \frac{\text{Measured plant output}}{\text{Nominal plant output}} = \frac{\text{Euser} + \text{Egrid}}{\text{GlobEff} \times \text{Area} \times \text{PVmodule efficiency}}$$

From the equation, we can calculate the PR all around the year is:

Measured plant output = 45.336 + 12.328 = 57.664 MWh

Nominal plant output = 1894× 157× 0.221 = 65.716 MWh

PR = $\frac{57.664}{65716}$ ×100 = 87.75 %

However, from the simulation it is found that performance ratio of the system is 87.07 %, this could be due to some losses (e.g. thermal losses) during the operation. In the summer, the performance ratio decreases although the produced useful energy is high because the ratio loss energy versus produced energy is greater than in winter months.

5.3. Arrow loss diagram

PV system is not able to convert 100% energy received from the solar radiation because of various losses. Figure 19 represents detailed losses occur in the proposed grid connected PV system. Global irradiance on horizontal plane is 1674 kWh/m2. After transposition includes the optical losses, the effective irradiance on collector is 1894 kWh/m2 multiply by the area 157 m2.

The efficiency of the PV array at STC is 22.10 %. After the PV conversion, the array nominal energy at standard testing conditions (STC) efficiency is 65.5 MWh. Biggest losses are done during PV array electric production with 9.7 % losses including PV loss due to irradiance level and temperature with 1.3% and 5.3%, respectively. Followed by 1.0 % loss due to module array mismatch, 1.0 % by module quality loss and 1.1 % is the Ohmic writing loss. After the various losses occur in this stage, annual array virtual energy at MPP is 59.4 MWh.

Available energy on annual basis at the inverter output facility is 57.7 MWh including 45.3MWh is supplied to the coffee shop and 12.3MWh is injected to grid. Two losses are found there, one is inverter loss during inverter operation with 2.7 % and inverter loss over nominal inv. power with 0.1 %.

