GETTING STARTED. iHOGA 3.4.

Updated April 18, 2023

Several example projects are shown to illustrate how iHOGA works. ***You can find more information in the User's Manual*** (https://ihoga.unizar.es/en/descarga/)

This guide is designed to follow sequentially.

Users of the EDU version can perform all the steps up to section 28 (except section 26, version 3). From this section it is only possible to continue with the PRO+ version.

CONTENTS:

BEFORE STARTING TO WORK:

iHOGA needs to run:

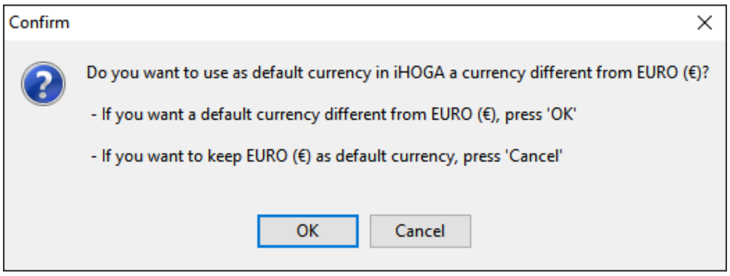
- Internet connection to check the license validity.

- A printer (physical or virtual) installed in the computer. This is necessary to print the reports. You can install a virtual pdf printer, for example the free doPDF (http://www.dopdf.com/es/)

1. Create a new project.

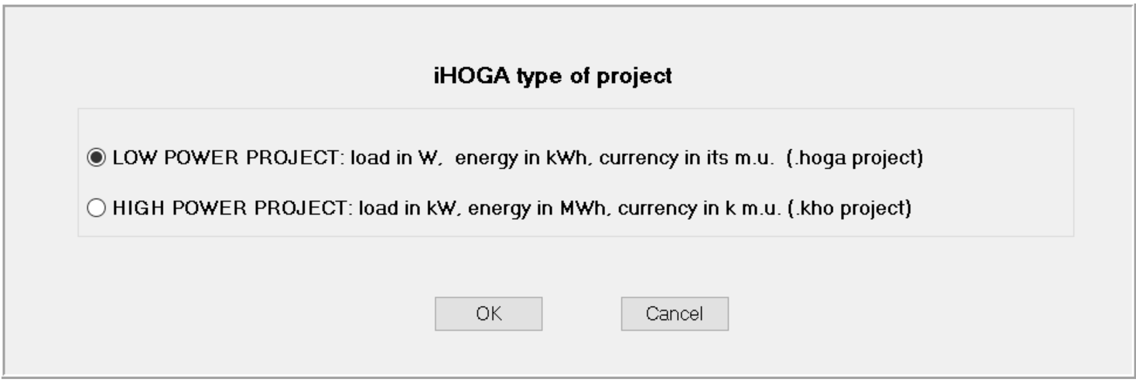
In the top menu, click **Project->New**.

The first time we create a project, iHOGA asks us if we want to change the default currency (which is EURO).



This starting guide is prepared with the EURO currency, so we have left the EURO as the default currency, by clicking "**Cancel**". However, if you prefer another currency you can click on "**OK**" and change the default currency to another by following the steps on section 3 of the user manual (https://ihoga.unizar.es/en/descarga/). In that case the economic results that will appear later in this guide (in €) will be different from yours (in another currency).

After selecting the default currency, the following window appears.



We can choose the type of project:

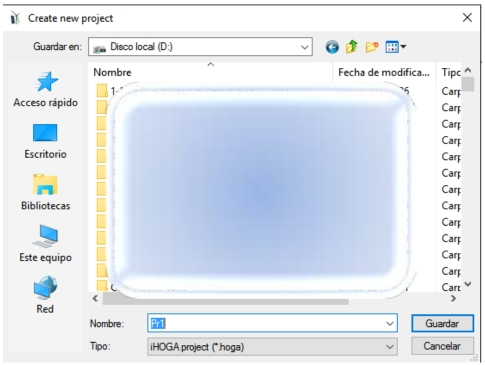
- **LOW POWER PROJECT**: in this case the load input values are in W, the results of the energy are shown in kWh and the default currency is shown as it is. The options are preselected for low power systems. The file extension of this type of project projects is **.hoga**.

- **HIGH POWER PROJECT**: in this case the load input values are in kW, the results of the energy are shown in MWh and the default currency is shown in kilo monetary unit (that is, in 1000 x the default monetary unit). The options are preselected for higher power systems. The file extension of this type of project projects is **.kho**. This kind of projects are allowed only in PRO+ version.

We choose **LOW POWER PROJECT** and then click **OK**.

Then a window appears where we must indicate where is the folder of the project and its name.

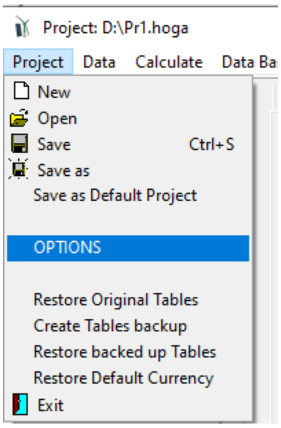
<u>The full path from the root directory to the file .hoga or .kho (depending the type of project) that will be created should not contain more than 60 characters, otherwise an error may occur.</u>



In our case, we create it directly in the root directory (or in the folder where you want provided the full path should not be longer than 60 characters) and call it "**Pr1.hoga"**, then clicking on "**Save**".

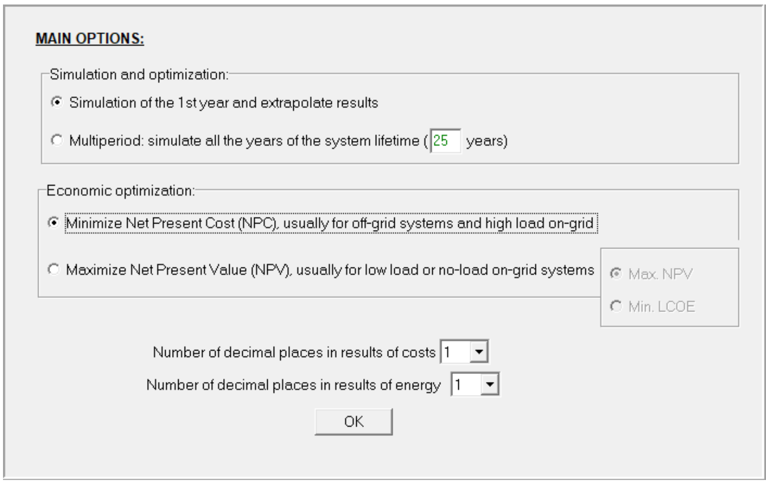
The file Pr1.hoga will be created in the folder selected, and a folder with the same name (Pr1) will also be created. If, later, after closing the project, you want to move or copy your project to another folder or share it with another person, you must move / copy / share the .hoga file and also the folder with the same name (in this case, you must move / copy / share Pr1.hoga file and Pr1 folder).

In PRO+ version, we can choose general options of the project (upper menu **Project-> OPTIONS**):



A window appears where:

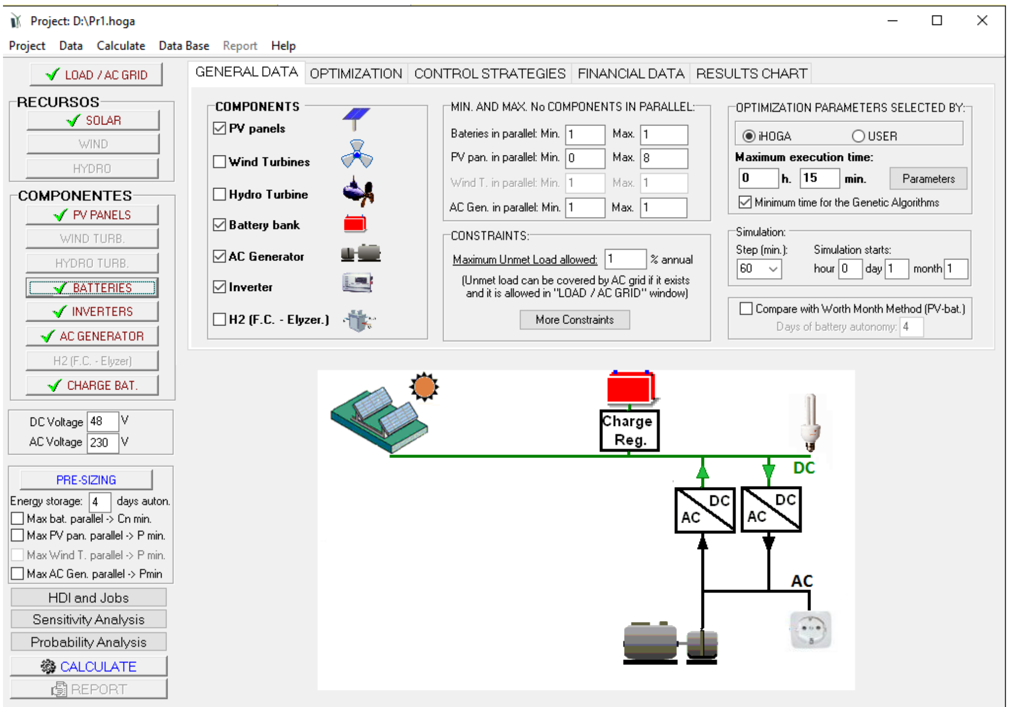
In the **Simulation and optimization** selection, we can select that the simulation is just for one year (extrapolating the results of that year, by default) or multiperiod, simulating the whole lifetime of the system (by default 25 years). Multiperiod is only possible for PRO+ version. We leave the default value.



In the **Economic optimization** selection, we can choose between minimizing the net present cost (NPC) of the system (for off-grid systems of grid-connected systems with load) or maximizing the net present value (NPV) of the system (for grid-connected generators without load or with low load). NPV optimization is only possible for PRO+ version. We leave the default value (minimization of NPC).

We click **OK**.

The default project is a Photovoltaic-Diesel-Battery system to cover the demand for a low-consumption housing (average AC consumption of 3.63 kWh/day). However, later we can change any of the data that appears by default.

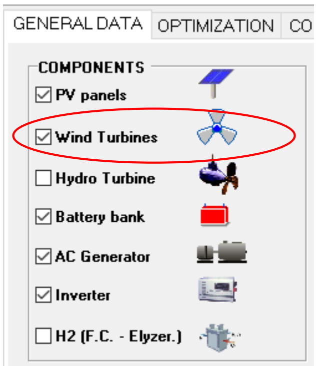


2. Type of system.

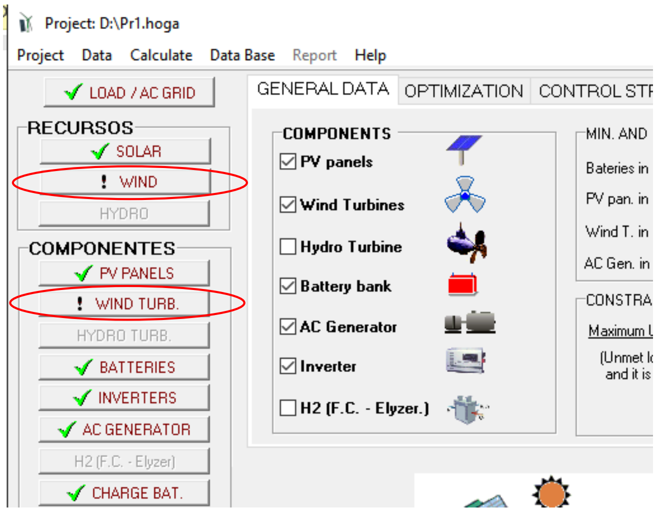
By default, the system to be optimized would be hybrid photovoltaic-diesel-batteries, evaluating different combinations of components.

We are going to assume that we are also interested in testing combinations with wind turbines, that is, that the system can be **photovoltaic-wind-diesel-batteries**.

In the main screen, in the default tab (**GENERAL DATA**), we click "**Wind turbines**", this way the system will also consider them.

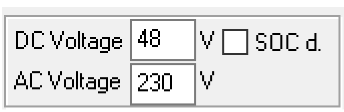


In the group of buttons on the left, the buttons "WIND" and "WIND TURB." are enabled, showing the "**!**" symbol indicating that data must be entered for wind speed and wind turbines.



3. DC and AC nominal voltages.

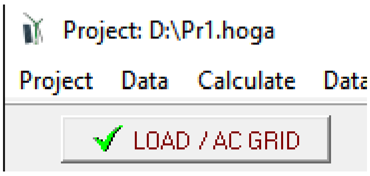
In the main screen, under the components buttons (central left zone), the nominal DC and AC bus voltages of the system are defined. Let's use the ones that appear by default.



If the checkbox "SOC d." is marked, the DC voltage will vary depending on the state of charge (SOC) of the batteries, situation more similar to the real one than if we consider DC voltage is fixed (without marking that checkbox). This option is only available in PRO+ version, so we leave this box unchecked.

4. Load data.

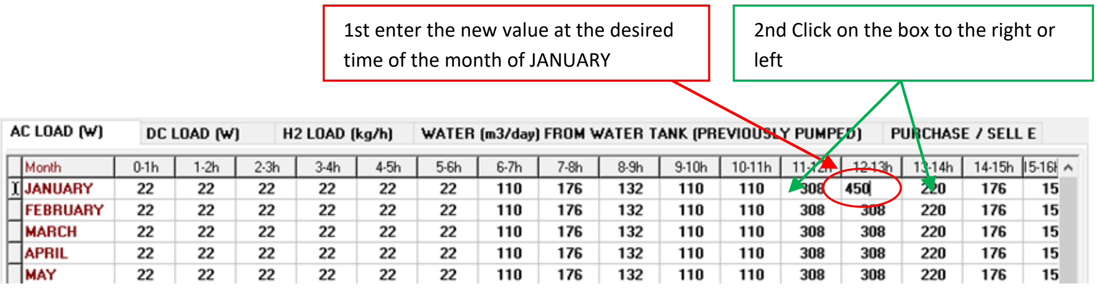
By clicking on the "**LOAD / AC GRID**" button, we can modify the load data (electric demand AC and/or DC, hydrogen load for external consumption or water consumption pumped from a river or a well to the water storage tank) and the data of purchasing and selling electrical energy to the AC grid or selling surplus hydrogen.



By default, the load demand is that of a low-consumption housing (average AC consumption of 3.63 kWh/day). Suppose that the consumption of our case is similar to the default values, with the following changes:

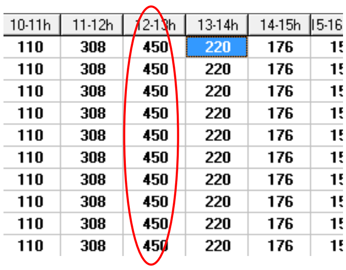
- Every day of the year, between 12 and 13 h the consumption is 450 W.
- Every day of the year, between 20 and 21 h the consumption is 370 W.

In the tab that appears by default, **AC LOAD (W)**, we click on the first row (JANUARY), column 12-13 h, entering the value 450:



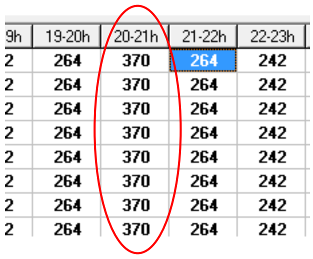
Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h
JANUARY	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
FEBRUARY	22	22	22	22	22	22	110	176	132	110	110	308	308	220	176	15
MARCH	22	22	22	22	22	22	110	176	132	110	110	308	308	220	176	15
APRIL	22	22	22	22	22	22	110	176	132	110	110	308	308	220	176	15
MAY	22	22	22	22	22	22	110	176	132	110	110	308	308	220	176	15

If you then click on one of the adjacent boxes (row JANUARY, column 11-12 or column 13-14), the new value of 450 W appears in all the boxes in the column where the data has been entered. In this way we avoid having to enter all the data in the column one by one:



10-11h	11-12h	12-13h	13-14h	14-15h	15-16
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!
110	308	450	220	176	1!

We repeat the same procedure for the case of 370 W between 20 and 21 h.

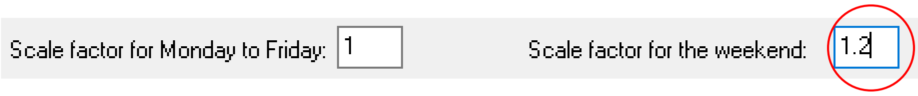


9h	19-20h	20-21h	21-22h	22-23h
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242
2	264	370	264	242

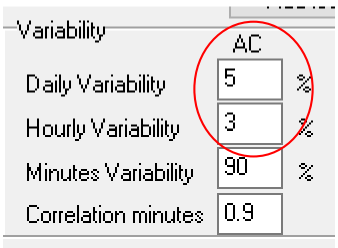
In our case let's suppose that the defined consumption load is for the weekdays, and that on the weekends the consumption is 20% higher (*note that iHOGA considers in the simulations that the two first days of the year are weekend*).

Enter the scale factor 1.2 for the weekend.

<u>In all iHOGA data boxes, the decimal spacing must be entered as defined in the Windows environment. The computer with which this guide was made has in Windows the decimal spacing as the dot (".") so we have introduced "1.2"; if your computer uses comma as decimal spacing you must introduce "1,2".</u>



Let's suppose that we want to add a randomness (variability) in the load consumption, of 5% per day (total energy envisaged for each day can be modified between +5 and -5%) and 3% per hour (the energy envisaged for each hour can be modified between +3 and -3%). We leave by default the randomness of the minutes and the correlation of the minutes (to obtain, by means of a first-order autoregressive model, the load consumption values in minutes). Enter these data in the corresponding boxes:



<u>The variability introduced may imply that the results obtained by the reader with his/her computer are slightly different from those obtained in this guide, since the AC load will not be exactly the same, due to the random variability introduced.</u>

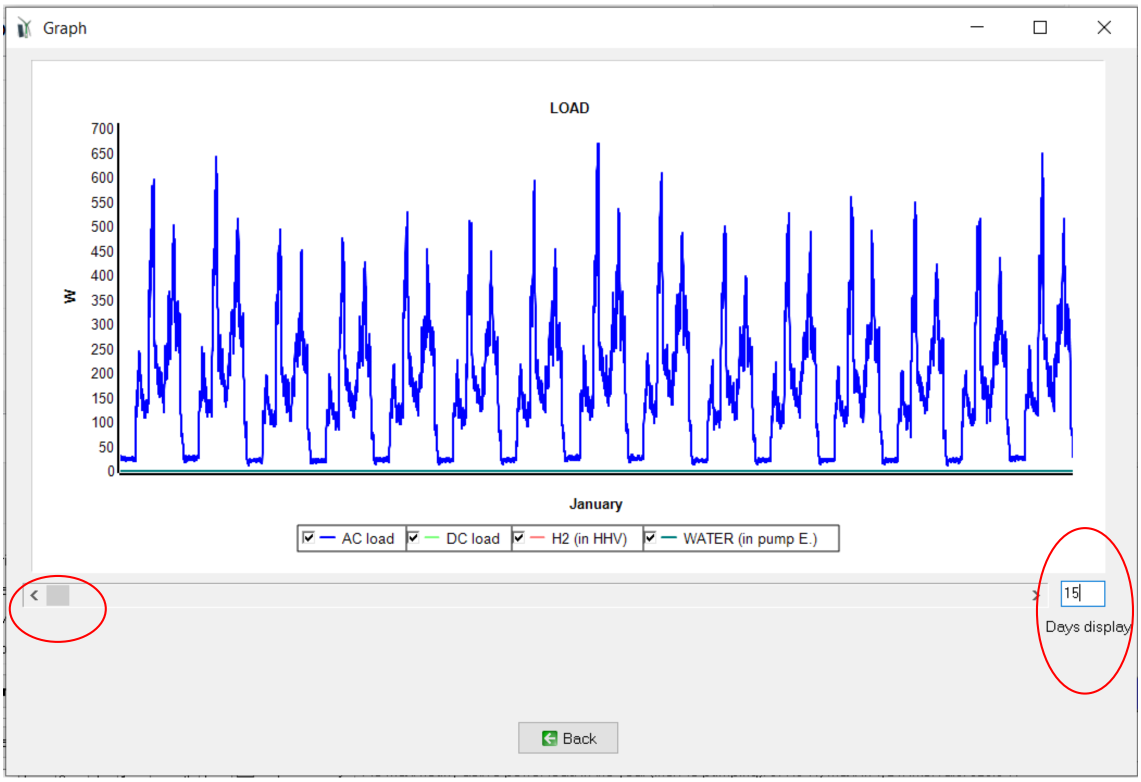
The only load is AC. We can see in the different tabs (DC LOAD, H2 LOAD and WATER load tabs) that the other load types are zero by default.

Then click the "**Generate**" button (lower left area) to generate the 8760 AC load hourly values (and the values for each minute within each hour).

At the bottom the average daily total consumption, around 4.07 kWh / day, is shown.

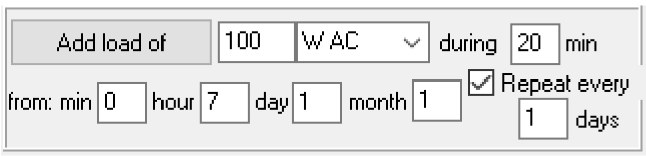
The load can be visualized in graphical form, with temporary steps between 1 and 60 minutes. Select 1 minute:

And then click on the "**Graph in steps of**" button the load curve is displayed (it can take some seconds to appear). In this case only the blue curve appears since only AC consumption has been defined. You can display several days at a time, changing the value in "Days display". In the example 15 days are seen. January 1st is supposed to start the weekend (Saturday). The remaining days of the year can be viewed by moving the scroll bar under the graph legend.



By clicking "**Back**" we return to the load screen.

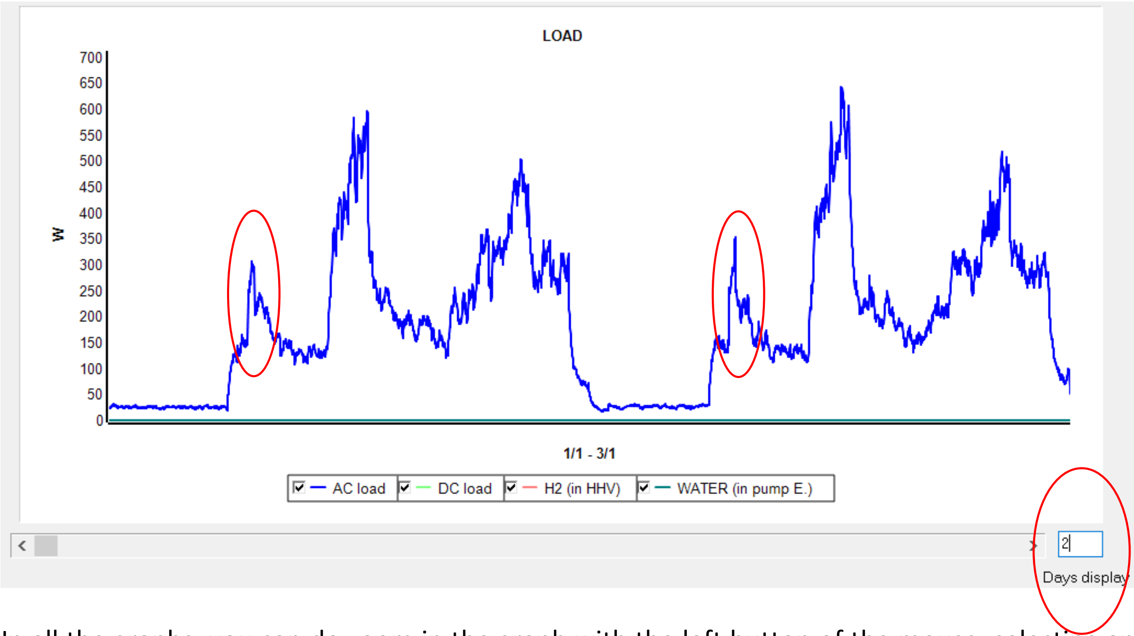
In the load screen, under the "Generate" button, we can add load for a certain time, which can be repeated or not. In this case we will add 100 W AC for 20 minutes, starting at 7 a.m. in the morning of January 1st, and it will be repeated every day (see next figure):



By clicking on the button "**Add load of**" this consumption is added to the one generated previously, with a confirmation window of the added load.

At the bottom of the screen it is shown the average daily total load, which is now around 4.11 kWh/day.

If we click again on the "Graph in steps of" button the following screen appears (after indicating that we only want to visualize 2 days), being able to observe how each day at 7 in the morning during 20 minutes has been added 100 W.

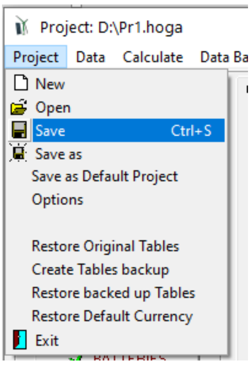


In all the graphs, you can do zoom in the graph with the left button of the mouse, selecting an area of the graph; later you can undo the zoom with the right button of the mouse.

We return to the load screen by clicking "**Back**".

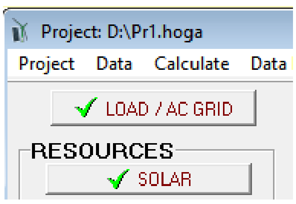
In this screen, by clicking "**OK**" (left bottom corner) we return to the main screen of the software.

Remember to save the project periodically (upper menu **Project-> Save**):



5. Irradiation data.

By clicking on the "**SOLAR**" button we can modify the solar resource data.

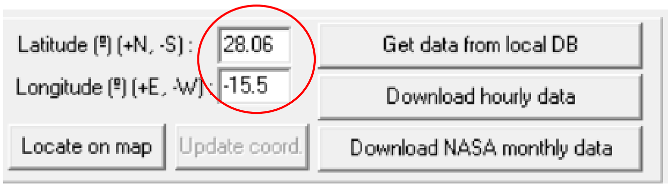


Within the irradiation screen, we must indicate the latitude and longitude of our location. If we know them, we indicate them directly.

If we do not know them, users of the PRO + version can obtain them directly with the button "**Locate on map**" (the first time they must introduce a Google Maps JavaScript API key, which can be obtained free of charge as shown in the user manual, section 3.3.2), then Google Maps open in your web browser, you click in the location, click in the "Confirm" button of the web and go back to MHOGA, irradiation screen, and click in "**Update coord**" button, then the coordinates are updated to the value of the location selected in the web (more info in the *user manual*, section 3.3.2).

Users of EDU version can search in [https://www.**google**.com/**maps**](https://www.google.com/maps) the location, once found, click the right button and you will see the latitude and longitude.

Suppose that the system will be near Las Palmas de Gran Canaria, latitude 28.06 ° (north, positive) and longitude -15.5 ° (west, negative). Enter these values (top left corner of the screen):



iHOGA can download resources data (irradiation, temperature, wind speed) from:

- Monthly average data:

  -NASA POWER (https://power.larc.nasa.gov/) for a specific year

  - Local database: monthly average values of 22 years from NASA (if you have installed the database)

- Hourly data:

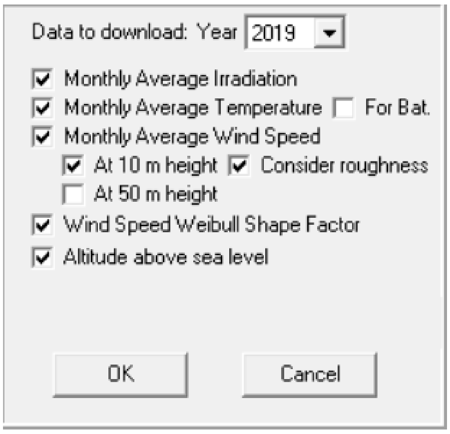
  -PVGIS (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html)

  -Renewables Ninja (https://www.renewables.ninja/)

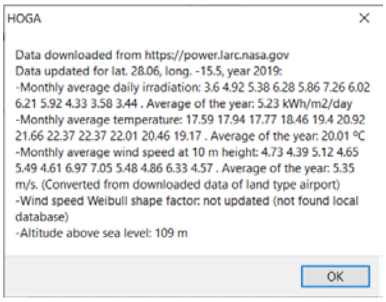
  - NASA (https://power.larc.nasa.gov/)

First we will use NASA monthly average data.

Then click on "**Download NASA monthly data**". A window appears asking us what data we want to download (we can also choose the year of the data to be downloaded):



We use the default values (2019 data) and click "**OK**". After some seconds (be patient, it can take even 30 seconds) the confirmation of the downloaded data appears:



Note that these values are average values of year 2019 for 1º lat x 1º long. around the location (solar data source is a global 1° x 1° latitude/longitude grid while the meteorological data sources are ½° x ⅝° latitude/longitude grid). Weibull shape factor will only appear if you have previously installed the local database, available in the download area of the iHOGA website (not necessary at the moment).

By clicking "**OK**", we return to the irradiation screen.

In this screen the average monthly data of irradiation in kWh/m2 have been updated:

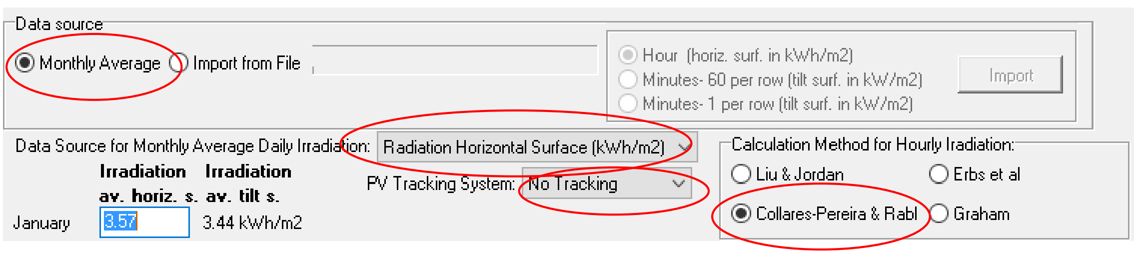
If NASA database fails (server error), you can use the local database of iHOGA (you must have previously installed the database by downloading and executing the self-extracting rar file "RESOURCES-ENG.exe", installing into the iHOGA installation folder, subfolder "RESOURCES". (Availalbe in https://ihoga.unizar.es/Desc/RESOURCES-EDU-eng.exe).

*To use the local database, in the irradiation screen, click on the button "**Get data from local DB**".*

Let's suppose that we want to use 22-year average data, instead of the data of a specific year. Then we should use the local database of iHOGA. If you do not want to install it, just **modify manually** the values with the following data (they are slightly different from the downloaded for 2019):

We can use as input data source data a file with data of global irradiation on horizontal surface (hourly values, file of 8760 rows, in each row the value in kWh/m^2 of each hour), a file with data in minutes (inclined surface) or average monthly data (12 data, one for each month, in different formats).

When downloading from NASA (monthly values) we obtain average daily data per month in kWh/m^2, so we don't change the default option "**Monthly average**", Radiation Horizontal Surface (kWh/m^2).

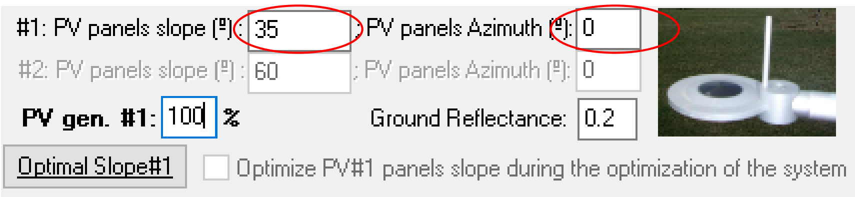


In this case we will assume that there is no solar tracking system (modules with fixed orientation and slope) and we will use the method of calculation of the hourly irradiation of Collares-Pereira and Rabl (default values).

We must indicate the slope and the azimuth of the photovoltaic modules. In EUD version there is only available one zone for the PV generator (PV gen. #1 is 100%). In PRO+ you can define two zones with different slope and azimuth.

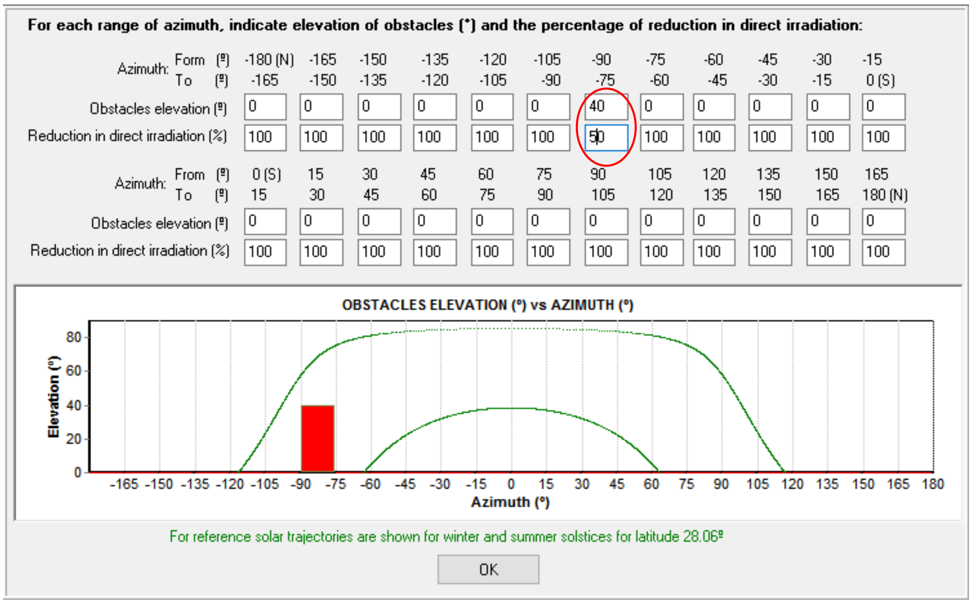
Sometimes these values of slope and azimuth are predetermined by the type of installation, for example if we want to place the modules on a roof with a certain slope and orientation.

If we can choose the inclination and orientation, the azimuth will be 0º (for northern hemisphere, that is, orientation towards the south) and the optimal inclination for our case will be obtained by pressing the button "Optimal slope#1" (only in the case of PRO + version, see User manual, section 3.3). If we use the EDU version, we will choose the slope that best fits our locality according to our knowledge. In this case we will choose 35º:



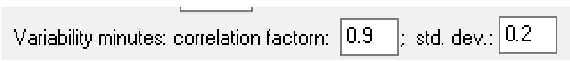
Shadows that affect our PV generator must be defined before calculating the irradiation or before downloading data from PVGIS, Renewables Ninja or NASA.

By clicking the button "**SHADOWS**" (down left) we access a window where we can define the existing obstacles that can shade the photovoltaic modules. Suppose that between -75 and -90° azimuth exists a 40° elevation obstacle, and that this obstacle eliminates 50% of the direct irradiation (because it occupies the middle of the strip between -75 and -90° of azimuth), we introduce these data:



By clicking "**OK**", we return to the irradiation screen.

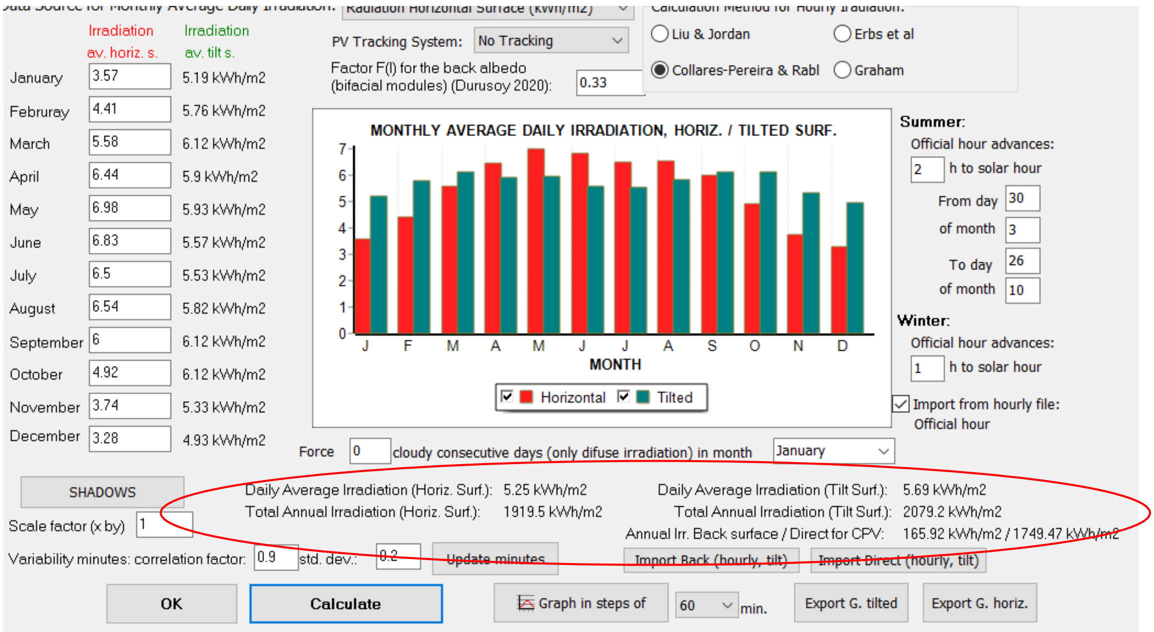
Before clicking on the Calculate button, we must define how the irradiation values of each minute will be obtained, since a first order autoregressive model is used. We must indicate the correlation factor and the standard deviation (kW/m^2). We use the default values (down left):



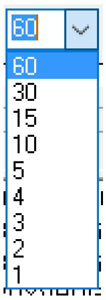
Then click the "**Calculate**" button (down) to obtain the 8760 values of hourly radiation on the tilted surface (35°) and for all the minutes within each hour:

The software also calculates the irradiation of the back surface (needed if we would consider bifacial PV modules) and the direct irradiation over the tilt surface (needed if we would consider concentrating PV, CPV).

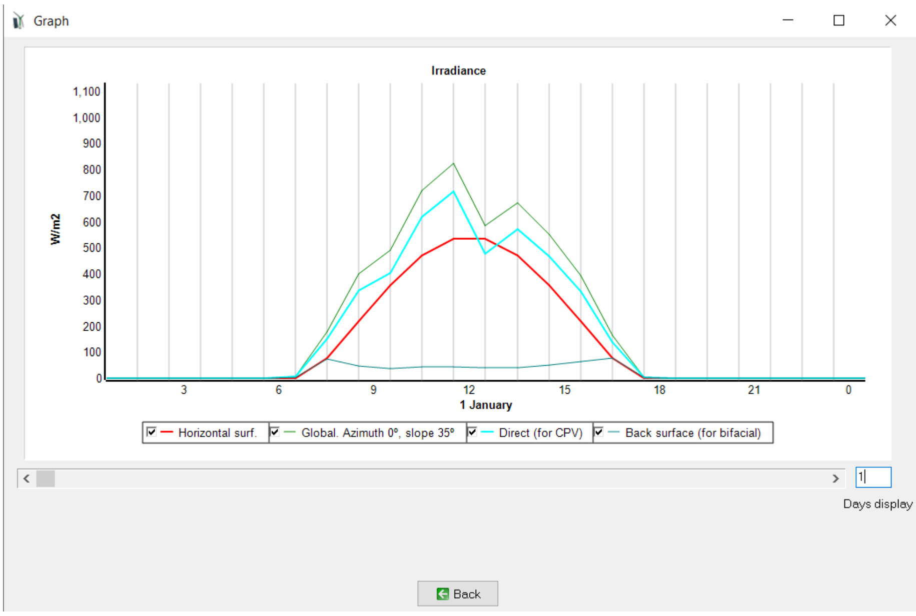
After calculation, it is shown (above the button Calculate) the daily global average and annual irradiation on horizontal surface and on tilted surface, the total annual irradiation over the back surface of the modules and the total direct irradiation over the titl surface, for CPV (*note that the user can obtain values slightly different because a correlation factor and standard deviation have been applied, implying that a randomness is applied*).



The "**Graph in steps of**" button is enabled. The display can be in intervals of between 1 minute and 60 minutes.

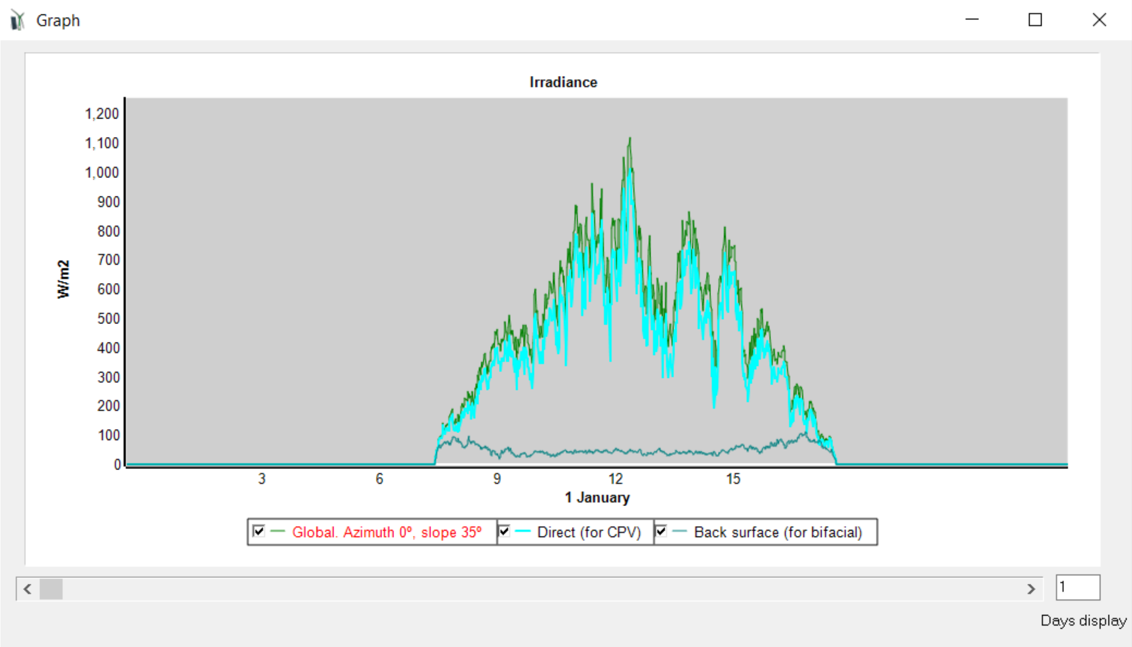


We use 60 minutes and when clicking in "**Graph in steps of**" the representation of the global irradiation on the inclined surface (35º) in shown in thick green line, the irradiation on horizontal surface in red (without random variability), the direct irradiation over the tilt surface (for CPV) in blue and the global irradiation over the back surface in teal.



If we change the days of visualization to 365, we see the distribution of the irradiation during a whole year:

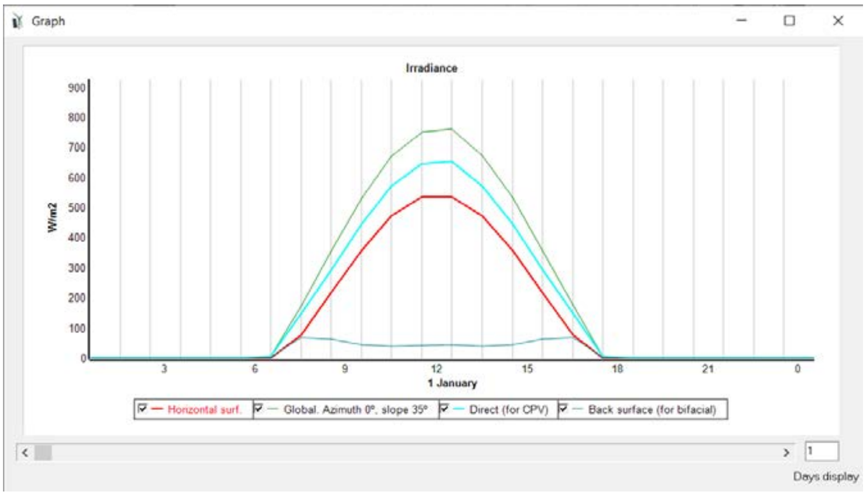
We change again the days of visualization to 1, we return ("**Back**" button) and change to 1 minute and click again on "Graph in steps of" button, we obtain the graph in minutes of the global irradiation on tilted surface, the direct over the tilted surface and the global over the back surface.



We can change the random variability for the minutes so that std. dev. is 0:

Then we click again the "**Calculate**" button and we obtain a different curve, without random variability, but the average monthly values are the same.

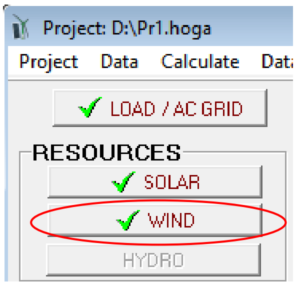
By clicking the button "**Graph in steps of**" (selecting 60 minutes) we obtain the following curve, without minute variability.



By clicking "**Back**" we return to the irradiation screen. Finally clicking "**OK**" it returns to the main screen of the program.

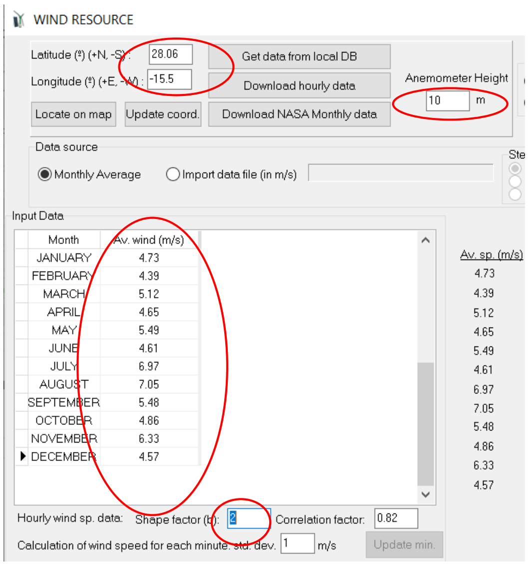
<u>6. Wind speed data.</u>

By clicking on the "WIND" button we can define the wind resource data.

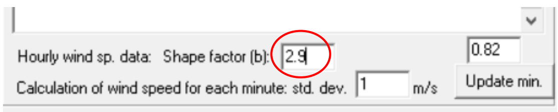


The Wind screen appears.

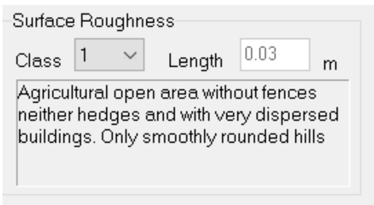
The monthly average wind data downloaded from NASA, year 2019, in the irradiation screen are already placed here: Latitude and Longitude, Anemometer height and Monthly average wind speed (m/s).



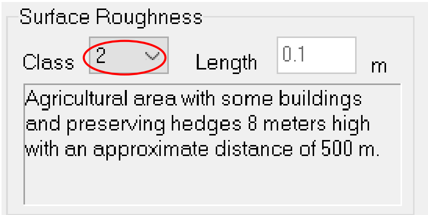
By default, Weibull shape factor is supposed to be 2. In our case, let's suppose that Weibull shape factor is 2.9, change to that value manually (value that would have been automatically obtained if we had the local database installed).



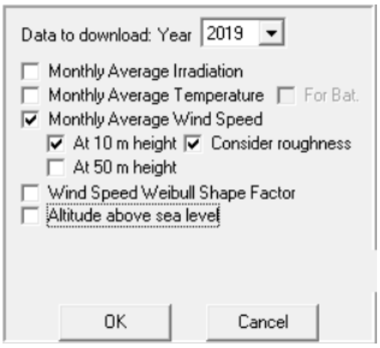
The wind speed data at 10 m height that has been imported from NASA are the ones corresponding to the roughness of the terrain that appears on the upper right side of the screen:



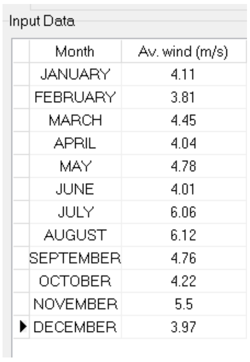
Suppose in our case the roughness of the terrain is different. We select the roughness class 2:



When changing the roughness, we need to import the data again. Click on "**Download NASA Monthly data**" and select <u>only</u> the wind speed at 10 m.



After clicking on "OK" the values corresponding to the roughness class of 2 are downloaded.


Input Data

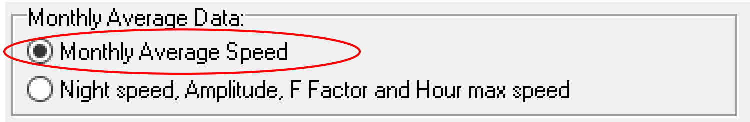
Month	Av. wind (m/s)
JANUARY	4.11
FEBRUARY	3.81
MARCH	4.45
APRIL	4.04
MAY	4.78
JUNE	4.01
JULY	6.06
AUGUST	6.12
SEPTEMBER	4.76
OCTOBER	4.22
NOVEMBER	5.5
DECEMBER	3.97

*If NASA database fails (server error), you can use the local database of iHOGA (you must have previously installed the database by downloading and executing the self extracting rar file "RESOURCES-ENG.exe". To use the local database, click on the button "**Get data from local DB**" (note that the values of the database will be different, as they are 22-year average values from NASA).*

We can choose between average monthly data (by default) or hourly data from file (which would be ideal, to know the wind of a typical full year).

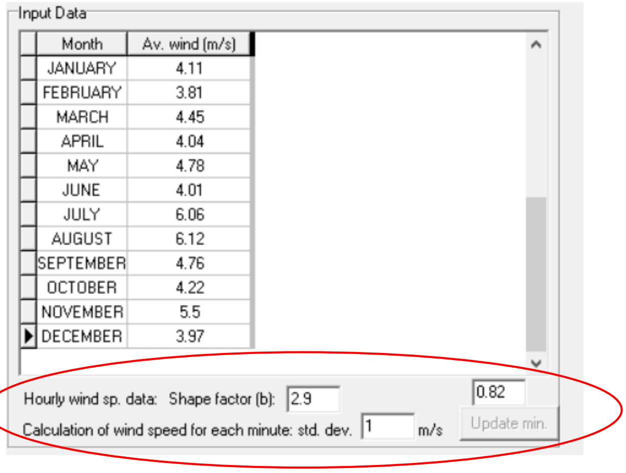
As in this case we do not know the hourly data, we will keep the monthly data as data source.

It is usual to know only the average monthly values (by default, we will use these data), and not knowing the distribution in average night speed, amplitude, etc., therefore we leave the default "Monthly Average Speed" selection:

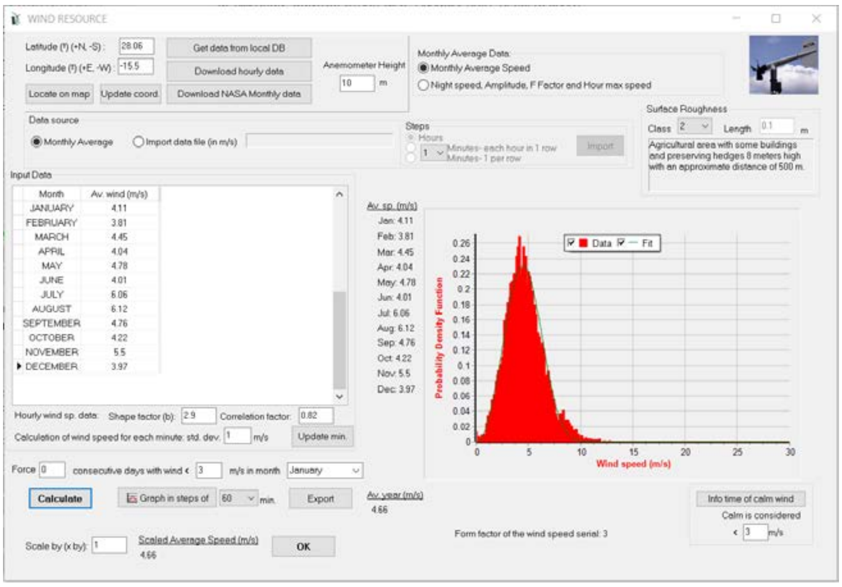


We could download hourly data from PVGIS, Renewables Ninja or NASA. However, in this case we will use the monthly average values downloaded from NASA.