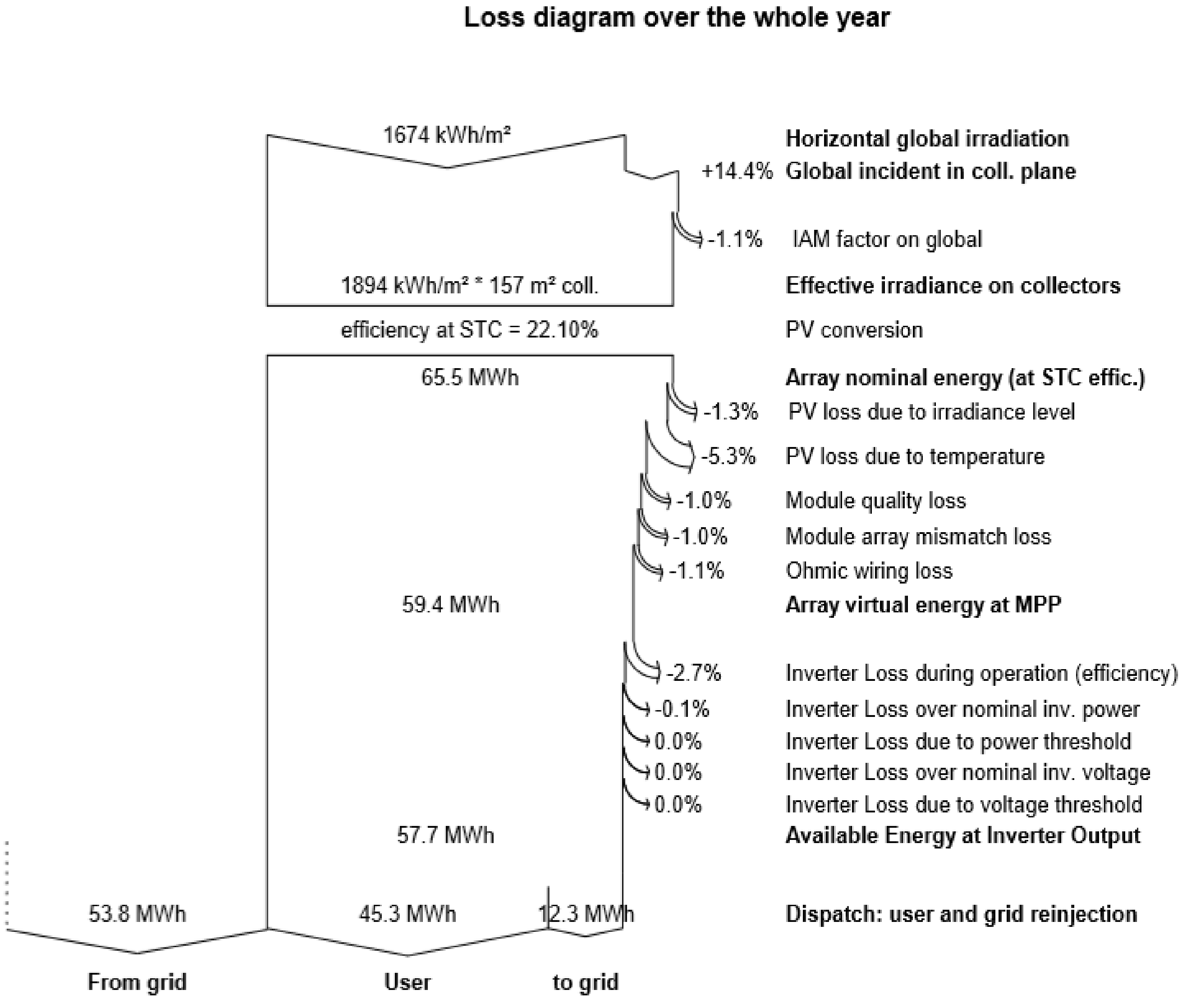


Figure 18. Arrow loss diagram over the whole year

5.4. Advantages

This part mentioned some important advantages when we use an own-consumption PV system. Firstly, a photovoltaic system provides green, renewable power by exploiting solar energy. We can use photovoltaic panels as an alternative energy source in place of electricity generated from conventional fossil fuels (e.g. gases). Consequently, the more we use PV panels (or other renewable energy technologies) to cover for our energy needs, the more we help reduce our impact to the environment by reducing CO2 emissions into the atmosphere [8].

By installing the own-consumption PV system, the coffee shop can saved CO2 Emissions:

$\boxed{\textbf{Carbon balance} = \textbf{E grid} \times \textbf{System Lifetime} \times \textbf{LCE Grid} - \textbf{LCE System}}$

= 57.7 MWh × 25 years × 287 g CO2/kWh – 61.0t CO2

= 306.669 t CO2

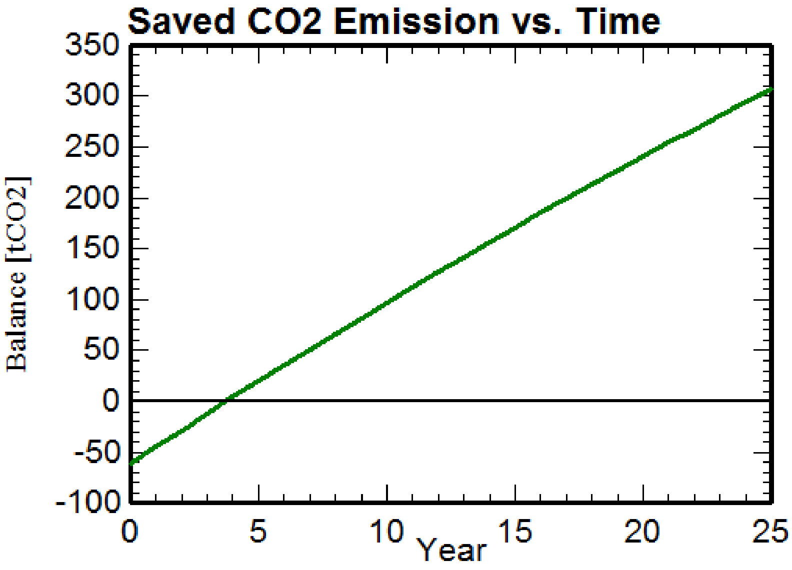


Figure 19. Chart shows CO2 emission savings in 25 years

The photovoltaic (PV) system not only provide clean energy but also operate autonomous without any noise generation since the panels do not incorporate any moving mechanical parts.

Secondly, an own-consumption photovoltaic system can cover our basic energy (electricity) needs for the user's own level, enables the user to reduce their electricity bill by consuming their self-produced energy first and then drawing additionally needed electricity from the utility grid.

The third benefit is the shop can take advantages of the PV system since most of the appliances in the coffee shop consume most energy during the day and since it is connected with a grid, we don't have to worry about storing energy for autonomous days.