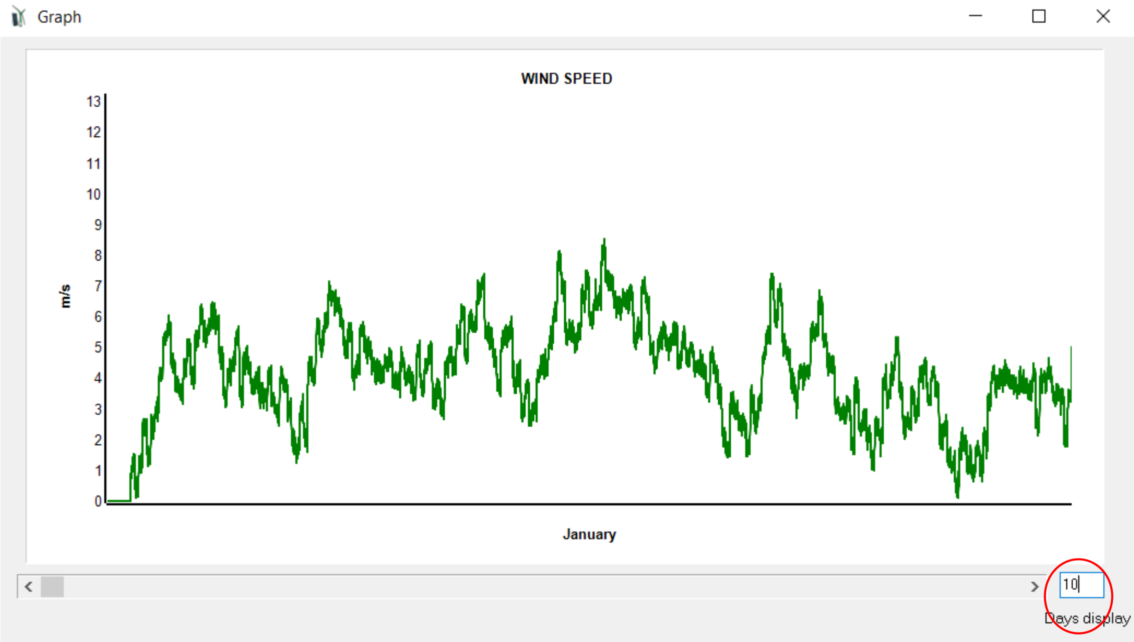
We have already set the Weibull shape factor (in this case 2.9), now we must set the correlation factor (default 0.82) to be used to calculate the hourly values from the monthly values. We also need the standard deviation within each hour to calculate the wind speed in minutes using a first order autoregressive model (default 1 m/s).



Leave the rest of the values unchanged and click the "**Calculate**" button (bottom left corner). A progress bar appears. After a few seconds the progress bar disappears, then the probability distribution curve of the wind speed is displayed (red) and the Weibull PDF curve which best fits the data (green curve), and the buttons that were disabled are enabled.



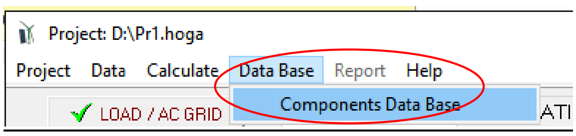
By clicking on "**Graph in steps of**" it shows the wind speed in the selected steps (in this case 1 minute), obtaining something like this (with 10 days of visualization):



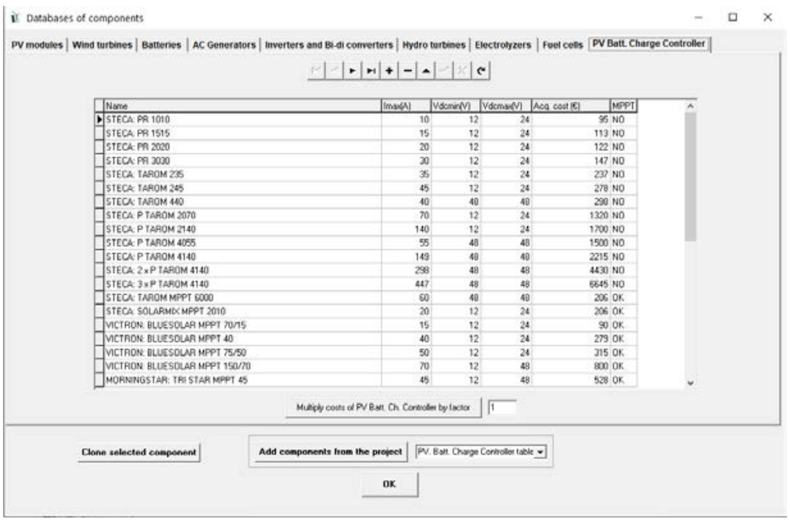
By clicking "**Back**" we return to the irradiation screen. Finally clicking "**OK**" return to the main screen of the program.

7. Components Databases.

By clicking on the top menu **Data Base -> Components Data Base** it displays the components defined in the databases.



The following screen appears:



The different tabs show the components stored in the databases. We can modify the data of each component, eliminate components or add others. We can also multiply all the prices of a given component by a factor. Some components are “generic”.

It should be noted that the prices of the components vary by country, even within the same country depends on different variables. Therefore, the designer must verify or modify the prices conveniently.

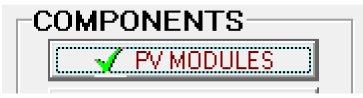
In inverters and inverter-chargers (bi-directional inverters), the manufacturer often does not supply the efficiency curve vs. the output power of the inverter, or supply the curve for different cases of voltage, so in many cases it has been estimated (in a conservative way, that is to say, real efficiency is probably in many cases slightly better).

We will leave everything as it is by default, later the designer can change what he/she wants.

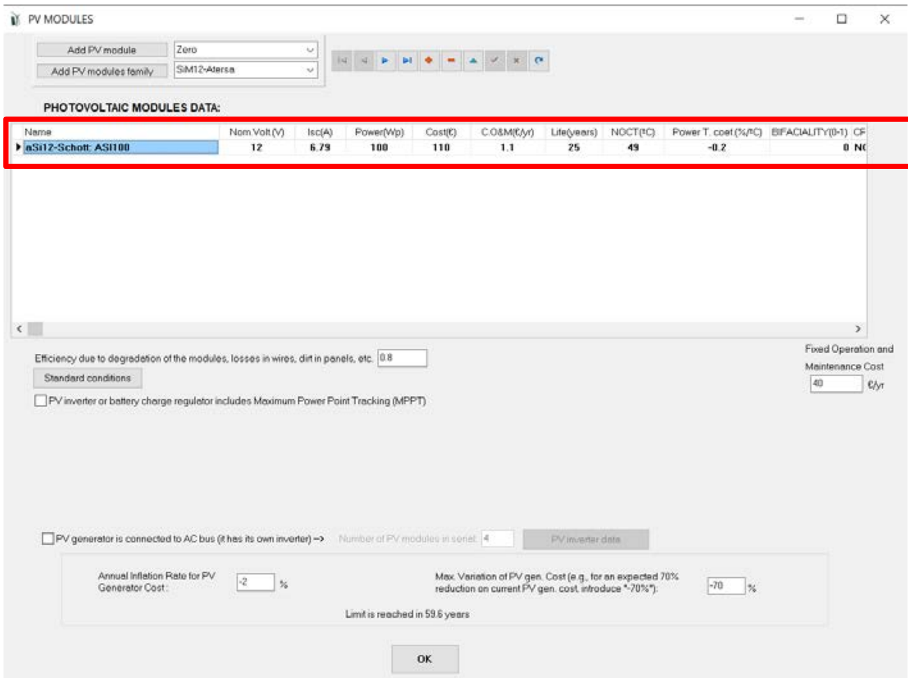
Finally clicking "**OK**" it returns to the main screen of the program.

8. Photovoltaic modules data.

By clicking on the "**PV MODULES**" button we can define the photovoltaic modules to take into account in the simulations and optimizations.



The following screen appears:

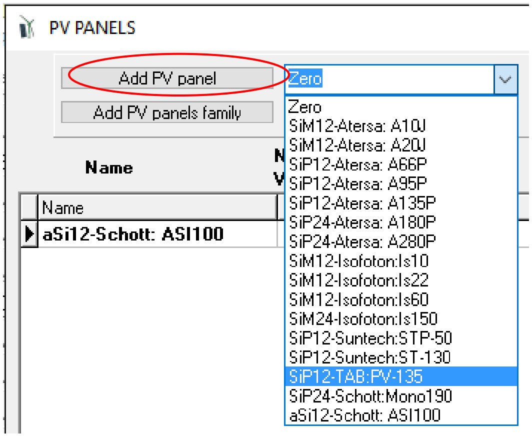


By default, there is only one type of photovoltaic module to consider, as there is just one row in the table, the type Schott ASI 100 of 100 Wp (in the optimization the software will consider several modules of this type in parallel, we will see it later).

Suppose we want to take into account also another type defined in the database, namely the TAB PV 135 (polycrystalline silicon, 12 V). The quickest way to add it is:

1. Select it from the list close to the "Add PV Panel" button.

2. Click on the button "**Add PV Panel**".



Now the project will take into account two types of possible modules:

PHOTOVOLTAIC MODULES DATA:

Name	Nom.Volt.(V)	Isc(A)	Power(Wp)	Cost(€)	C.O&M(€/yr)	Life(years)	NOCT(ºC)	Power T. coef.(%/ºC)	ions(kgCO2/
aSi12-Schott: ASI100	12	6.79	100	110	1.1	25	49	-0.2	8
SiP12-TAB:PV-135	12	8.73	135	247	2.47	25	45	-0.47	8

The acquisition cost of the PV modules must include the proportional cost of the mounting structure, cabling, connectors, etc.

Suppose in our case we want to consider that the cost of the module added is not the one that appears (€ 247) but € 160 (suppose the module plus proportional cost of structure etc. have now this cost). We can modify it in the database (see point 7) and then in the panel screen, by clicking on the row of this panel, its cost will be updated. Another option is to change the name on the screen (for example, add "mod") and change the price. If we do not change the name, any changes we make will not be effective because the software will consider the data in the database. Keep in mind that the number of characters in the name is limited.

We change the name by clicking in the cell and adding at the end of the name “-mod”:

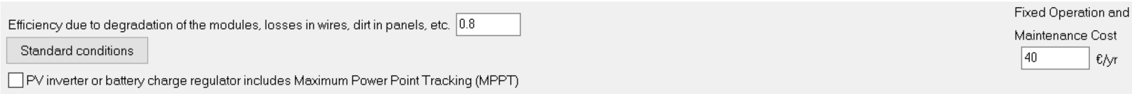
SiP12-TAB:PV-135-mod

And then we change the cost to € 160 and the O&M cost to € 1.6 (we want to keep the O&M cost as 1% of the acquisition cost):

Name	Nominal Voltage	Shortcut Current	Nominal Power	Acquistion Cost	O&M Cost (unit)
Name	(V)	(A)	(Wp)	(€)	(€/year)
aSi12-Schott: ASI100	12	6.79	100	110	1.1
SiP12-TAB:PV-135-mod	12	8.73	135	160	1.6

We have defined two types of possible components of PV modules. Later, when doing the optimization of the system, in each combination of components there will be one of them, several number in parallel (it will be seen later).

In the central area of the screen we see the efficiency due to degradation, losses, dirt (default 0.8), the fixed O&M cost (default 40 €/year, to be added to the O&M cost of each individual module), the button "Standard conditions" (where the standard conditions for the PV and CPV data are set) and the option to consider MPPT.

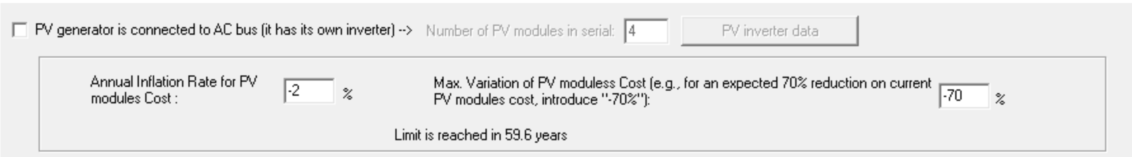


In our case we assume that the charge controller of the batteries does not incorporate MPPT system, so we keep unchecked the corresponding box.

When not considering MPPT, the effect of the temperature is minimal (since the DC voltage is fixed by the batteries) and iHOGA does not consider this. If we click on the box of MPPT (only in PRO+ version) it would appear a screen where you can take into account the effect of the temperature on the production of power by the PV modules.

We keep unchecked the MPPT box.

In the bottom of the screen we could select that the PV generator is connected to the AC bus by its own inverter, by checking the option "**PV generator is connected to AC bus (it has its own inverter)**", in that case the number of PV modules in serial should be introduced and also the PV inverter data. In our case the PV generator will be connected to the DC bus so that checkbox remains unchecked.

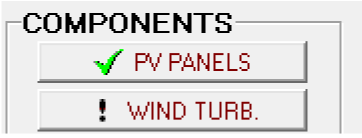


At the top bottom we can set the annual inflation rate for the PV modules cost (default -2%, this means that each year the PV modules cost will be reduced in 2%) and the maximum variation of that cost (default -70%, this means that after 59.6 years, calculated below, this limit of -70% in the PV cost reduction will be reached, as $(1-0.02)^{59.6}=0.3$, then after that year the technology will be considered as mature and the cost will be increased with general inflation). This values would be used to calculate the replacement cost of the PV generator, if its lifetime was lower than system lifetime (it is not our case, as PV generator lifetime is 25 years, the same as the system lifetime). If, for example we had defined the system lifetime (study period of the system) to be 40 years, then in the year 25 the PV generator should be replaced, and the replacement cost would be the initial investment cost multiplied by $(1-0.02)^{25}$. And in the year 40 the residual cost would be also calculated considering this inflation rate.

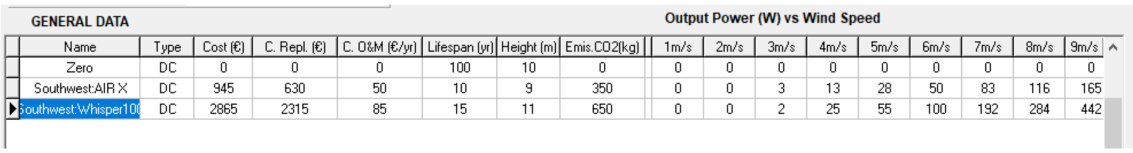
Finally clicking "**OK**" it returns to the main screen of the program.

9. Wind turbines data.

By clicking on the "**WIND TURB.**" button we can define the wind turbines to take into account.



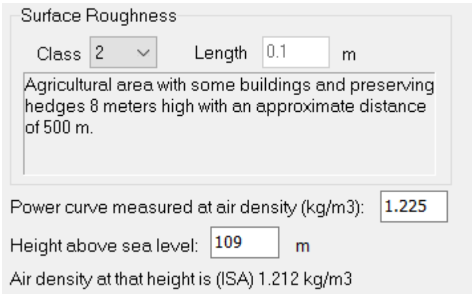
A screen appears with a table where several predetermined wind turbines are shown. Suppose that in our case we agree with the turbines that appear by default: the AIRX, the Whisper and a hypothetical "Zero" wind turbine to take into account the option that there is no wind turbine in the system.

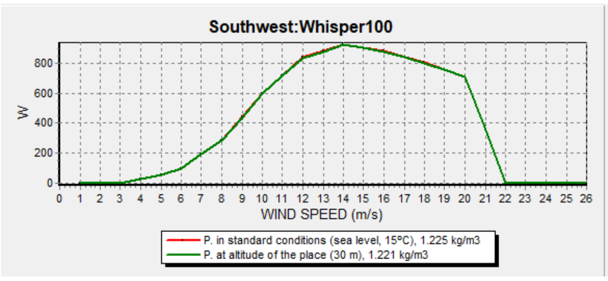


GENERAL DATA / Output Power (W) vs Wind Speed

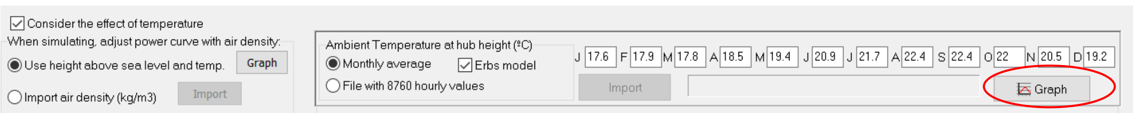
Name	Type	Cost (€)	C. Repl. (€)	C. O&M (€/yr)	Lifespan (yr)	Height (m)	Emis.CO2(kg)	1m/s	2m/s	3m/s	4m/s	5m/s	6m/s	7m/s	8m/s	9m/s
Zero	DC	0	0	0	100	10	0	0	0	0	0	0	0	0	0	0
Southwest:AIR X	DC	945	630	50	10	9	350	0	0	3	13	28	50	83	116	165
Southwest:Whisper10(	DC	2865	2315	85	15	11	650	0	0	2	25	55	100	192	284	442

We must indicate the kind of roughness of the surface of the terrain (already chosen on the wind screen, but here it could be changed), the air density conditions of the power curve supplied by the wind turbines manufacturer (default at standard conditions, sea level and 15ºC, that is, 1.225 kg/m^3) and the altitude above sea level (already updated when we obtained data from NASA, in our case 109 m above sea level), as they are ok we will not change anything. iHOGA shows the air density at the height above sea level (in our case 1.212 kg/m^3) and it shows the power curve of the wind turbine selected by the mouse in red in standard conditions and in green (over the other curve) the power curve considering the air density at the height above sea level of our case.

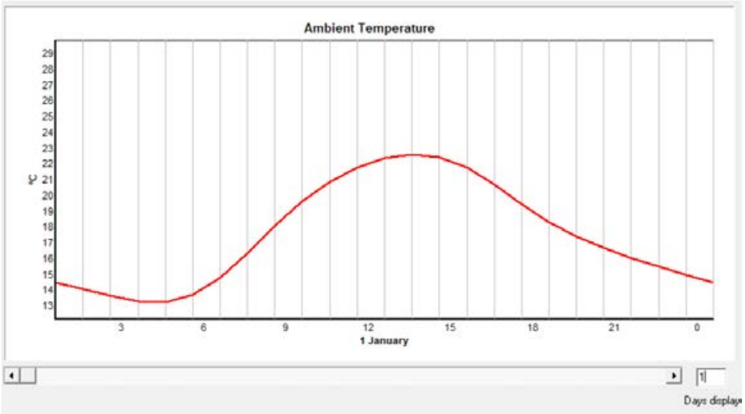




We will consider the effect of the ambient temperature (the corresponding box is selected by default). The monthly average ambient temperature values have been previously downloaded from NASA. The Erbs model is selected to obtain hourly time-dependent data (which depend on the hour of the day and of the irradiation).

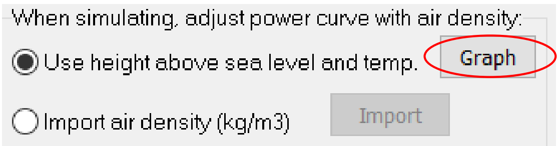


If we click on "**Graph**" we see the representation of the hourly temperature.

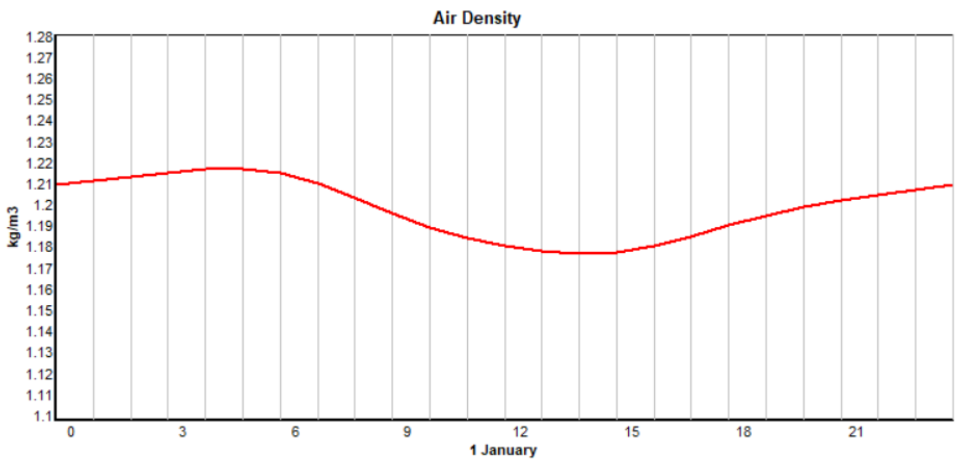


Click on “**Back**” to return to the wind turbines screen.

When iHOGA performs the simulation of the different combinations of components (when optimizing the system), for each hour of the year it will adjust the power curve of the wind turbines to the air density of that hour. We can choose to calculate the hourly air density by using the height above sea level and temperature (if the temperature effect is considered by checking its checkbox) or we can import the air density hourly file (8760 rows, in each row the hourly air density in kg/m^3). We don’t change it.

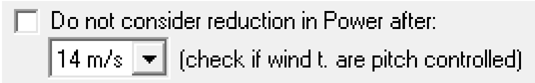


By clicking the “**Graph**” button we can see the hourly air density, calculated for each hour considering the height above sea level and the hourly temperature:



Click “**Back**” to return to the wind turbines screen.

In the bottom of the wind turbines screen we can select not to consider the reduction in the output power of the wind turbine (due to the density lower than standard) after a specific wind speed. It would be selected if the wind turbine is pitch controlled (for high power wind turbines), as the output power above around 14 m/s is limited to its rated power. Therefore, selecting that check box, after that wind speed we would not want that the power curve was reduced. As in our case the wind turbines are not pitch controlled, this checkbox will remain unchecked.



Also in the bottom left corner of the screen we should set the annual inflation rate expected for the wind turbine costs (default -1%) and the maximum variation expected for that rate (default -35%). We leave the default values and iHOGA informs us that this maximum reduction in cost will be achieved in 42.9 years ($0.99^{42.9}$=0.65). These data will be used to calculate the replacement cost when the wind turbines must be replaced (after 10 or 15 years, depending on its lifetime) and to calculate the residual value of the wind turbines when the system lifetime ends (in the year 25).

Finally clicking "**OK**" it returns to the main screen of the program.

10. Batteries data.

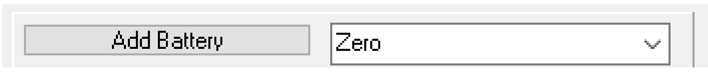
By clicking on the button "**BATTERIES**" we can define the batteries to be taken into account in the project.

The battery screen shows a table where by default several types of batteries are taken into account. In the penultimate column of the table it is seen that they are all lead-acid batteries (defined by "LA" or "Pb").

BATTERIES DATA: Float life at 20 °C — Cycles to Failure vs. Depth of Discharge (%)

Name	Cnom.(A·h)	Volt.(V)	Cost(€)	C.O&M(€/yr)	SOCmin(%)	Self_d(%/mon.)	Imax(A)	Eff(%)	Float(yr)	10%	20%	30%	40%	50%	60%	70%	80%	90%	TYPE	V
OPZS-Hawker:TLS-3	180	2	127	1.27	20	3	36	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	LA	
OPZS-Hawker:TLS-5	270	2	178	1.78	20	3	54	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	LA	
OPZS-Hawker:TVS-5	390	2	164.9	1.65	20	3	78	85	18	12000	6500	4250	3100	2500	2050	1800	1600	1500	LA	

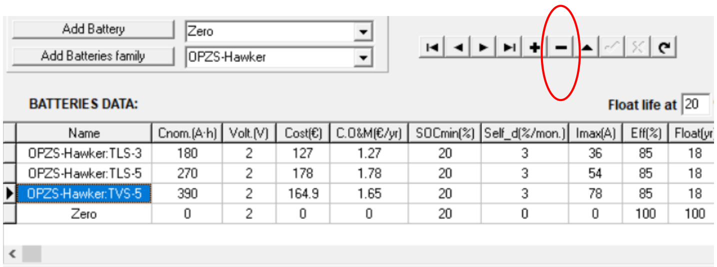
We will add the "Zero" battery to consider that there is no battery in the system, selecting in the box "Zero" battery and then clicking the "**Add Battery**" button



Now the "Zero" is added:

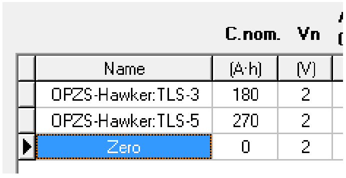
Name	C.nom. (A·h)	Vn (V)
OPZS-Hawker:TLS-3	180	2
OPZS-Hawker:TLS-5	270	2
OPZS-Hawker:TVS-5	390	2
Zero	0	2

Suppose we are not interested in considering the OPZS-Hawker: TVS-5 of 390 Ah. To delete a row, do the following: select the row to remove (by clicking on any cell in that row) and then click the "**-**" button on the button above the table:



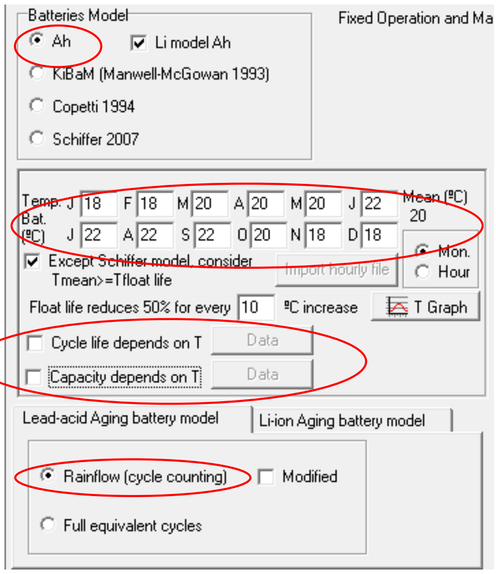
Name	Cnom.(A·h)	Volt.(V)	Cost(€)	C.O&M(€/yr)	SOCmin(%)	Self_d(%/mon.)	Imax(A)	Eff(%)	Float(yr
OPZS-Hawker:TLS-3	180	2	127	1.27	20	3	36	85	18
OPZS-Hawker:TLS-5	270	2	178	1.78	20	3	54	85	18
OPZS-Hawker:TVS-5	390	2	164.9	1.65	20	3	78	85	18
Zero	0	2	0	0	20	0	0	100	100

Once removed the other ones remain:



Name	C.nom. (A·h)	Vn (V)
OPZS-Hawker:TLS-3	180	2
OPZS-Hawker:TLS-5	270	2
Zero	0	2

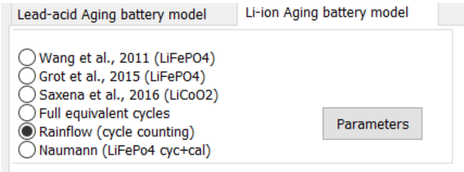
We will take into account the **Ah** battery model. Regarding the average monthly temperature, we leave the default values, taking into account that the temperature is the average at which the batteries are estimated to be. The lifespan of the lead-acid batteries will be calculated according to the Rainflow model of cycle count.



We have not chosen in this example the Schiffer model (much more accurate) since it cannot be considered in the EDU version.

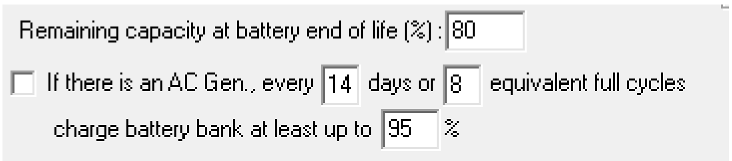
Cycle life depends on temperature, and also the battery capacity depends on temperature. However, as in EDU version it is not allowed, we leave the checkboxes "**Cycle life depends on T**" and "**Capacity depends on T**" unchecked. If you use PRO+ version, in your own projects you should select these options.

The batteries chosen are all lead-acid batteries, which are the only ones allowed in the EDU version. In the PRO+ version you can consider lithium-ion batteries, in that case you must specify the aging model of li-ion batteries, clicking on the next tab and choosing the model:



At the bottom, we can set the remaining capacity at battery end of life (default 80%), that is, we consider that when the remaining capacity is 80% the battery will be dead and it must be replaced, we leave the default value.

Also, in PRO+ version we can check the box "If there is an AC Gen., every ...." so that the backup generator will charge the batteries after a specific number of days without full charge or after a specific number of full equivalent cycles, as some inverter-charges do. In this case we leave this unchecked, as it is not allowed in EDU version.



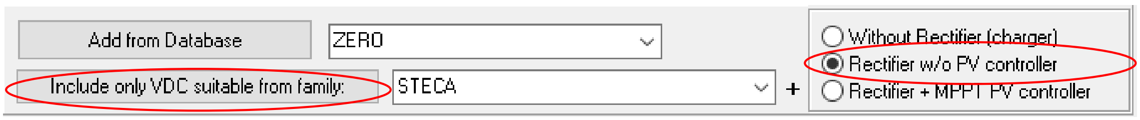
We will use the rest of the default data. Finally clicking "**OK**" it returns to the main screen of the program.

11. Inverters data.

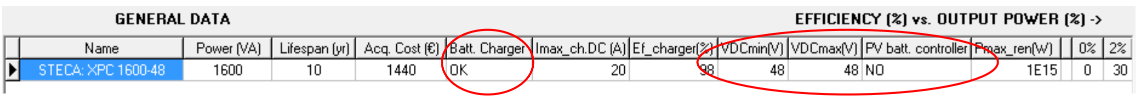
By clicking on the "**INVERTERS**" button we can define the inverters to take into account in the project.

The table shows a single inverter table, suitable for 48 VDC.

If we click on the button "**Include only VDC suitable from family**" and we have selected the family STECA and "Rectifier without PV controller" (we want inverter-charger but the PV controller will be apart):



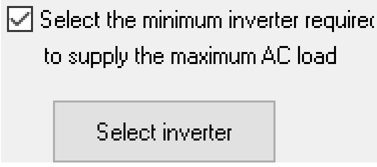
A single inverter-charger that meets the specifications will appear in the table:



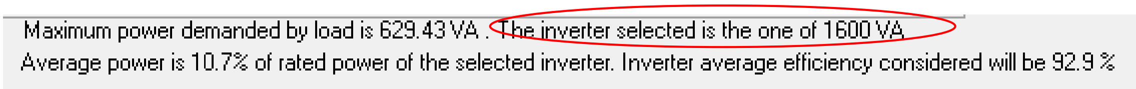
GENERAL DATA												EFFICIENCY (%) vs. OUTPUT POWER (%) ->		
Name	Power (VA)	Lifespan (yr)	Acq. Cost (€)	Batt. Charger	Imax_ch.DC (A)	Ef_charger(%)	VDCmin(V)	VDCmax(V)	PV batt. controller	Pmax_ren(W)		0%	2%
STECA: XPC 1600-48	1600	10	1440	OK	20	98	48	48	NO	1E15		0	30

We will force that the minimum inverter that can supply the AC load peak defined in the consumption screen is used in all the combinations. In this case iHOGA will select the only available, but if there were several it would choose the minimum such that its power was higher than the peak maximum AC power hourly consumption, which is around 630 VA.

To do this, keep the "**Select the minimum...**" box checked and click the "**Select Inverter**" button.



Below the efficiency vs. power chart we are informed of the selected inverter:

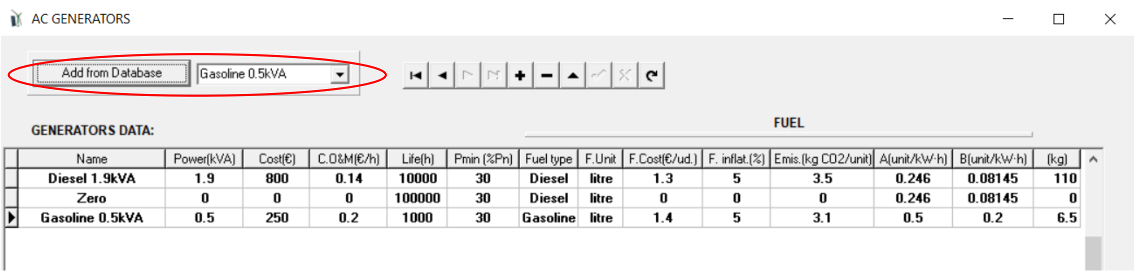


Finally clicking "**OK**" it returns to the main screen of the program.

12. AC generators data.

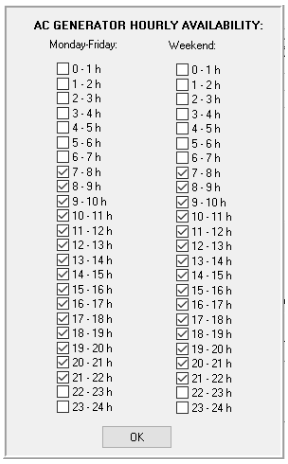
By clicking on the "**AC GENERATOR**" button we can define the AC generators to take into account in the project.

By default, there is the generator "Zero" (to take into account the possibility that there is no AC generator) and a 1.9 kVA diesel. We will add a 0.5 kVA gasoline generator from the database, selecting it from the dropdown menu (the penultimate of the drop-down list) and then clicking on "**Add from database**".



Name	Power(kVA)	Cost(€)	C.O&M(€/h)	Life(h)	Pmin (%Pn)	Fuel type	F.Unit	F.Cost(€/ud.)	F. inflat.(%)	Emis.(kg CO2/unit)	A(unit/kW·h)	B(unit/kW·h)	(kg)
Diesel 1.9kVA	1.9	800	0.14	10000	30	Diesel	litre	1.3	5	3.5	0.246	0.08145	110
Zero	0	0	0	100000	30	Diesel	litre	0	0	0	0.246	0.08145	0
Gasoline 0.5kVA	0.5	250	0.2	1000	30	Gasoline	litre	1.4	5	3.1	0.5	0.2	6.5

In our case we won't allow the AC generator to run from 10 p.m. in the night to 7 a.m. in the morning, due to possible noise disturbances. To do this click on "**AC generator availability**" button and deselect the corresponding boxes:



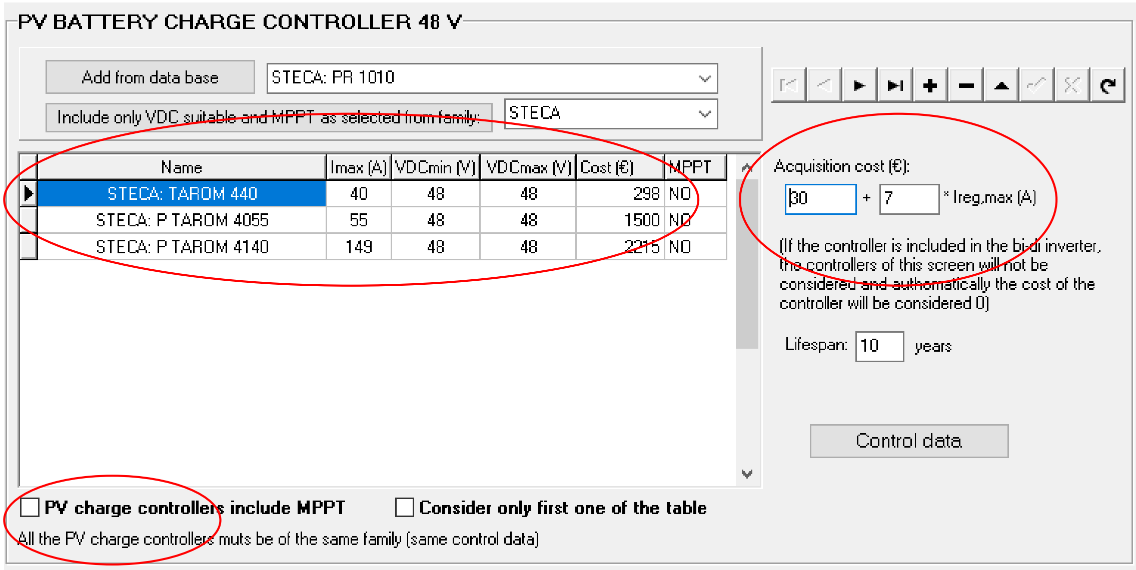
By clicking "**OK**" and then "**OK**" it returns to the main screen of the software.

An info message appears showing that extra ageing is considered when running out of the optimal conditions of the diesel genset, so in some cases (diesel-only systems) the equivalent hours running of the diesel can be higher to the total number of hours of the year (8760 h). We click **OK**.

13. PV battery charge controller and battery charger.

In low power projects, by clicking the "**CHARGE BAT.**" button, we define the characteristics of the photovoltaic charge controller of the batteries and of the rectifier (or battery charger, that is, the AC/DC converter to charge the batteries from the AC bus).

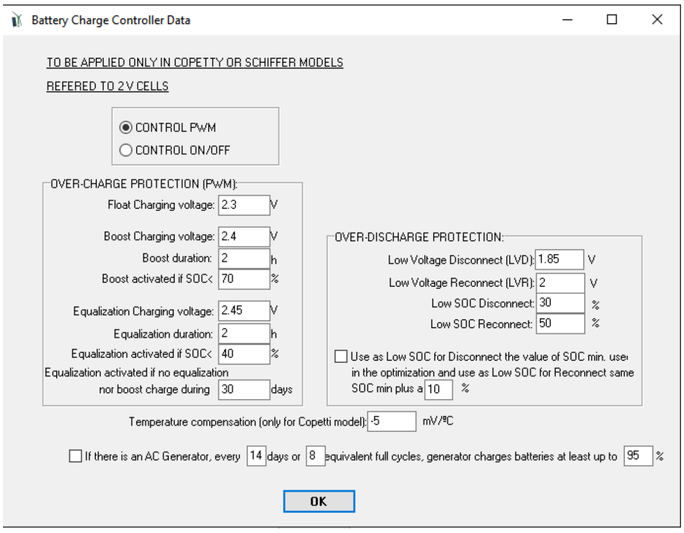
In the case of the **PV battery charge controller**, several 48 V DC controllers are shown as default. For each combination of the other components of the system (and control strategy) the minimum controller of the table will be selected so that its maximum assigned current (Imax) is higher than that obtained in the simulation. If no controller in the table is adequate, a "generic" one will be selected, whose cost follows the line parameterized in the equation shown at the right of the table.



We must indicate whether they include MPPT or not (by default), and we will leave it by default.

In the case of using the Schiffer or Copetti models for batteries, all the controllers in the table must be of the same family, as the control data must be the same for all of them (by clicking the "**Control data**" button we can modify the control parameters, to be applied only if battery models are Schiffer or Copetti). As in our case the selected battery model is "Ah", the controllers of the table could be of different families.

By clicking on the "**Control data**" button, the following screen will show the parameters of the controllers.

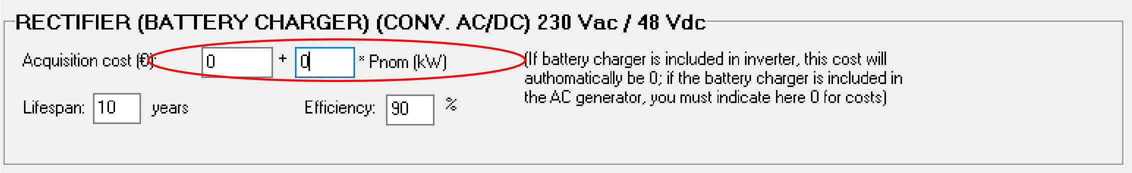


If the Schiffer or Copetti model was chosen for the batteries, the characteristics of the control of the charging and discharging of the batteries should be indicated, the voltage values being relative to 2V cells. As we will later use Schiffer model (in PRO+ version), we are going to indicate these values now. In our case, we will assume that the regulator used is PWM and it has the characteristics that appear by default, except that the float charging voltage is 2.25 V per cell (because it is the value of the controllers of the table or because it is programmable and we want to fix this value):

Some controllers have the possibility to start the AC generator to charge the battery bank (until a specified SOC is reached, by default 95%) when a specified number of days have been passed since the last full charge (default 14) or when a certain number of equivalent full cycles have been performed by the batteries (default 8). The controllers selected do not have this characteristic (and EDU version does not allow it) so we leave unchecked the option on the bottom:

Regarding the **<u>battery charger (rectifier or AC / DC converter)</u>**, used by the diesel or gasoline AC generator to charge the battery bank, the software does not take into account different sizes of this element. Instead of considering different sizes, its size (power of the rectifier) is selected as the minimum power needed, obtained after performing the simulation of each combination of components and control strategies. It is therefore necessary to indicate the acquisition cost line as a function of the nominal power of the rectifier. Also indicate the duration (default 10 years) and rectifier efficiency.

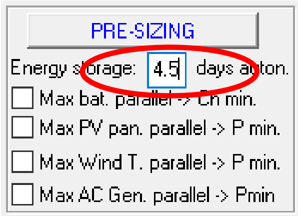
In our case, in the inverter screen (section 11) we have chosen an inverter-charger, so the battery charger is included in the inverter-charger, therefore the charger data of this screen will not be taken into account. Anyway, we set the coefficients for the cost line as 0:



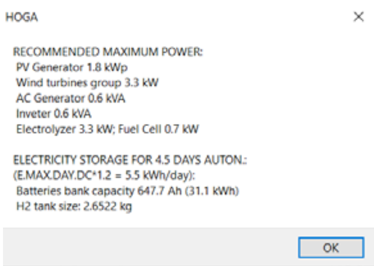
By clicking "**OK**" it returns to the main screen of the program.

14. Pre-sizing.

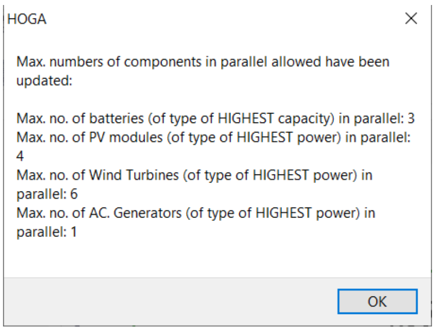
With the "**PRE-SIZING**" button, we obtain the maximum sizes (and maximum number of components in parallel) recommended for the different components (batteries, PV modules, wind turbines and AC generators), taking into account the powers of the largest components selected in their screens and a certain number of days of autonomy (default is 4, however, we will change it to 4.5 days manually).



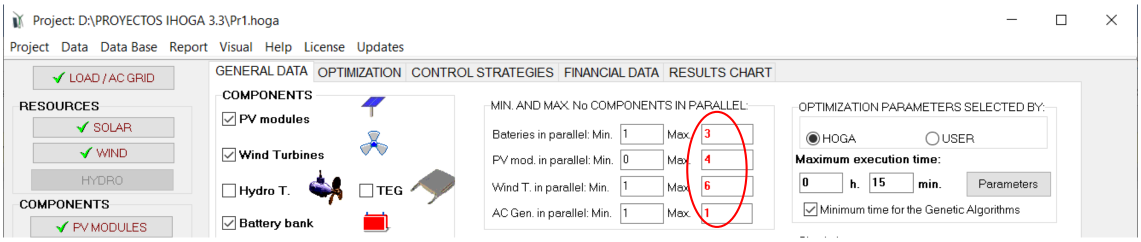
Then click on "**PRE-SIZING**" and a window appears indicating the results of the pre-sizing (in your computer these vales can be a bit different because your total load can be a bit different, considering the variability of the load):



By clicking "**OK**" another screen appears where the maximum number of recommended components in parallel is indicated.



By clicking on "OK" we return to the main screen, where, in the "GENERAL DATA" tab, the maximum numbers of components in parallel have been updated (they appear in red):

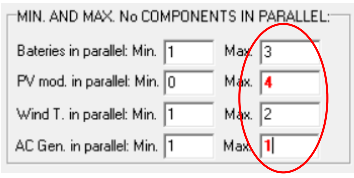


15. Minimum and maximum number of parallel components.

In the main screen, in the "**GENERAL DATA**" tab, the minimum and maximum number of components in parallel allowed must be set. The more variability you leave the more possibilities of combinations of components will be evaluated, however also the computation time will be higher. Let's leave the values that appear after the pre-sizing.

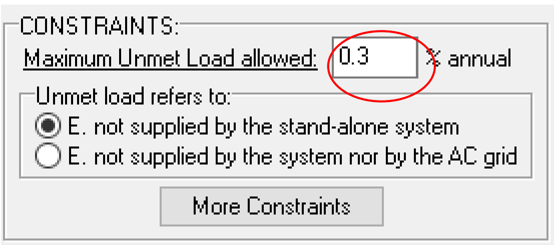
The minimum number of PV modules in parallel has been considered 0 to have the possibility that there is no photovoltaic generator in the system.

Let's suppose that we want to change some maximum values, for example we will just allow a maximum of 2 wind turbines in parallel. We change this maximum value (after changing the values manually, colour red changes to black):



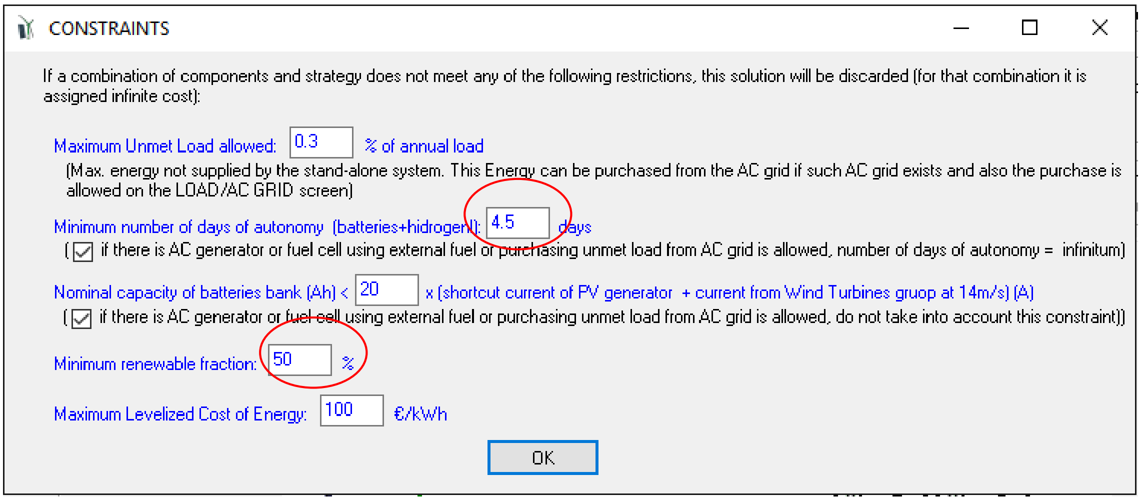
16. Constraints.

In the main screen, in the "**GENERAL DATA**" tab, the main restriction must be set, that is, the maximum unmet load allowed (default 1%). We will change it to 0.3%, which means that the combinations which stand-alone system (without considering the AC grid) cannot supply at least 99.7% of the demand, will be discarded.



By clicking on the "**More Constraints**" button we access a screen where there are more restrictions which, if not met by a certain combination of components (and control strategy), that combination will be discarded.

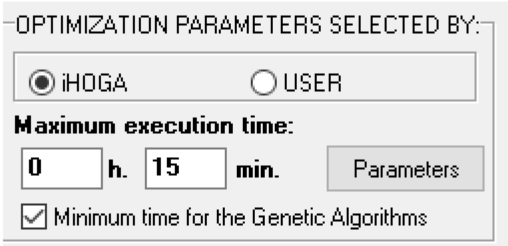
We will modify the value of the minimum autonomy to 4.5 days (as was done in pre-sizing) and the minimum renewable fraction to 50% (indicating that at least 50% of the energy must be covered by renewable sources):



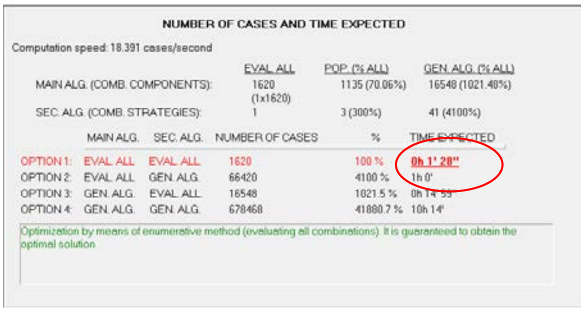
Finally clicking on "**OK**" it returns to the main screen.

17. Maximum execution time allowed.

In the main screen, in the "**GENERAL DATA**" tab we should set the maximum execution time (maximum time the optimization can last) and who (the user or iHOGA) must set the optimization parameters (recommended iHOGA). The longer the time allowed the more likely it is that all the possible combinations can be evaluated and thus obtain the optimum. If sufficient time were not left, genetic algorithms will be used to optimize the system (without evaluating all combinations) in the allowed time. We will leave the 15 minutes by default, enough time in this case so that all possible combinations can be evaluated (enumerative method).

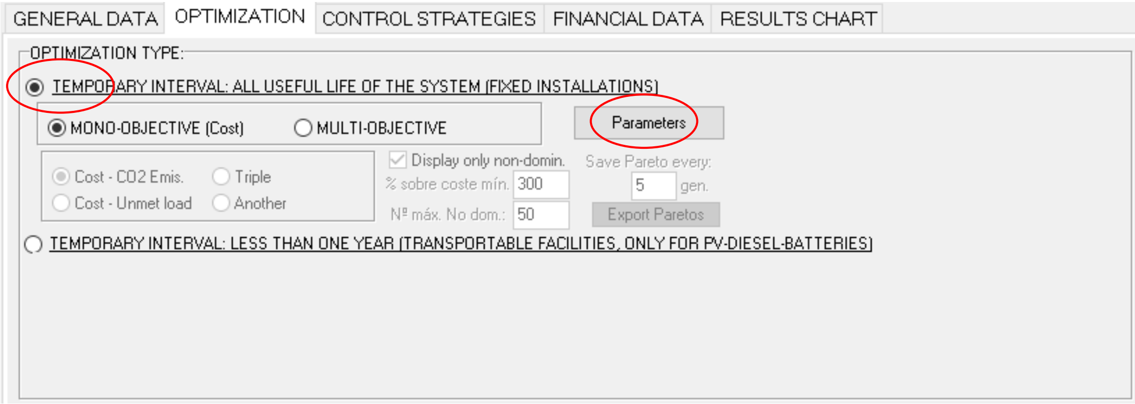


If we pass with the mouse on the zone of maximum and minimum number of components in parallel (see point 15) we are informed that the method chosen for the optimization will be the enumerative method (EVAL. ALL, to evaluate all the possible combinations), since the allowed time (15 minutes) is greater than that needed to evaluate all the combinations (1620 possible combinations). In this computer the estimated calculation speed is 18 cases per second, so in 1'28'' it is expected that all combinations will be evaluated and the optimum will be found.