Fourthly, photovoltaic (PV) panels have become very popular in the past years particularly in both home energy applications (domestic level) and small-scale power generation applications. Their high popularity has been driven on one hand by the ease of installation and use and, on the other hand, by reduction in PV costs (PV investment and installation) driven by industrial maturity of PV technologies [8].

Finally, using own-consumption PV systems can be ideal for distributed power generation. By maintaining relatively small power generation stations in a distributed power network, we can minimize energy losses in the network that caused by the long distance between power generation and power consumption points. By utilizing small photovoltaic PV power stations, we can achieve cost reductions on the power network from increased network efficiency and lower power losses; similarly, distributed small scale Photovoltaic (PV) stations will also lead to lower capital expenditure for the construction of power network lines [8].

5.5. Disadvantages

Perhaps the biggest disadvantage here is in 2015, the Spanish government approved a new national law requires self-consumption PV system owners to pay the same grid fees that all electricity consumers in Spain pay, plus a so-called “sun tax”.

Those with own-consumption PV systems over 10kW must pay for the whole power capacity installed (the power that you contracted to your electricity company, plus the power from your PV installation) and also another tax for the electricity that you generate and self-consume from your own PV installation. Hence, the “sun tax” is not an advantage for a coffee shop since our “enter planned power” is 34.5 kW. The law is retroactive meaning that all existing self-consumption PV installations need to comply with the new regulations otherwise they face an exceptionally high penalty fee of up to €60 million. Moreover, the fine doubles in the event of a radioactive leak from a nuclear plant [5]. However, assuming that there is no “sun tax” in our study, we just want to know how much savings the own-consumption PV system can have if there is no tax adapted.

Another drawback is although PV panels have no considerable maintenance or operating costs, they are fragile and can be damaged relatively easily. Additional insurance costs are therefore of ultimate importance to safeguard a PV investment.

Furthermore, in case of land-mounted PV panel installations, they require relatively large areas for deployment. Usually the land space is committed for this purpose for a period of 20 to 25 years, or even longer.

6. CONCLUSION

In conclusion, my main objective is to design an own-consumption photovoltaic system for a coffee shop located in Valladolid, Spain. Thanks to the help of the PVSYST V6.62 software, detailed system configuration, system output and system losses are determined in this study.

Through numerous tests, the optimal tilt for the PV modules is 25° and the best enter planned power for the PV system is 34.5 kWp. The PV system comprises 96 PV modules of 360Wp - 50V made of Si-mono from "SunPower" manufacturer, together with one triphased inverter of 30kW 200-800V from "Kaco new energy" manufacture. All the PV modules are arranged in 12 strings, with each string made up of 8 modules in series.

In one year, the coffee shop consumes approximately 99116 kWh. The PV system itself will generate 57.7 MWh, including 45.3 MWh is supplied to the user and 12.3 MWh is the excess energy will be injected to the grid. The lack of energy we will take it from the grid with 53.8 MWh per year. Performance ratio of the system is about 87.07% due to several losses from irradiation, PV modules, inverter, wirings, etc.

Assuming that there is no tax adapted and the price of electrical we have to buy annually will not increase in the next 25 years, the advantages if we install an own-consumption PV system still dominate the disadvantages. Since it provide clean – green energy and producing no noise at all. It can save up to 306.669 tons CO2 in 25 years. Moreover, this PV system can cover the basic energy needs for the coffee shop during the day and then help reducing the money buying energy from the grid in the night time. The money our PV system produces is 5.55 c€/ kWh, cheaper than the price we buy electricity from electrical company. The savings we can have in 25 years is 89970€ and after 12 years we can have the benefit. Finally, own-consumption PV system is especially appropriate for smart energy networks with distributed power generation.

7. ACKNOWLEDGEMENTS

Foremost, I would like to give thanks to my thesis advisors, Prof. Julián Manuel Pérez García for his continuous support of my Bachelor study and research. I want to thank you for your guidance throughout this project and for the opportunity I was given to conduct my final thesis at the University of Valladolid. My thesis could not have been successfully conducted without your dedicated help.

Last but not least, I would like to thank my family and all my friends for providing me motivation and encouragement throughout my semester at the University of Valladolid, despite of the distance. This accomplishment would not have been possible without them.

Thank you all.

Valladolid, 30th June, 2018.

Ninh Giang Le Ngoc.

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