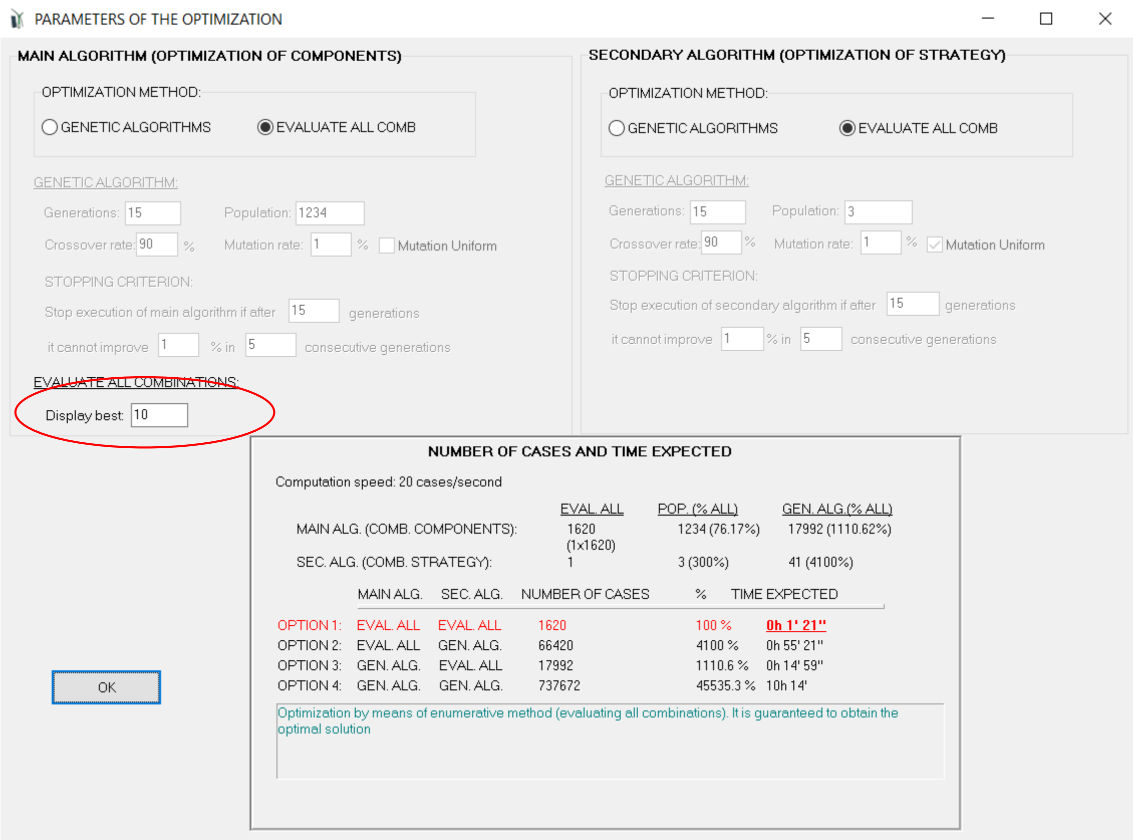
18. Optimization type.

In the main screen, tab "**OPTIMIZATION**" we must indicate if in the optimization it is considered the entire system life (usual, fixed installations, default) or temporary transportable installations (only for PRO+ version). We leave the optimization by default: “TEMPORARY INTERVAL: ALL USEFUL LIFE OF THE SYSTEM (FIXED INSTALLATIONS)”.



We must indicate if the optimization is mono-objective (minimizing the total cost over the life of the system, considering all the costs transferred to the initial moment of the investment, NPC) or if it is multi-objective, where it seeks to minimize several objectives at a time. Let's leave the default mono-objective.

By clicking in the button “**Parameters**” we can see the details of the optimization. In this case all the combinations will be evaluated, in the results we will see the best 10 combinations, we could change that value in the field “Display best” (see next figure).

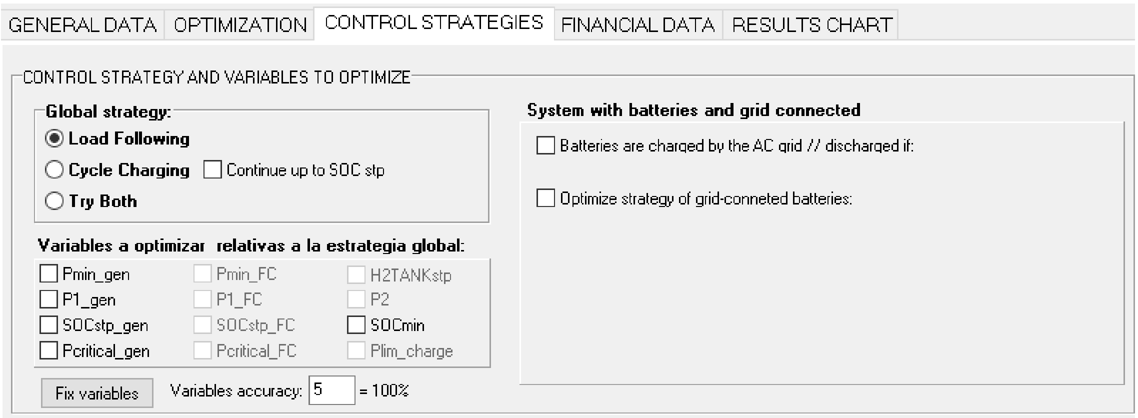


19. Control strategy.

In the main screen, the "**CONTROL STRATEGY**" tab indicates the type of control strategy: load following or cycle charging, or testing both. In addition, different control variables can be set to be optimized. In EDU version only load following strategy is allowed.

In the PRO+ version you can set or optimize the strategy of charging/discharging the batteries in systems connected to the AC grid (charging batteries by the AC grid when the electricity price is low and discharging batteries when the AC grid electricity price is high).

Let's leave everything by default.

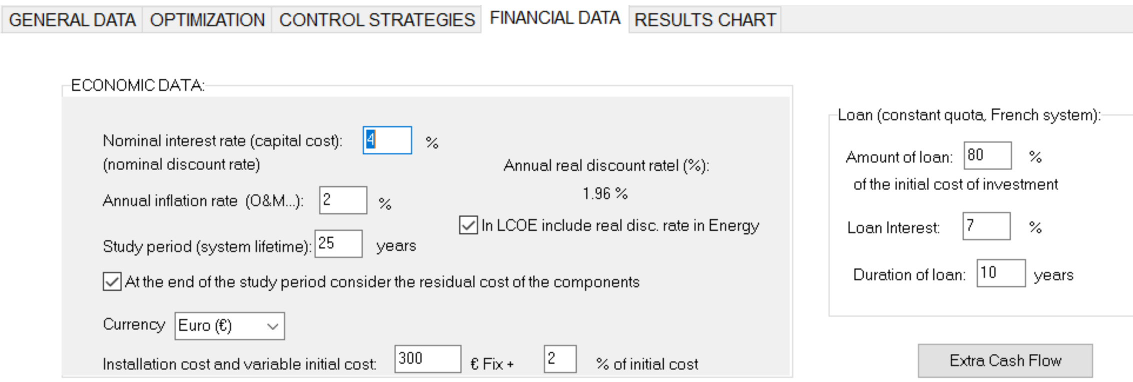


20. Financial data.

In the main screen, in the tab "FINANCIAL DATA" we must set different economic variables (interest or price of money, general inflation, study period, currency, installation costs, and loan). Let's leave the data by default.

By default, at the end of the study period (25 years) the residual cost of the components will be considered as incomes.

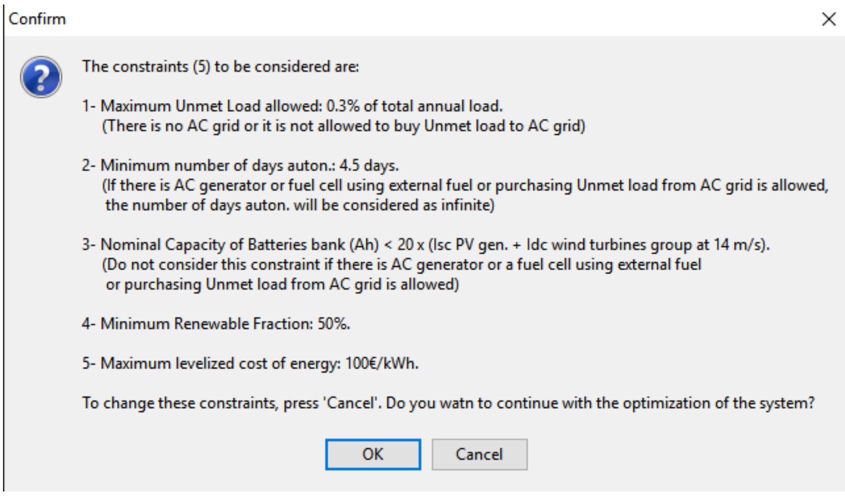
Also, by default the LCOE (levelized cost of energy) will be calculated considering in the energy the real discount rate (see user manual, section 3.1.4)



21. Calculate (optimize the system).

Before calculating, it is important to save the project (in the main screen, upper menu **Project-> Save**).

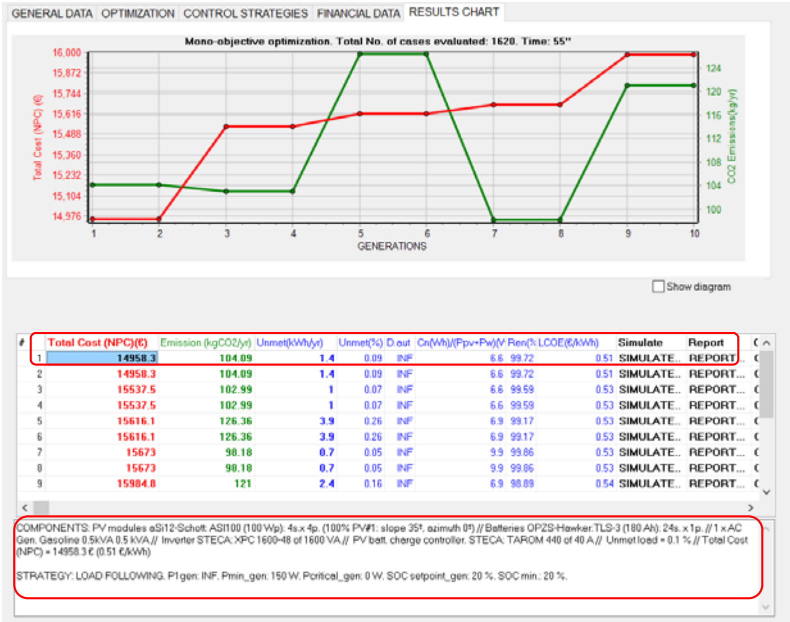
In the general screen, clicking on the "**CALCULATE**" button a window appears indicating the 5 constraints that are going to be considered and if it is agreed, the calculation of the optimization begins.



22. Results.

When using the optimization enumerative method, iHOGA evaluates all the possible combinations of components and, for each combination of components, it evaluates all the combinations of control strategies (but in this case there is only one control strategy). Each combination is simulated during a whole year, in this case in steps of 1 hour. If that simulation meets all the constraints, then it calculates the Net Present Cost (NPC), considering all the costs during the lifetime of the system (25 years) and moving all the costs to the first year (taking into account inflation and interest rate). The combinations that do not meet all the constraints are discarded, assigning them a NPC of "infinite" and showing them in the graph with a cost NPC of 0.

Once the evaluation of the different combinations is finished, the results are shown.



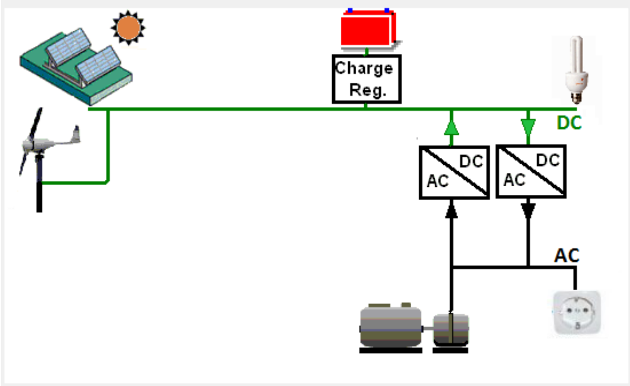
<u>Due to the random variability introduced for the AC load in section 4, and also for the irradiation and wind speed, it is possible that the results obtained by the reader with his/her computer are slightly different from those obtained in this guide, since the AC load and the resources will not be exactly the same for all the time steps (due to the random variability introduced).</u>

In the "**RESULTS CHART**" tab it is shown the graph of the total cost of the best solution (in red) and of the life cycle annual CO2 equivalent emissions (green) of the 10 best solutions found. iHOGA has used the ENUMERATIVE METHOD, that is, all possible combinations have been evaluated. In addition, instead of the scheme of the components a table with the results of the best combinations appears. The table shows the 10 best combinations ordered from best to worst: the best is the first of the table (#1), second best is the #2,…. The number of the best combinations shown (in this case the 10 best ones) can be modified by clicking the "**View Parameters**" button in the tab “**GENERAL DATA**” of the main screen, next to where the maximum execution time is set.

After finishing the optimization, the number of solutions to be shown can also be modified in the main screen, bottom left corner, close to the button “**See best**”. After changing the value, if you click that button, the best number of results will be shown in the table and in the chart.

To see the diagram of the components, click on the "**Show diagram**" button above the table, on the right:

Appearing again the diagram instead of the table:



Although DC load appears in the scheme, as we have not defined it and by default DC load is 0, such load is not considered.

To see the results table again, uncheck "**Show diagram**".

Below the table the characteristics of the optimal solution (corresponding to the first row of the table, solution #1) are shown. This text can be copied (select and Ctrl + C).

COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0.1 % // Total Cost (NPC) = 14958.3 € (0.51 €/kWh)

STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

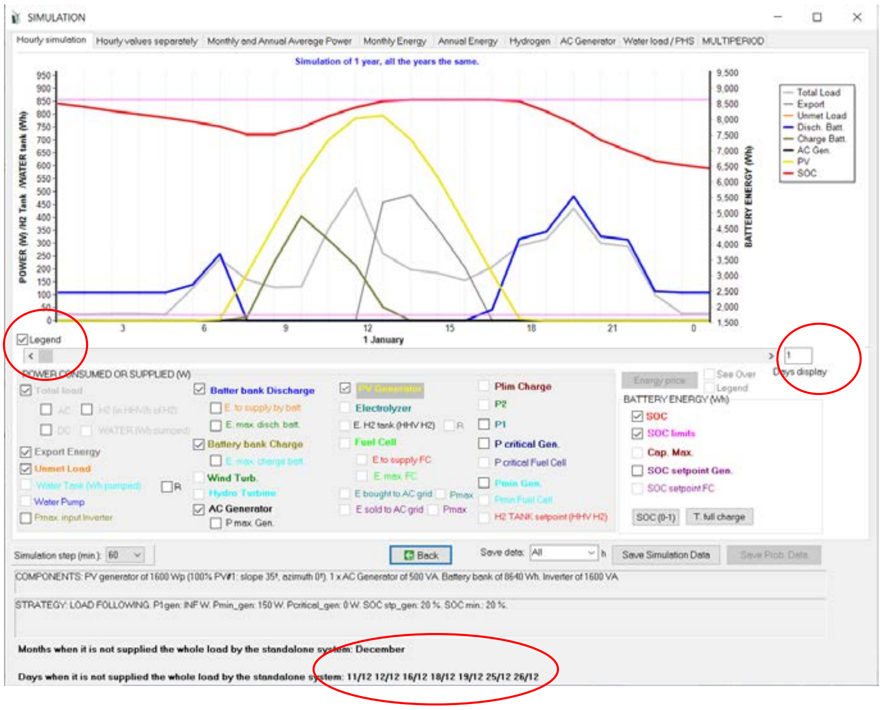
If we move through the table with the bottom bar, and focus on the first row, we can see many results. In blue we can see the results of the annual energy (load, PV generation….), for example, we can see the annual energy charged by the batter (energy that enters into the battery, but the energy stored will be lower, as the charge efficiency is lower than 100%), the annual energy discharged by the battery (energy that effectively supplies the battery, considering efficiency) or the energy supplied by the AC gasoline generator (just 2.8 kWh per year). In black, we can see the hours that it runs in the year (just 18.6 hours) and the battery lifetime (11.36 years).

E ch. bat(kWh)	E disch. bat (kWh)	E elyzer. (kWh)	E gen (kWh)	E FC (kWh)	Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. E
1078.4	922.6	0	2.8	0	18.6	11.36	3119	52
1078.4	922.6	0	2.8	0	18.6	11.36	3119	52
1081.3	924.7	0	5.1	0	12.19	11.31	3127	52
1081.3	924.7	0	5.1	0	12.19	11.31	3127	52
1069.6	915.3	0	8.6	0	53.84	11.36	3159	52
1069.6	915.3	0	8.6	0	53.84	11.36	3159	52
1078.3	925.7	0	1.4	0	10.22	17.3	3118	52
1078.3	925.7	0	1.4	0	10.22	17.3	3118	52
1076.8	921.4	0	14.2	0	33.85	11.32	3178	53

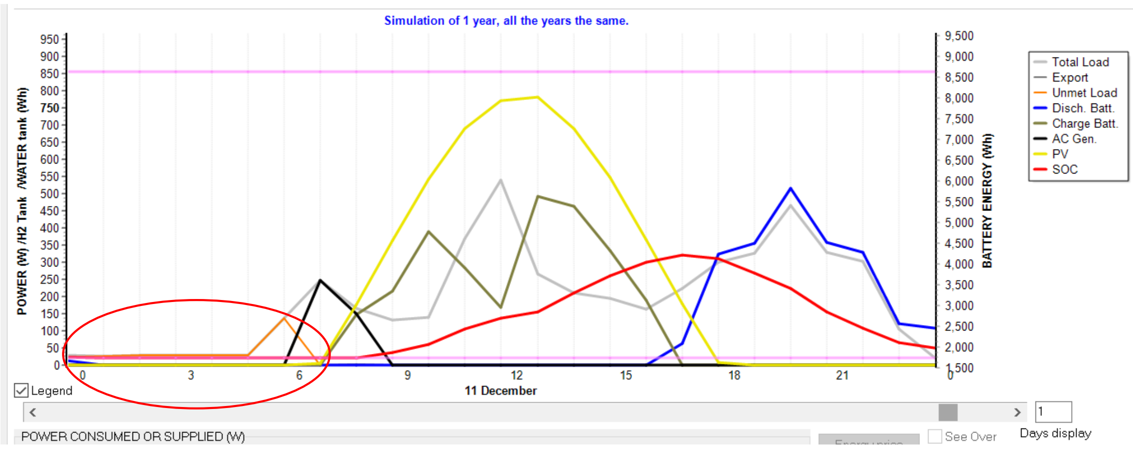
We can see the simulation of the operation of the optimal solution by clicking on the first row of the table, in "**SIMULATE**":

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	14958.3	104.09	1.4	0.09	INF	6.6	99.72	0.51	SIMULATE..	REPORT...	C

The simulation screen appears as shown below (if it has not appeared, click on the iHOGA icon in the taskbar at the bottom of the computer screen and the simulation screen will appear):

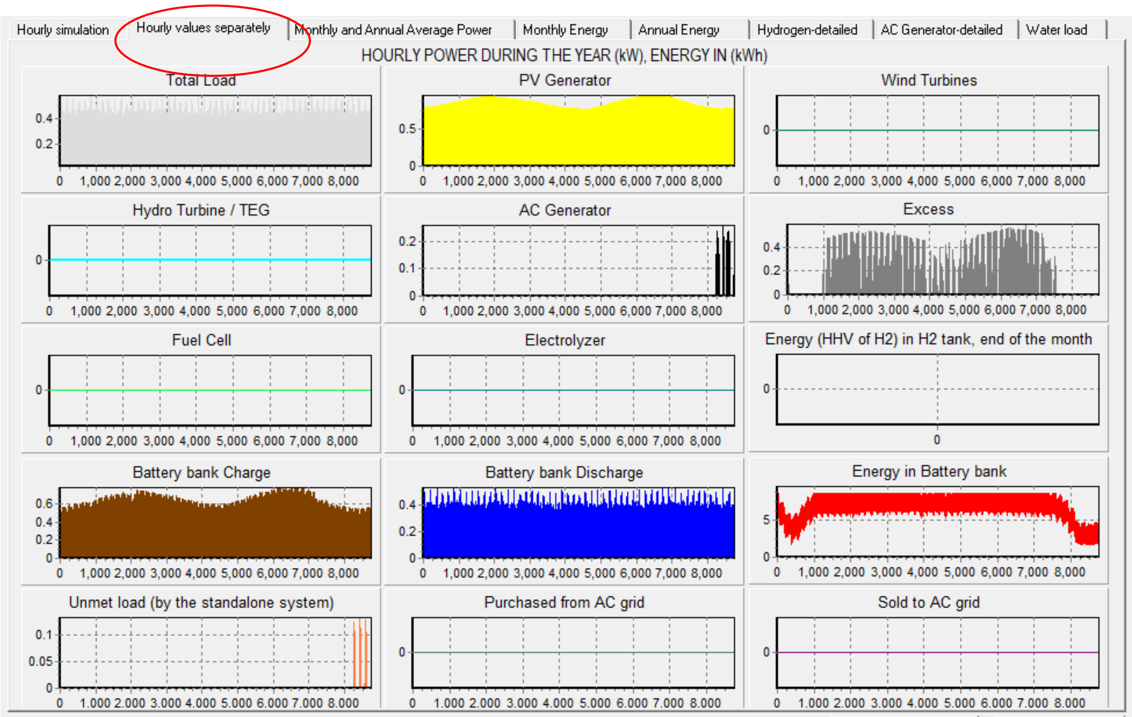


We can see that during several days in December there is unmet load. The first day with unmet load is in December 11th, from 0 to 7 a.m. (*due to the random variability introduced for the AC load in section 4, and also for the irradiation and wind speed, it is possible that the results obtained by the reader are different, the first day with unmet load can be December 12th*), shown in orange, during these hours the battery is at the minimum SOC (so it cannot supply load) and the gasoline generator cannot work because we did not allow it in the AC generator screen (see section 12).



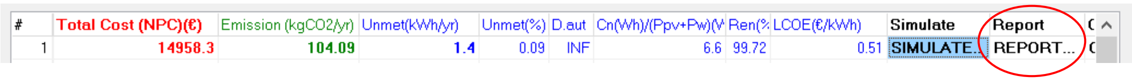
By changing the number of days to show (center right "Days display") you can see several days at a time. You can select and deselect the curves you want by clicking in their respective boxes.

You can see the results of the simulation in different tabs, separated time values, average monthly and annual power, monthly values, annual values ...



By clicking on the simulation screen in "**Back**" button we return to the main screen.

We can see the report of the optimal solution by clicking on the first row of the table, in "**REPORT**".

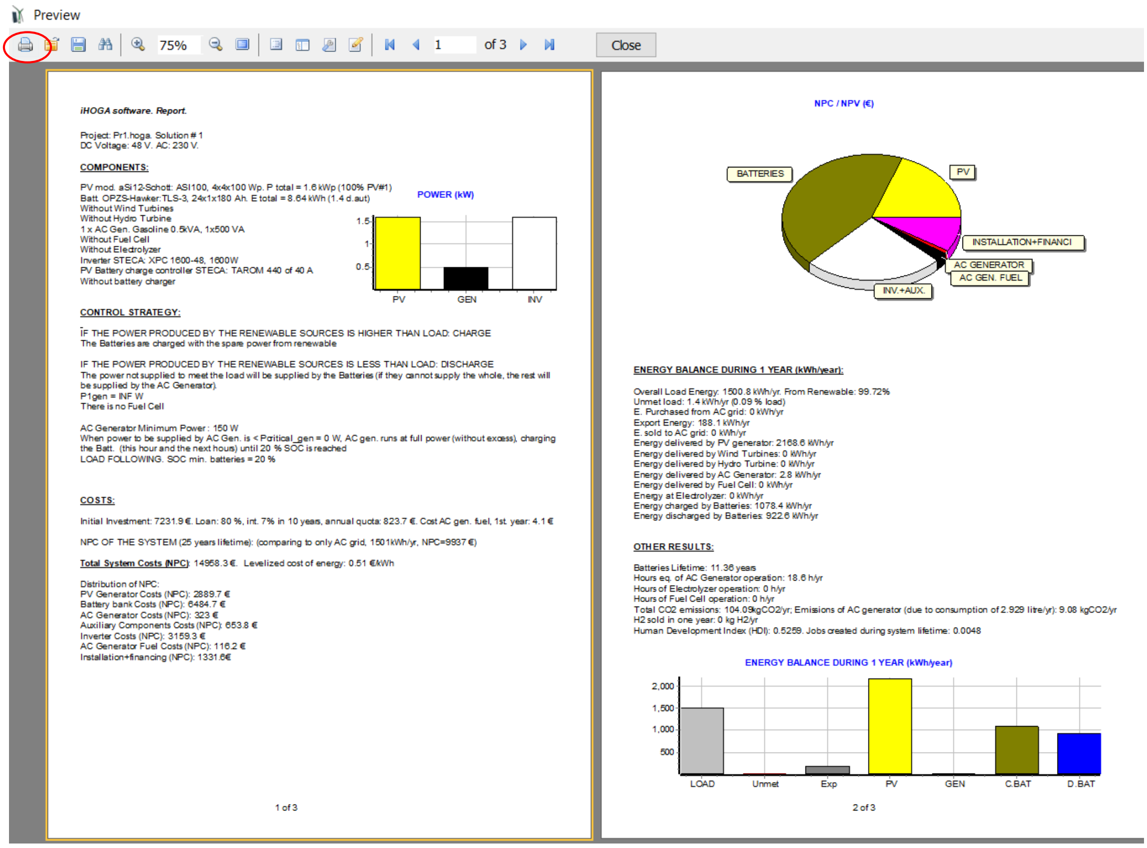


The screen of the report of the best solution appears.

(The same report would have been obtained if we click in the bottom left corner button

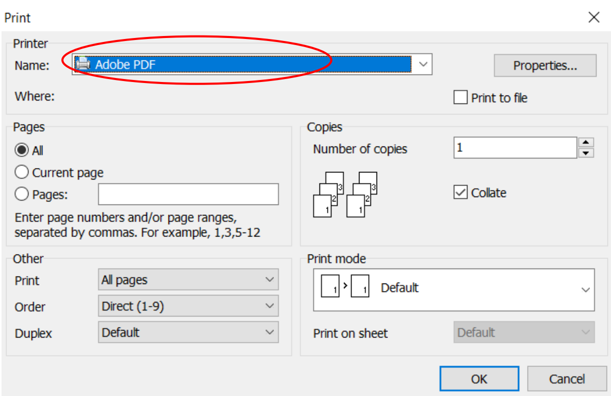
showing this button the best solution found)

The AC gasoline generator implies that autonomy is infinite, complying with the constraint of at least 4.5 days of autonomy, and, since the batteries do not comply (in the optimal solution the batteries only give 1.4 days of autonomy, see 5th line of the report), the presence of the generator implies infinite autonomy.



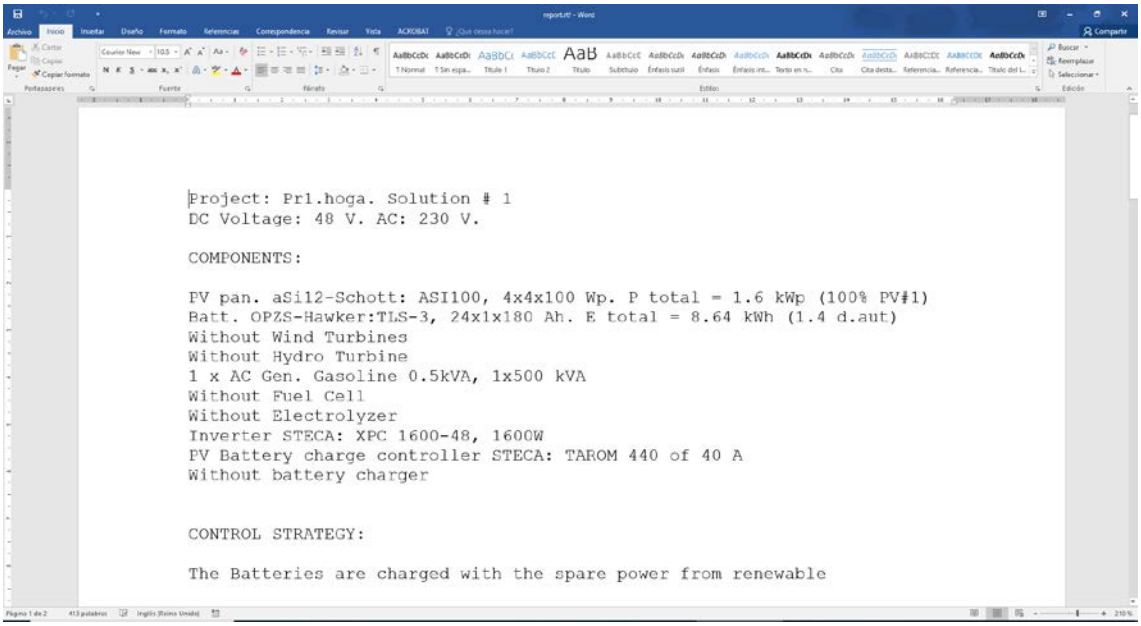
The report can be printed, on paper or in PDF format (if you have installed a virtual Pdf printer, for example Adobe Acrobat or doPDF, which is free).

Press the print button  and then select the physical or vitual printer (in the example, Adobe PDF):



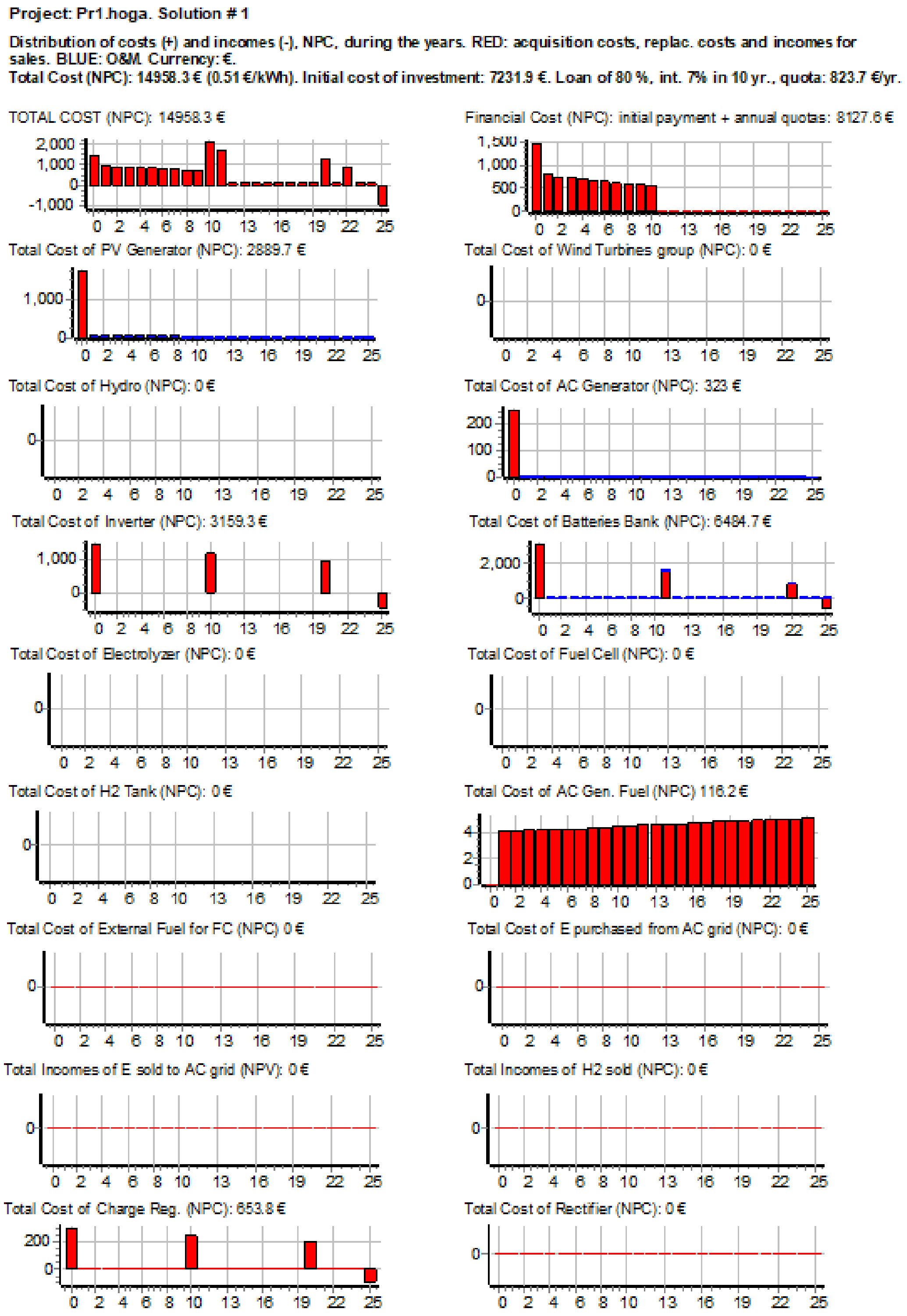
Once the printer is selected (physical or virtual PDF), the report is printed or the PDF file is created by clicking OK (a dialog appears in the Windows taskbar, where you must select the location of the PDF file).

By clicking on the "**Close**" button, the software ask us if we want to save the report in .rtf format (which can be open by Microsft Word). We click YES, we save it and then we can open it with Word:

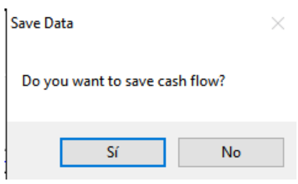


In the main screen, we click on the "COSTS" button of the results table (close to "SIMULATE" button), in the first row:

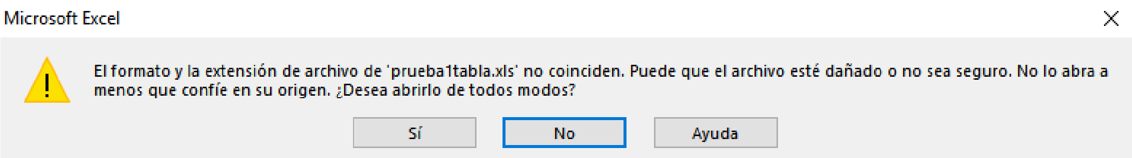
The following screen appears, informing us graphically of the different costs throughout the life of the system:



As in the case of the report screen, you can print or create the PDF. If we close ("**Close**" button) it asks if we want to save the cash flows in Excel.

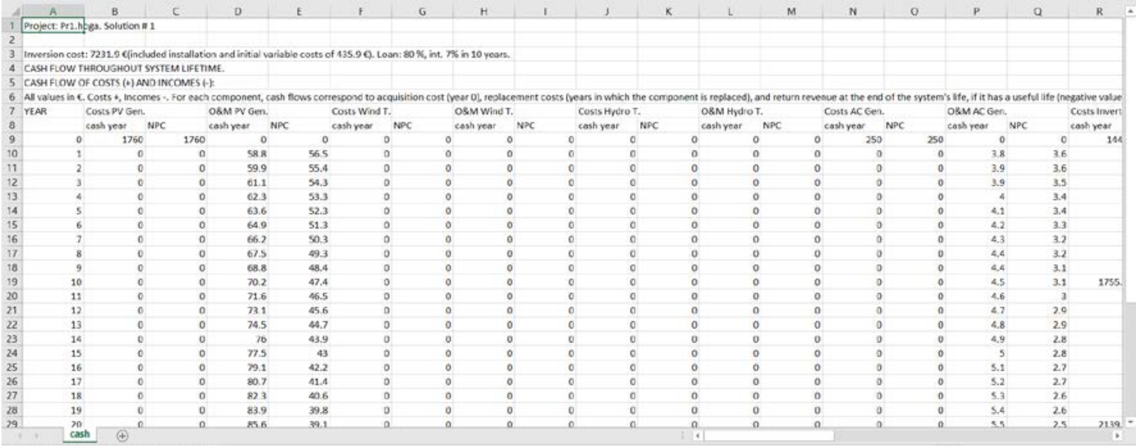


We save the file. Open the saved file with Microsoft Excel (or equivalent software). When opening it we will see a warning:



We answer "Yes" and the Excel file opens perfectly, showing the table of costs.

- Keep in mind that the decimal separation appears as a point. If the decimal separation defined in Windows is comma (usual in Spain and other countries), for Excel to treat the data as numbers we have to:
  - Select the entire Excel sheet and change points by commas
  - Or, in the properties of the Excel sheet, indicate that the decimal separation is the point for this file.



Project: Pr1.hoga. Solution # 1

Inversion cost: 7231.9 €(included installation and initial variable costs of 435.9 €). Loan: 80 %, int. 7% in 10 years.
CASH FLOW THROUGHOUT SYSTEM LIFETIME.
CASH FLOW OF COSTS (+) AND INCOMES (-):
All values in €. Costs +, Incomes -. For each component, cash flows correspond to acquisition cost (year 0), replacement costs (years in which the component is replaced), and return revenue at the end of the system's life, if it has a useful life (negative value

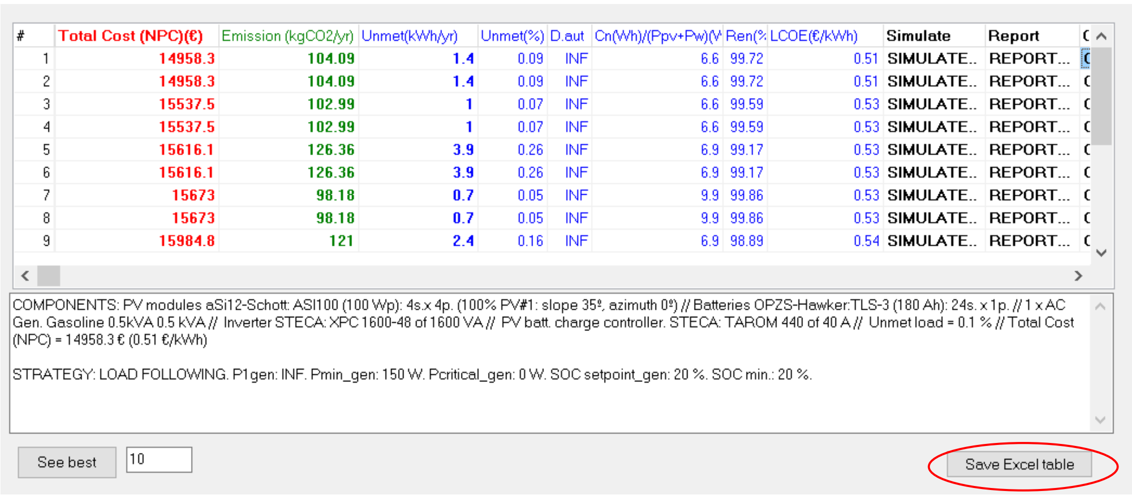
YEAR	Costs PV Gen.		O&M PV Gen.		Costs Wind T.		O&M Wind T.		Costs Hydro T.		O&M Hydro T.		Costs AC Gen.		O&M AC Gen.		Costs Invert
	cash year	NPC	cash year	NPC	cash year	NPC	cash year	NPC	cash year	NPC	cash year	NPC	cash year	NPC	cash year	NPC	cash year
0	1760	1760	0	0	0	0	0	0	0	0	0	0	250	250	0	0	144
1	0	0	58.8	56.5	0	0	0	0	0	0	0	0	0	0	3.8	3.6	
2	0	0	59.9	55.4	0	0	0	0	0	0	0	0	0	0	3.9	3.6	
3	0	0	61.1	54.3	0	0	0	0	0	0	0	0	0	0	3.9	3.5	
4	0	0	62.3	53.3	0	0	0	0	0	0	0	0	0	0	4	3.4	
5	0	0	63.6	52.3	0	0	0	0	0	0	0	0	0	0	4.1	3.4	
6	0	0	64.9	51.3	0	0	0	0	0	0	0	0	0	0	4.2	3.3	
7	0	0	66.2	50.3	0	0	0	0	0	0	0	0	0	0	4.3	3.2	
8	0	0	67.5	49.3	0	0	0	0	0	0	0	0	0	0	4.4	3.2	
9	0	0	68.8	48.4	0	0	0	0	0	0	0	0	0	0	4.4	3.1	
10	0	0	70.2	47.4	0	0	0	0	0	0	0	0	0	0	4.5	3.1	1755.
11	0	0	71.6	46.5	0	0	0	0	0	0	0	0	0	0	4.6	3	
12	0	0	73.1	45.6	0	0	0	0	0	0	0	0	0	0	4.7	2.9	
13	0	0	74.5	44.7	0	0	0	0	0	0	0	0	0	0	4.8	2.9	
14	0	0	76	43.9	0	0	0	0	0	0	0	0	0	0	4.9	2.8	
15	0	0	77.5	43	0	0	0	0	0	0	0	0	0	0	5	2.8	
16	0	0	79.1	42.2	0	0	0	0	0	0	0	0	0	0	5.1	2.7	
17	0	0	80.7	41.4	0	0	0	0	0	0	0	0	0	0	5.2	2.7	
18	0	0	82.3	40.6	0	0	0	0	0	0	0	0	0	0	5.3	2.6	
19	0	0	83.9	39.8	0	0	0	0	0	0	0	0	0	0	5.4	2.6	
20	0	0	85.6	39.1	0	0	0	0	0	0	0	0	0	0	5.5	2.5	2139.

cash

We can save this Excel file by the "Save As" option of Microsoft Excel in Excel format (*.xlsx) and the next time we open it, the previous warning will no longer appear.

23. Save results table.

In the main screen, we can save the results table by clicking on the button "**Save Excel table**"



#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	14958.3	104.09	1.4	0.09	INF	6.6	99.72	0.51	SIMULATE..	REPORT...	C
2	14958.3	104.09	1.4	0.09	INF	6.6	99.72	0.51	SIMULATE..	REPORT...	C
3	15537.5	102.99	1	0.07	INF	6.6	99.59	0.53	SIMULATE..	REPORT...	C
4	15537.5	102.99	1	0.07	INF	6.6	99.59	0.53	SIMULATE..	REPORT...	C
5	15616.1	126.36	3.9	0.26	INF	6.9	99.17	0.53	SIMULATE..	REPORT...	C
6	15616.1	126.36	3.9	0.26	INF	6.9	99.17	0.53	SIMULATE..	REPORT...	C
7	15673	98.18	0.7	0.05	INF	9.9	99.86	0.53	SIMULATE..	REPORT...	C
8	15673	98.18	0.7	0.05	INF	9.9	99.86	0.53	SIMULATE..	REPORT...	C
9	15984.8	121	2.4	0.16	INF	6.9	98.89	0.54	SIMULATE..	REPORT...	C

The table is saved in the file indicated. When we open the file with Microsoft Excel, after accepting the warning, the table appears.

Project: D:\PROYECTOS IHOGA 3.3\Pr1.hoga

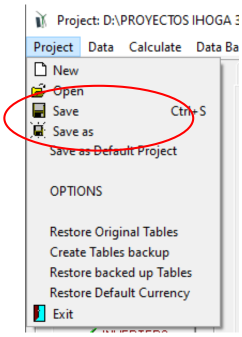
No.	NPC(€)	Em.CO2(kg/yr)	Unmet(kWh/yr)	Unmet(%)	Days auton.	Cn(Wh)/(Ppv+Pw)(W)	Renewable fraction (%)	LCOE (€/kWh)
1	14958.3	104.088	1.398	0.09	1E+10	6.63	99.72	0.5086
2	14958.3	104.088	1.398	0.09	1E+10	6.63	99.72	0.5086
3	15537.5	102.989	1.03	0.07	1E+10	6.63	99.59	0.5282
4	15537.5	102.989	1.03	0.07	1E+10	6.63	99.59	0.5282
5	15616.1	126.364	3.925	0.26	1E+10	6.87	99.17	0.5319
6	15616.1	126.364	3.925	0.26	1E+10	6.87	99.17	0.5319
7	15673	98.185	0.69	0.05	1E+10	9.94	99.86	0.5327
8	15673	98.185	0.69	0.05	1E+10	9.94	99.86	0.5327
9	15984.8	121.003	2.448	0.16	1E+10	6.87	98.89	0.5439
10	15984.8	121.003	2.448	0.16	1E+10	6.87	98.89	0.5439
11	16201.4	116.994	2.372	0.16	1E+10	10.31	99.43	0.5513
12	16201.4	116.994	2.372	0.16	1E+10	10.31	99.43	0.5513
13	16276.3	97.832	0.516	0.03	1E+10	9.94	99.78	0.5531
14	16276.3	97.832	0.516	0.03	1E+10	9.94	99.78	0.5531
15	16648	109.672	1.657	0.11	1E+10	10.31	99.32	0.5662
16	16648	109.672	1.657	0.11	1E+10	10.31	99.32	0.5662
17	16843.301	122.357	0	0	1E+10	4.67	100	0.5722
18	17122.801	126.776	0.736	0.05	1E+10	4.79	99.88	0.582
19	17473.801	122.357	0	0	1E+10	4.67	100	0.5936
20	17748.5	127.389	0.456	0.03	1E+10	4.79	99.82	0.6031
21	18021.1	125.8	0	0	1E+10	7	100	0.6122
22	18235.9	126.44	0	0	1E+10	7.18	100	0.6195
23	18263.9	104.749	0.095	0.01	1E+10	13.25	99.98	0.6205
24	18263.9	104.749	0.095	0.01	1E+10	13.25	99.98	0.6205
25	18651.6	125.8	0	0	1E+10	7	100	0.6336
26	18654.301	110.891	0	0	1E+10	5.15	100	0.6337

table

We can save this Excel file by the "Save As" option of Microsoft Excel in Excel format (*.xlsx) and the next time we open it, the previous warning will no longer appear.

24. Save the project.

In the top menu of the main screen, click **Project-> Save**, the project will be saved. It should have been done periodically.



25. Save as default project.

We won't do it, but, in the top menu of the main screen, clicking **Project-> Save as Default Project** we could save the present project to be the default project when we create new projects (you don't have to do it in this case). Later we can change the default project to another one that interests us more.

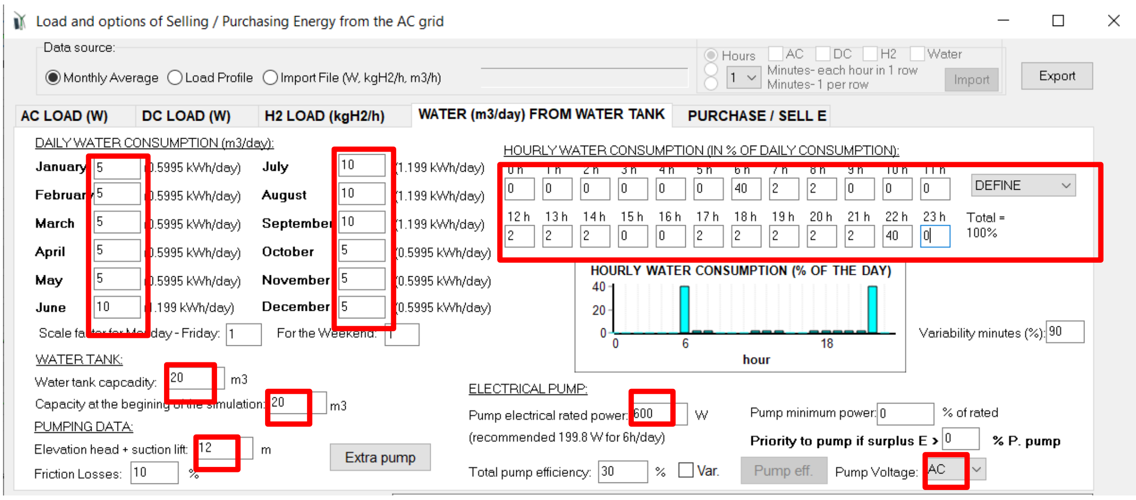
26. Consumption of water previously pumped to tank.

Now we are going to add water pumping consumption to the project.

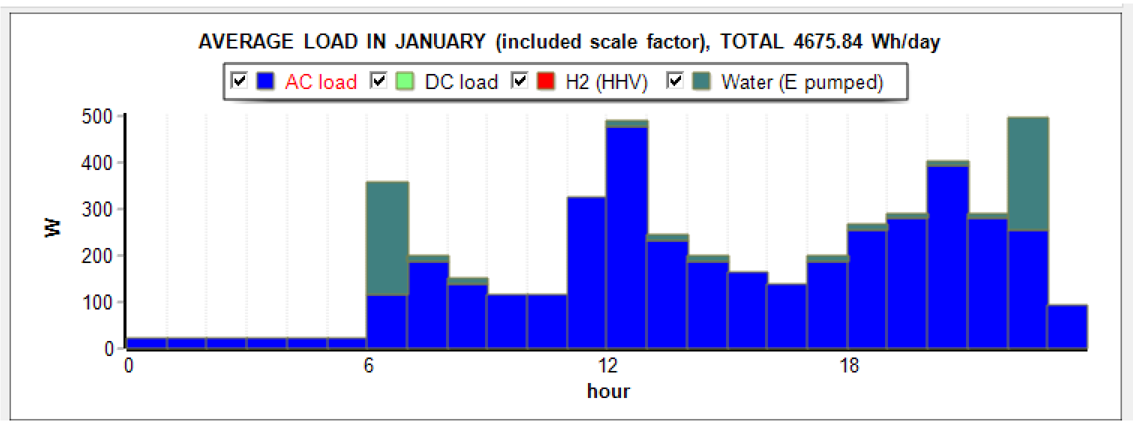
We save the project with another name. To do this, in the top menu of the main screen click **Project-> Save As** and the project will be saved with another name, preserving the original saved. Let's save it as with the name "**Pr1-Water.hoga**".

Clicking on the main screen on the button "**LOAD / AC GRID**" it shows the screen where the demand is indicated.

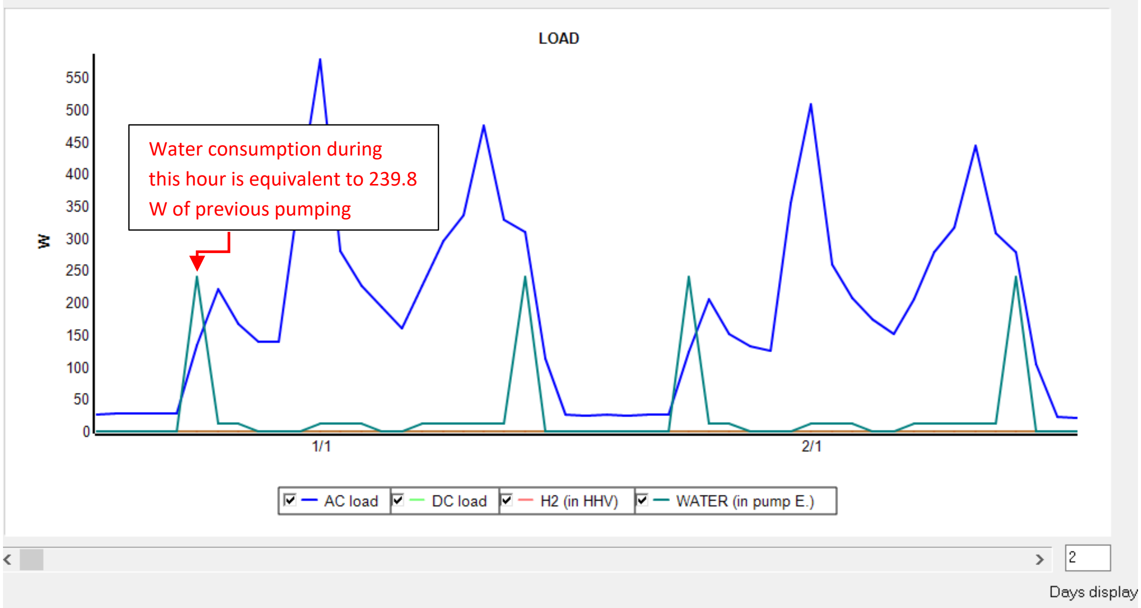
The water consumption data are indicated in the tab "**WATER (m3/day) FROM WATER TANK (PREVIOUSLY PUMPED)**". Suppose the house has a well so that we pump water to a 20 m^3 tank, assuming it is full at the beginning of the year. The pumping height is 12 m. Consumption, mainly for irrigation, is 10 m^3/day in summer (June-September) and 5 m^3/day the rest of the year, with a consumption profile like the one shown in the figure. The pump is AC type of 600 W. The estimated performance of the pump is 30%. The rest of the data is left by default.



The graph below the data shows the average daily consumption for the month selected (where you clicked the last time the daily water consumption):



By clicking on "**Generate**" button you get the new total consumption of the system. In the lower part of the screen you can see the average value of 4.88 kWh/day. If we visualize the graph in steps of 60 minutes, it can be seen the first two days of January:



AC power consumption is shown in blue color and in turquoise color is water consumption (translated to W previously pumped). For example, in 1st January the water consumption in the hour that goes between 6 and 7 h a.m. is 40% of the day (40/100·5 = 2 m^3), which will have been previously pumped a height of 12 m plus 10% friction losses (equivalent to a total height of 13.2 m) with a 30% efficiency pump. The energy needed to pre-pump that volume of water is:

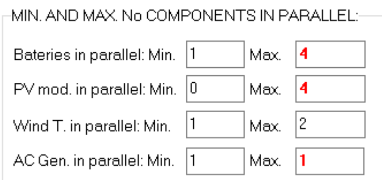
$$E = volume\cdot density\cdot g\cdot height\cdot (1+friction\_losses)/Efficiency =$$

$$=2m^3\cdot 1000kg/m^3\cdot 9.81m/s^2\cdot 12m\cdot (1+0.1)/0.3 = 863280\ J = 239.8\ Wh.$$

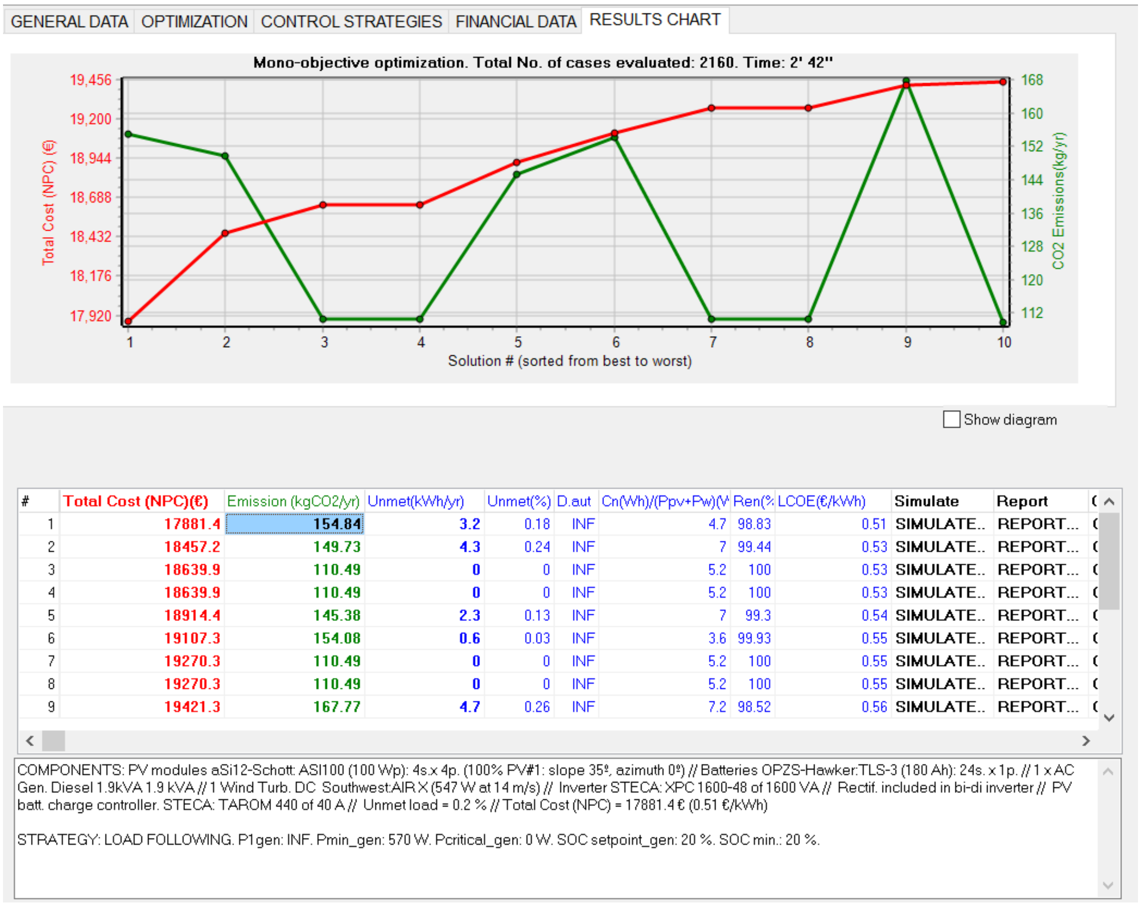
That is, equivalent to a consumption of 239.8 W during that hour, as shown in the graph.

We return to the main screen of the program.

Click on "**PRESIZING**" and we see how the maximum numbers of components in parallel are updated. But we will change manually to the following, reducing the maximum allowed:



Save the project. By clicking on "**CALCULATE**" the system is optimized, obtaining the following results:



#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	17881.4	154.84	3.2	0.18	INF	4.7	98.83	0.51	SIMULATE..	REPORT...	(
2	18457.2	149.73	4.3	0.24	INF	7	99.44	0.53	SIMULATE..	REPORT...	(
3	18639.9	110.49	0	0	INF	5.2	100	0.53	SIMULATE..	REPORT...	(
4	18639.9	110.49	0	0	INF	5.2	100	0.53	SIMULATE..	REPORT...	(
5	18914.4	145.38	2.3	0.13	INF	7	99.3	0.54	SIMULATE..	REPORT...	(
6	19107.3	154.08	0.6	0.03	INF	3.6	99.93	0.55	SIMULATE..	REPORT...	(
7	19270.3	110.49	0	0	INF	5.2	100	0.55	SIMULATE..	REPORT...	(
8	19270.3	110.49	0	0	INF	5.2	100	0.55	SIMULATE..	REPORT...	(
9	19421.3	167.77	4.7	0.26	INF	7.2	98.52	0.56	SIMULATE..	REPORT...	(

COMPONENTS: PV modules aSi12-Schott ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker.TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 kVA // 1 Wind Turb. DC Southwest.AIR X (547 W at 14 m/s) // Inverter STECA: XPC 1600-48 of 1600 VA // Rectif. included in bi-di inverter // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0.2 % // Total Cost (NPC) = 17881.4 € (0.51 €/kWh)

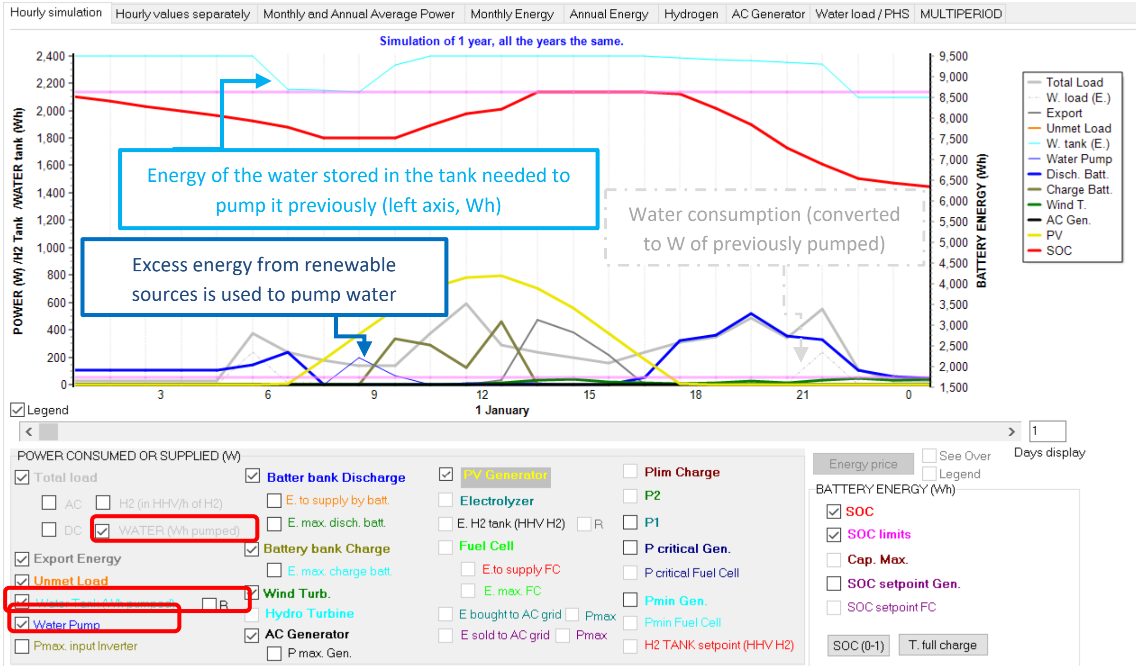
STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

Remember, for all the results: due to the random variability introduced for the AC load in section 4, and also for the irradiation and wind speed, it is possible that the results obtained by the reader with his/her computer are slightly different from those obtained in this guide, since the AC load and the resources will not be exactly the same for every time step (due to the random variability introduced).

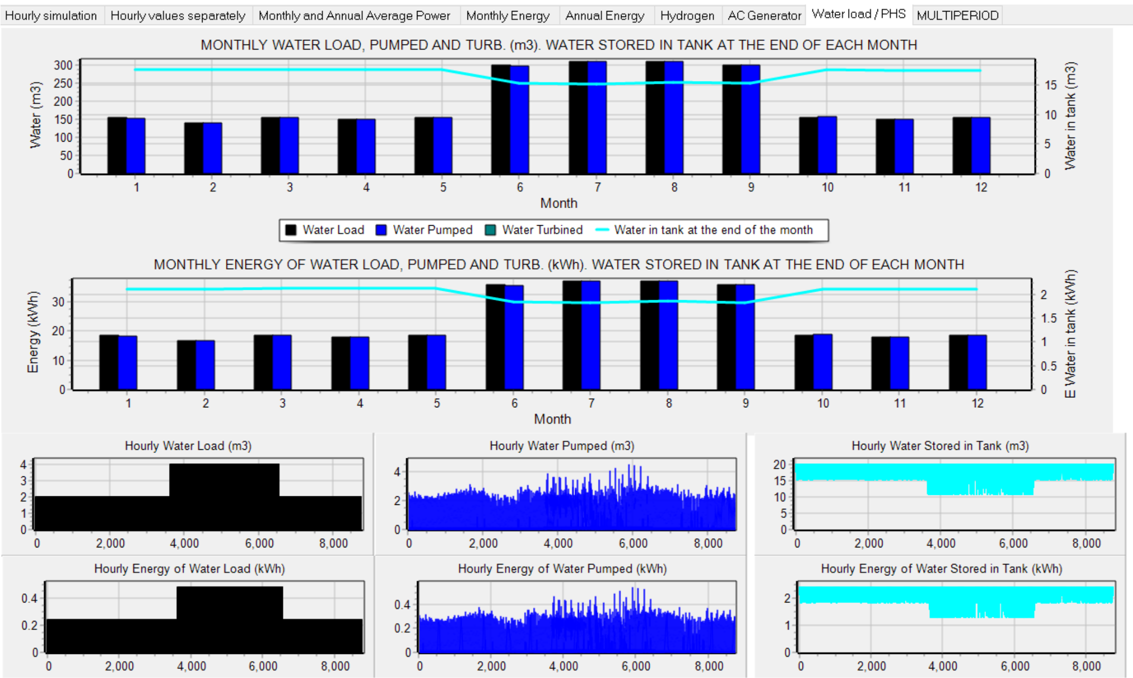
The optimal system differs from the original (Pr1.hoga) in that it includes a wind turbine and backup generator is diesel of 1.9 kVA.

In the simulation of the optimal system (first row of the table), the energy equivalent of the water tank can be seen (energy needed to pump the water previously, in Wh, referred to the left axis) in light blue.

In dark blue, a fine line shows the pumping, which occurs when there is surplus energy from the renewables, dedicating the remaining energy primarily to pumping, and when the tank is full, it is dedicated to charging the batteries.



In the last tab of the simulation window, "**Water load**", the following is shown:

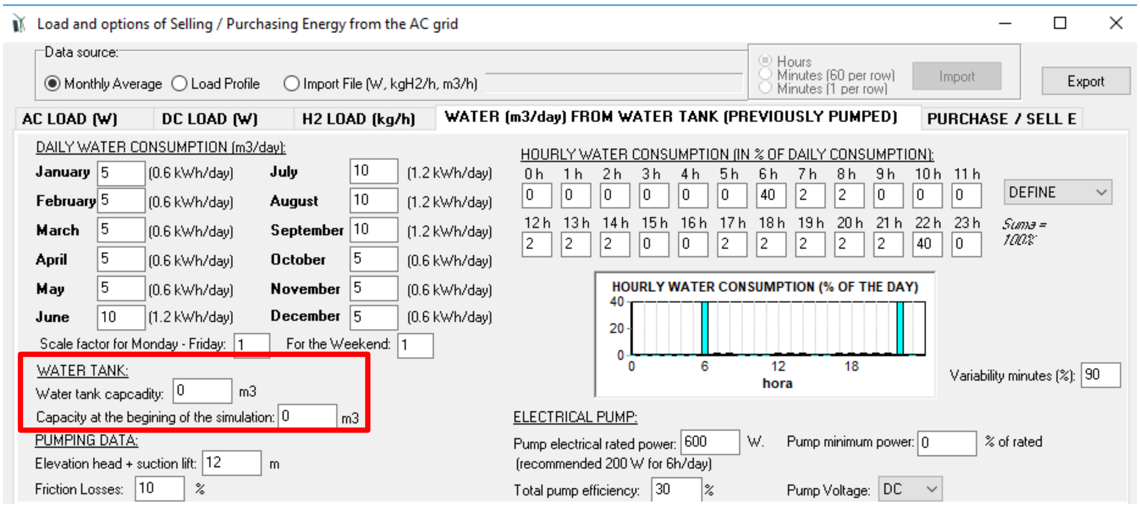


<u>Version 2: water consumption by direct pumping (without water tank):</u>

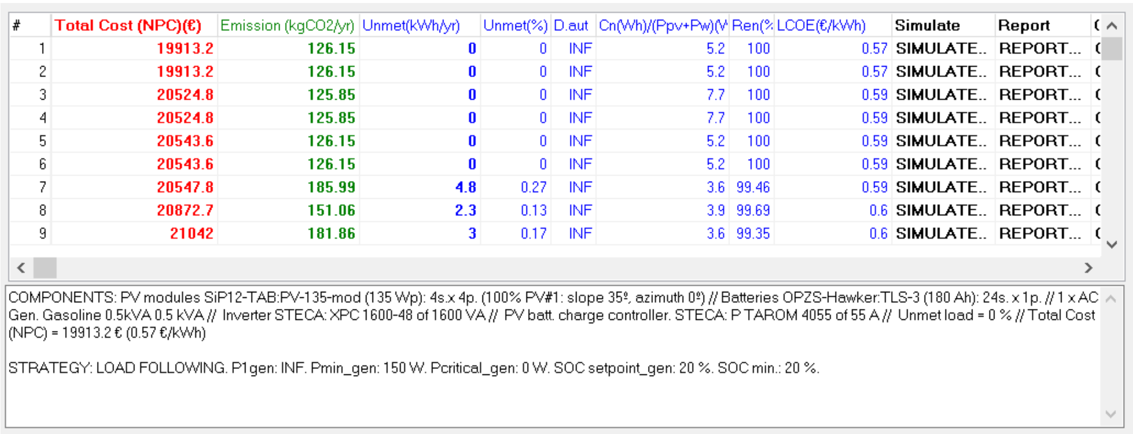
Let's now assume the same case but without water tank (pumping the water directly when we need to consume it).

We save the project. Then **Project-> Save As** and save the project with the name "**Pr1-Water-NoTank.hoga**".

In the water consumption screen, we set the tank capacity to 0 (and the initial volume):



Click on **Generate** button. **OK**. In the main screen, save the project and **CALCULATE** again. The optimal system is the following:

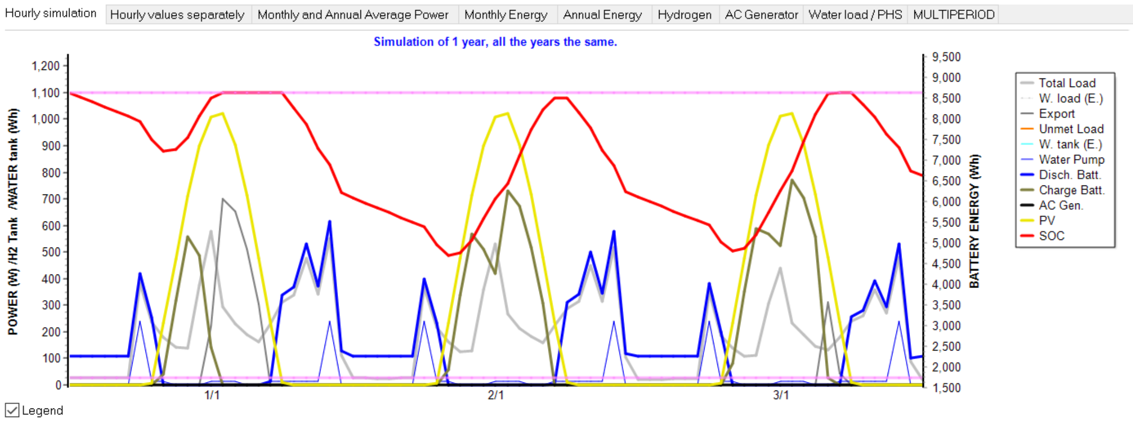


#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	19913.2	126.15	0	0	INF	5.2	100	0.57	SIMULATE..	REPORT...
2	19913.2	126.15	0	0	INF	5.2	100	0.57	SIMULATE..	REPORT...
3	20524.8	125.85	0	0	INF	7.7	100	0.59	SIMULATE..	REPORT...
4	20524.8	125.85	0	0	INF	7.7	100	0.59	SIMULATE..	REPORT...
5	20543.6	126.15	0	0	INF	5.2	100	0.59	SIMULATE..	REPORT...
6	20543.6	126.15	0	0	INF	5.2	100	0.59	SIMULATE..	REPORT...
7	20547.8	185.99	4.8	0.27	INF	3.6	99.46	0.59	SIMULATE..	REPORT...
8	20872.7	151.06	2.3	0.13	INF	3.9	99.69	0.6	SIMULATE..	REPORT...
9	21042	181.86	3	0.17	INF	3.6	99.35	0.6	SIMULATE..	REPORT...

COMPONENTS: PV modules SiP12-TAB:PV-135-mod (135 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: P TAROM 4055 of 55 A // Unmet load = 0 % // Total Cost (NPC) = 19913.2 € (0.57 €/kWh)

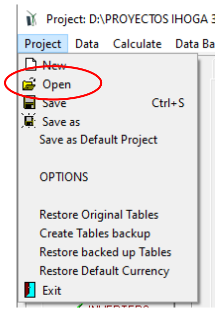
STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

In the simulation of the optimal system (first row of the table) we can see that the batteries supply the consumption when there is no solar irradiation. The wind turbines supply very little energy due to the low wind speed. It can be seen that the discharge power of the batteries is a little higher than the AC consumption, due to the losses in the inverter. At the end of the year some hours the diesel generator supplies the demand.



<u>Version 3: AC grid available (not allowed in version EDU).</u>

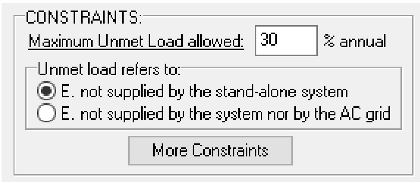
We save the project. Then we open the previous project, **Project->Open**, select **Pr1-Water.hoga**.



Then we save it as "**Pr1-Water-Grid.hoga**".

We assume that we have access to the electricity grid, but for example we want at least 70% of the energy to be covered autonomously (that is, by the stand-alone system without AC grid), and that the AC grid can provide as much as 30% of the annual energy.

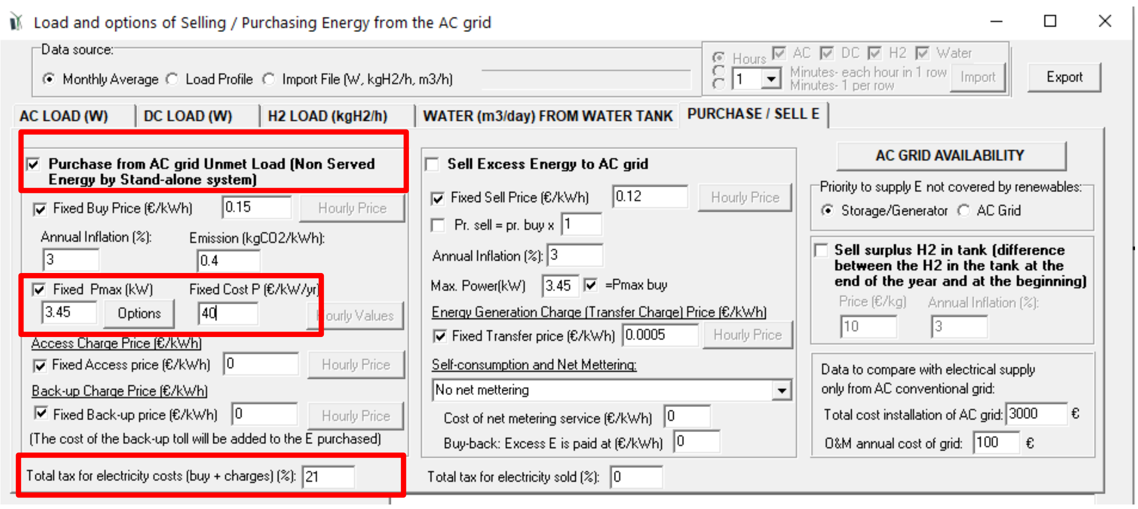
For this, in the main screen, tab "**GENERAL DATA**", in Restrictions we change the maximum unmet load allowed (by the stand-alone system) to 30%.



Then click on the "**LOAD / AC GRID**" button on the main screen, and access the consumption and grid data screen. Click on the last tab ("**PURCHASE / SELL E**").

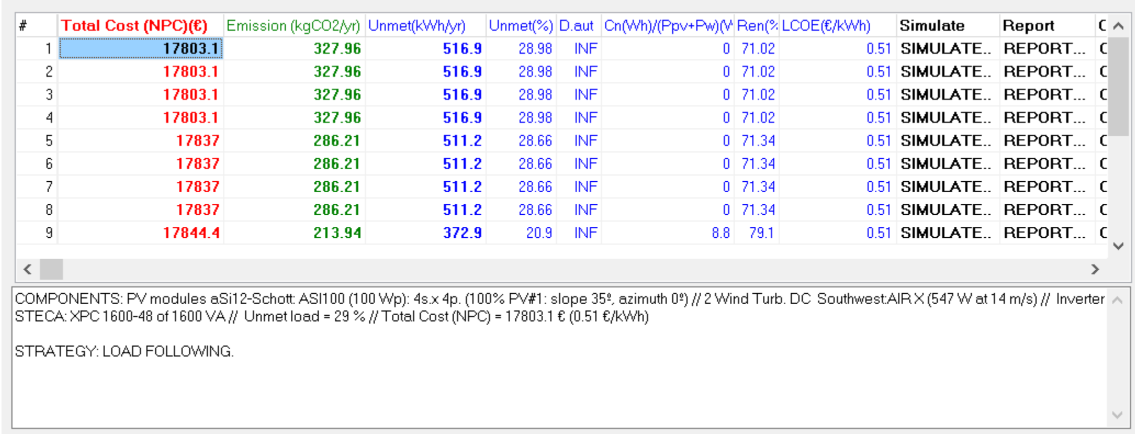
There we mark the box "**Purchase from AC grid Unmet Load** ..." and we put the taxes at 21%. The maximum contracted power is 3.45 kW and the annual cost is 40 €/year. We leave the other data by default.

The kWh costs 15 c€ (plus 21% tax). The annual inflation of the price of electricity is 3% and the emissions due to the energy of the AC grid are 0.4 kg of CO_2 per kWh.



We return to the main screen, save the project and calculate.

The optimal system no longer includes AC generator nor batteries.

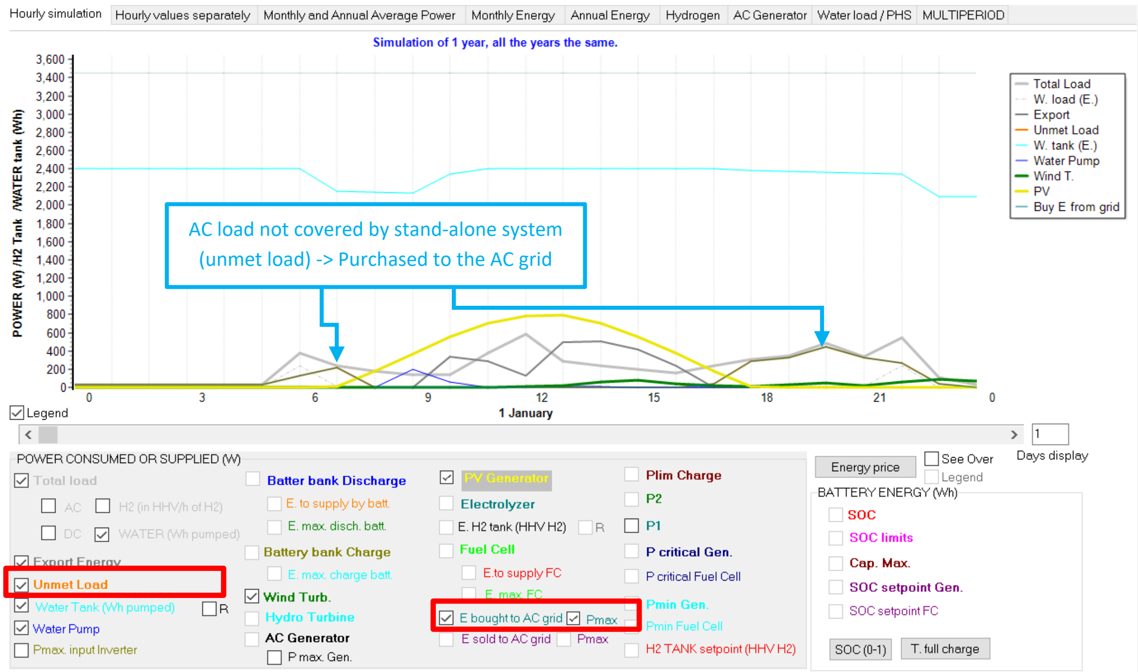


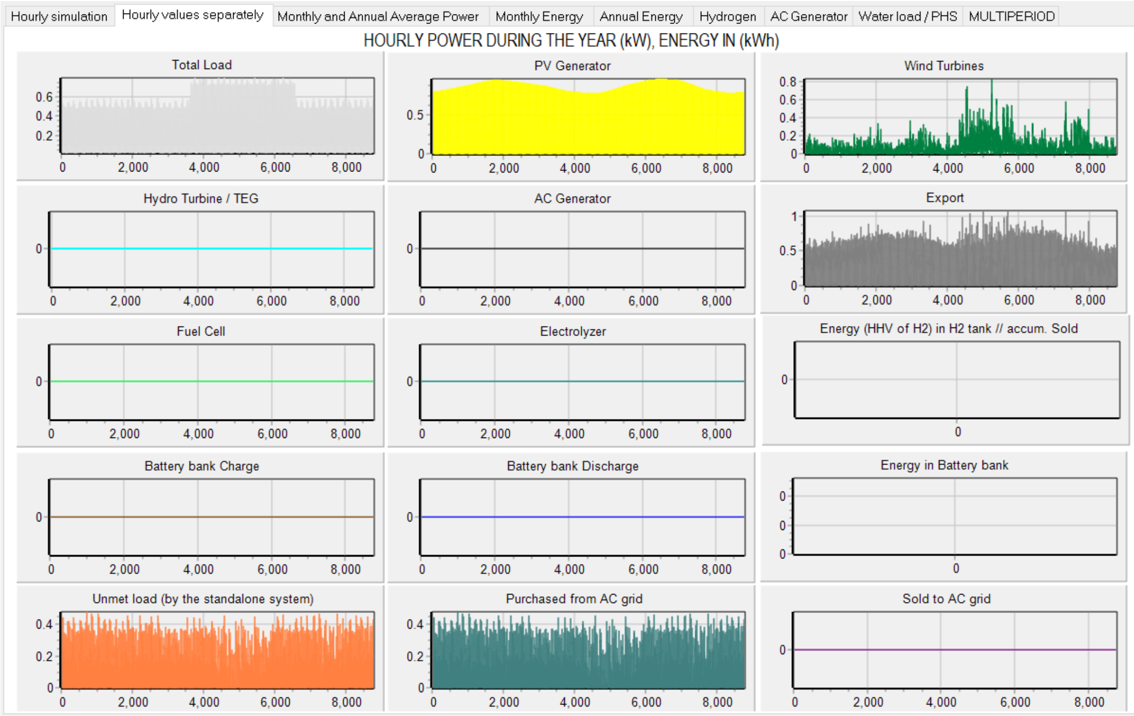
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	17803.1	327.96	516.9	28.98	INF	0	71.02	0.51	SIMULATE..	REPORT...	C
2	17803.1	327.96	516.9	28.98	INF	0	71.02	0.51	SIMULATE..	REPORT...	C
3	17803.1	327.96	516.9	28.98	INF	0	71.02	0.51	SIMULATE..	REPORT...	C
4	17803.1	327.96	516.9	28.98	INF	0	71.02	0.51	SIMULATE..	REPORT...	C
5	17837	286.21	511.2	28.66	INF	0	71.34	0.51	SIMULATE..	REPORT...	C
6	17837	286.21	511.2	28.66	INF	0	71.34	0.51	SIMULATE..	REPORT...	C
7	17837	286.21	511.2	28.66	INF	0	71.34	0.51	SIMULATE..	REPORT...	C
8	17837	286.21	511.2	28.66	INF	0	71.34	0.51	SIMULATE..	REPORT...	C
9	17844.4	213.94	372.9	20.9	INF	8.8	79.1	0.51	SIMULATE..	REPORT...	C

COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // 2 Wind Turb. DC Southwest:AIR X (547 W at 14 m/s) // Inverter STECA: XPC 1600-48 of 1600 VA // Unmet load = 29 % // Total Cost (NPC) = 17803.1 € (0.51 €/kWh)

STRATEGY: LOAD FOLLOWING.

In the simulation, for example, we can see that on January 1st, during all the night until 7 a.m., there is AC load that cannot be covered by the stand-alone system (there is no solar irradiation and there are no batteries, so it is unmet load by the stand-alone system), so that load is purchased from the AC grid.





27. Using hourly irradiation and wind speed data from PVGIS or Renewable Ninja.

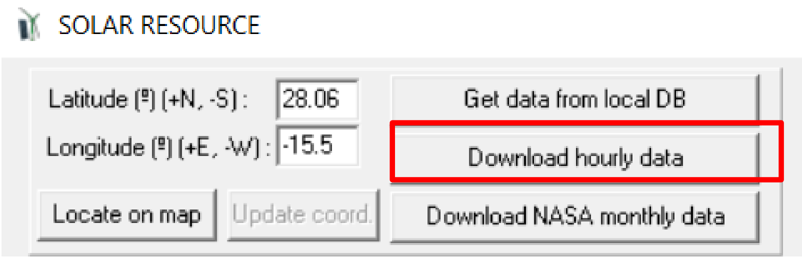
We can use hourly data for irradiation, temperature and wind speed data obtained from the database of PVGIS or from the database of Renewable Ninja. We could also use hourly data from NASA.

We save the project.

We open the project “Pr1.hoga” (**Project -> Open**).

Then we save the project with another name, **Project-> Save As**, let's save it as "**Pr1-Ninja.hoga**".

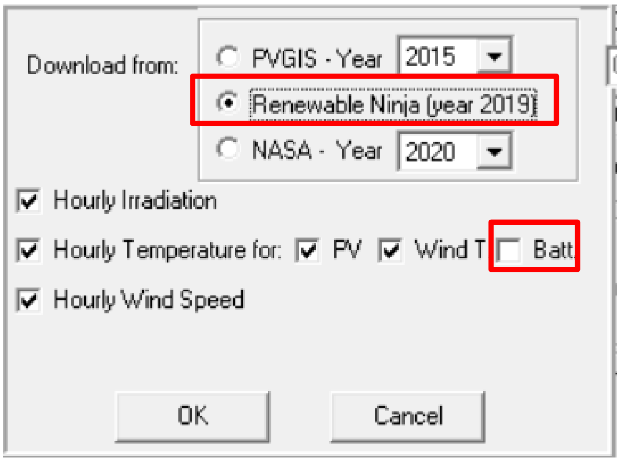
In the SOLAR or WIND resource windows, click in “**Download hourly data**”.



Then a small window appears, showing the database to choose (PVGIS or Renewable Ninja) and the that can be downloaded.

Renewable Ninja data:

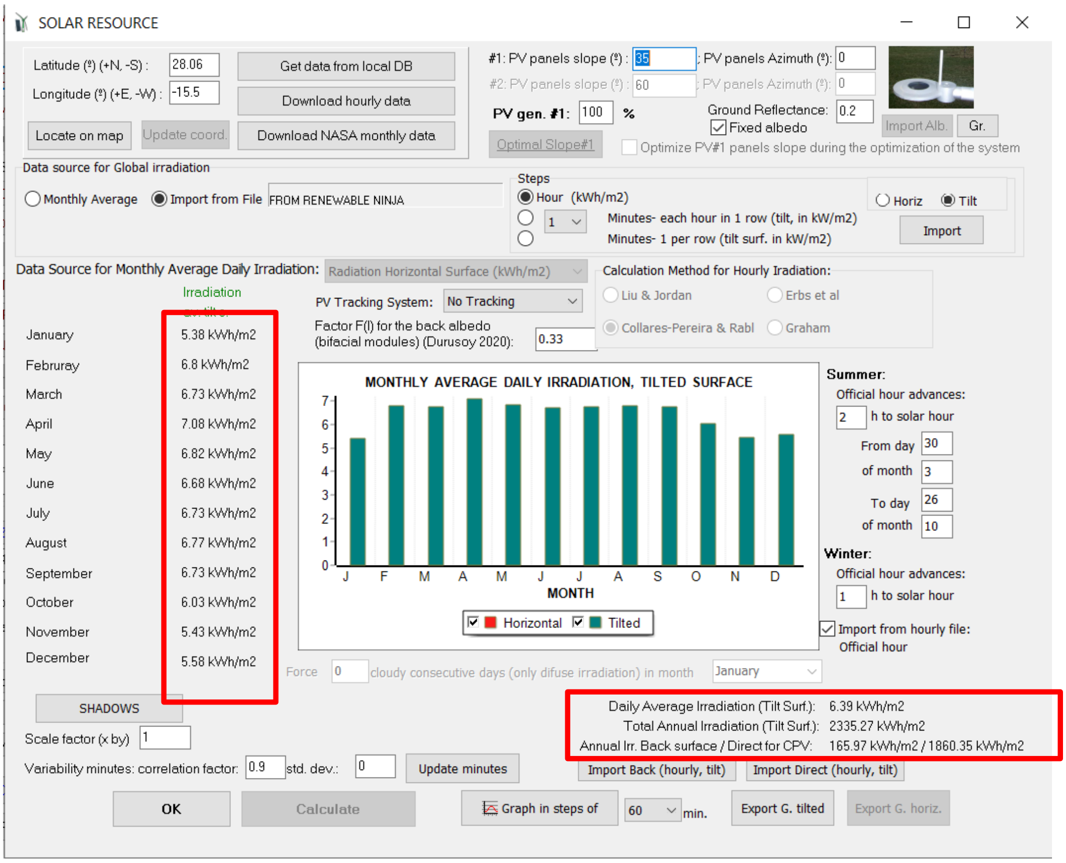
First we select the database of Renewable Ninja. This database has some restrictions: with this database we can only download data of year 2019, and we can do only 5 downloads per day (each download of irradiation/temperature is counted and also each download of wind speed is counted) however if you can change your IP (for example using a free VPN service as https://www.tunnelbear.com/) you can do 5 downloads each time you have a new IP. These restrictions are not for PVGIS database.



We leave the checked default values, all are checked except for the temperature of the batteries, because we can suppose the batteries temperature is different from ambient temperature, assuming they are into a place and not in the outdoor (their temperature will be defined later in the batteries window).

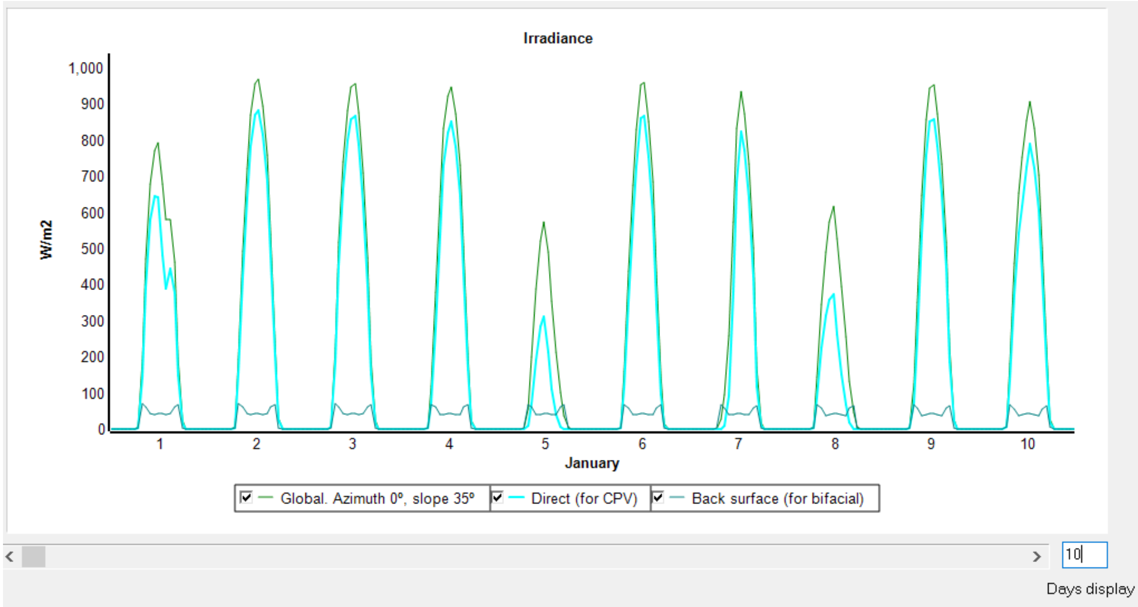
By clicking "**OK**" an info message appears, we click "**OK**" again and hourly data are downloaded, in two times, first irradiation over tilted surface and temperature and later wind speed.

In the solar resource window, we can see hourly irradiation over tilted surface data imported from Renewable Ninja.

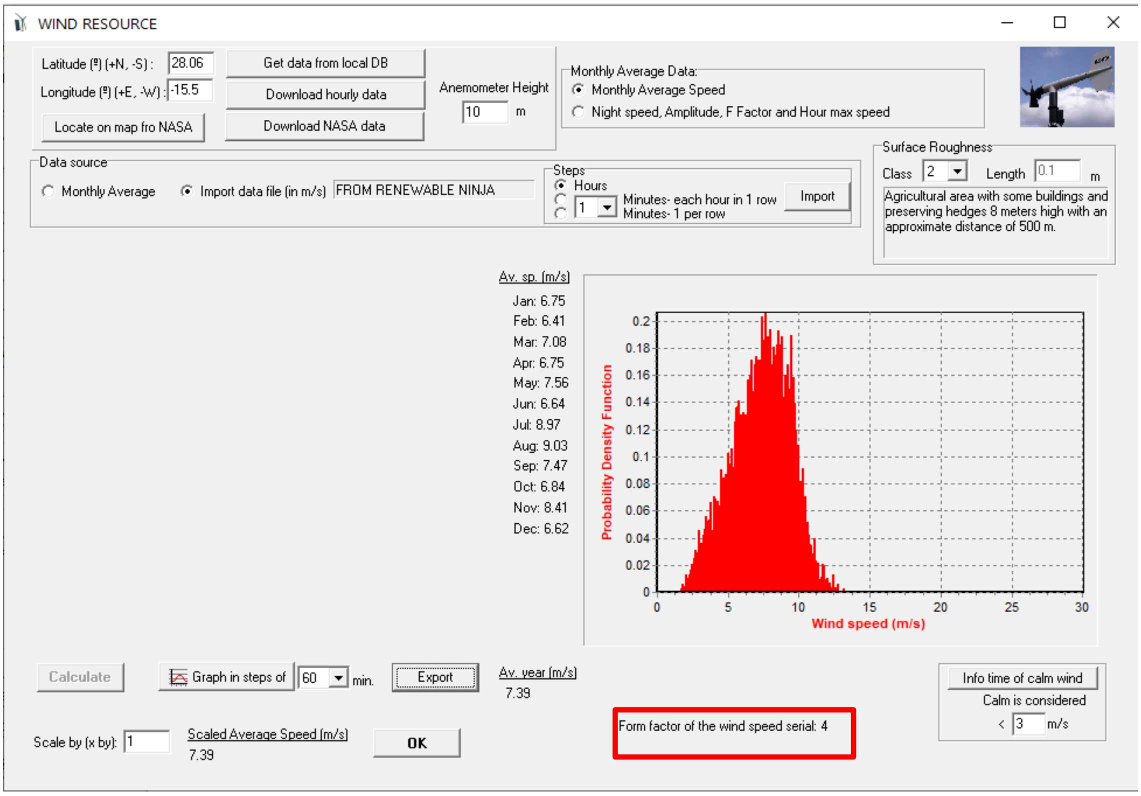


Total annual irradiation over the inclined surface is 2335 kWh/m^2, compared to 2079 kWh/m^2 obtained with NASA data (obtained in section 5).

If we click on the button "**Graph in septs of**" (60 min.) we see the hourly irradiation downloaded from Renewable Ninja:

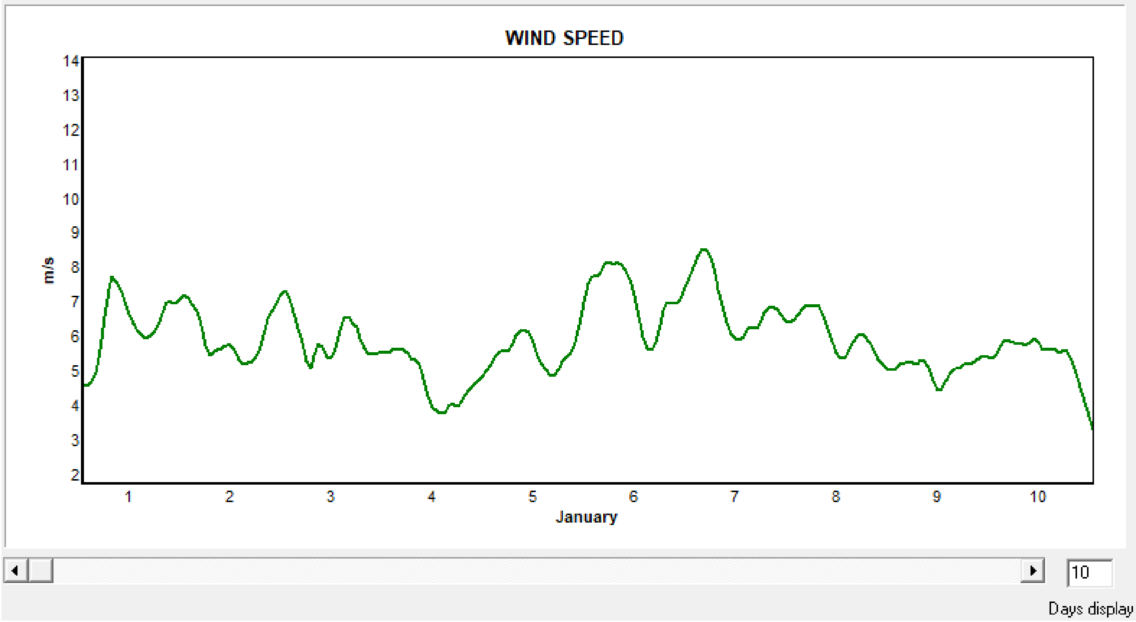


In the wind resource window, we see the data downloaded from Renewable Ninja:

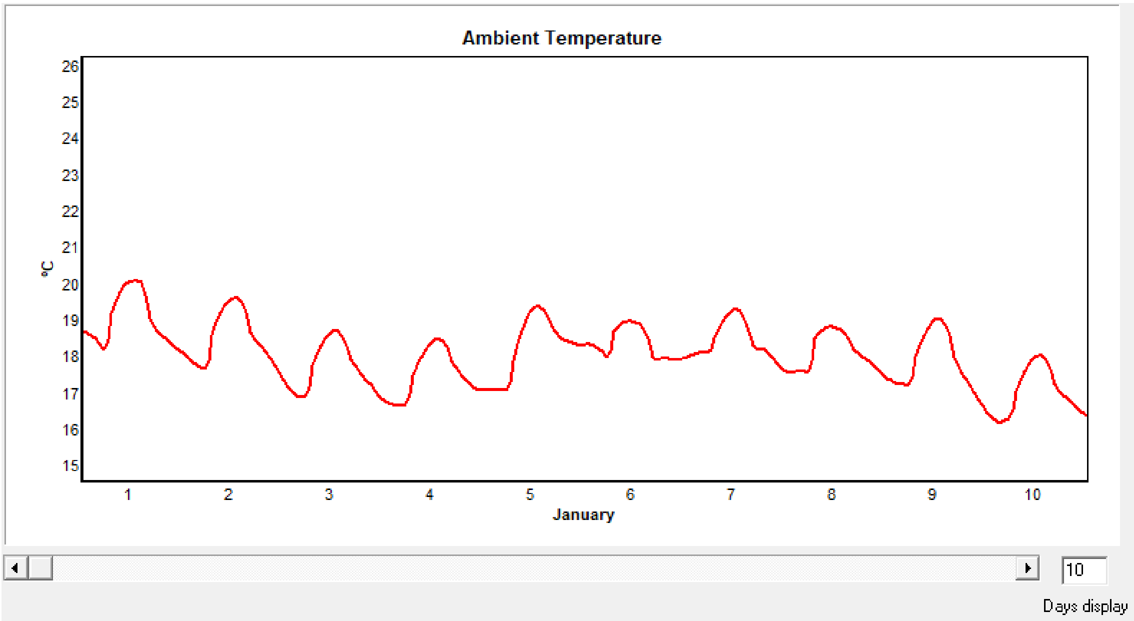


In this case average wind speed is 7.39 m/s and the Weibull form factor of the downloaded data is 4. Previously, in section 6, with NASA data an average wind speed of 4.62 m/s was obtained.

If we click on the button "**Graph in septs of**" (60 min.) we see the hourly irradiation downloaded from Renewable Ninja:



In the Wind turbines window, we can see the air temperature downloaded:

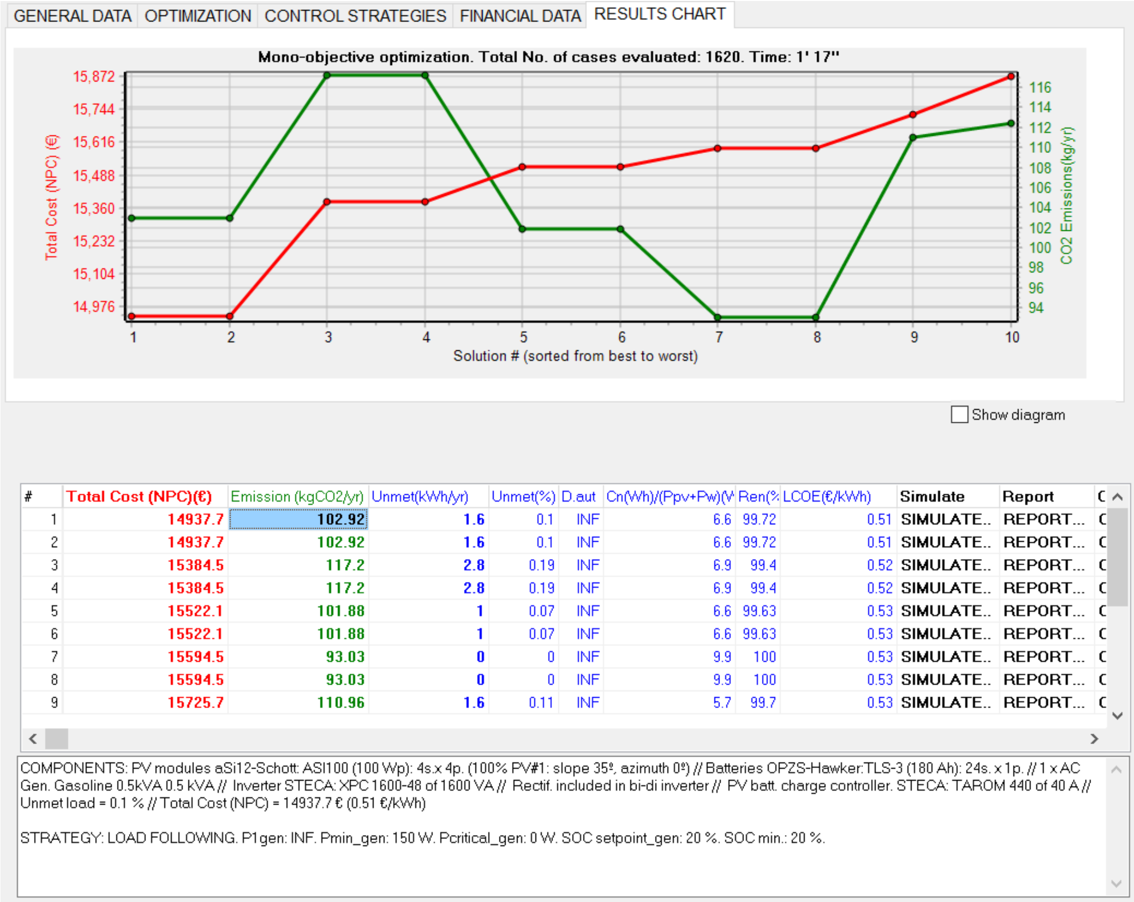


You must accept the wind turbines window (OK) so that the temperature values downloaded are considered.

In the PV modules window we would see this if there was MPPT, but we do not consider MPPT so temperature has no effect.

Now, in the main window, save the project and click "**CALCULATE**" to optimize the system with the new data downloaded from Renewable Ninja.

We obtain an optimal system similar to the obtained with NASA.



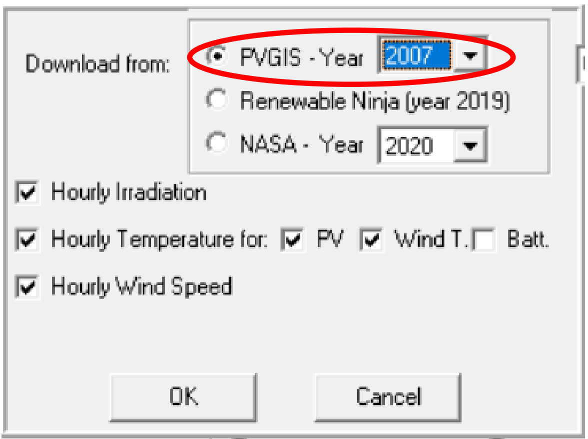
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	14937.7	102.92	1.6	0.1	INF	6.6	99.72	0.51	SIMULATE..	REPORT...
2	14937.7	102.92	1.6	0.1	INF	6.6	99.72	0.51	SIMULATE..	REPORT...
3	15384.5	117.2	2.8	0.19	INF	6.9	99.4	0.52	SIMULATE..	REPORT...
4	15384.5	117.2	2.8	0.19	INF	6.9	99.4	0.52	SIMULATE..	REPORT...
5	15522.1	101.88	1	0.07	INF	6.6	99.63	0.53	SIMULATE..	REPORT...
6	15522.1	101.88	1	0.07	INF	6.6	99.63	0.53	SIMULATE..	REPORT...
7	15594.5	93.03	0	0	INF	9.9	100	0.53	SIMULATE..	REPORT...
8	15594.5	93.03	0	0	INF	9.9	100	0.53	SIMULATE..	REPORT...
9	15725.7	110.96	1.6	0.11	INF	5.7	99.7	0.53	SIMULATE..	REPORT...

<u>PVGIS data:</u>

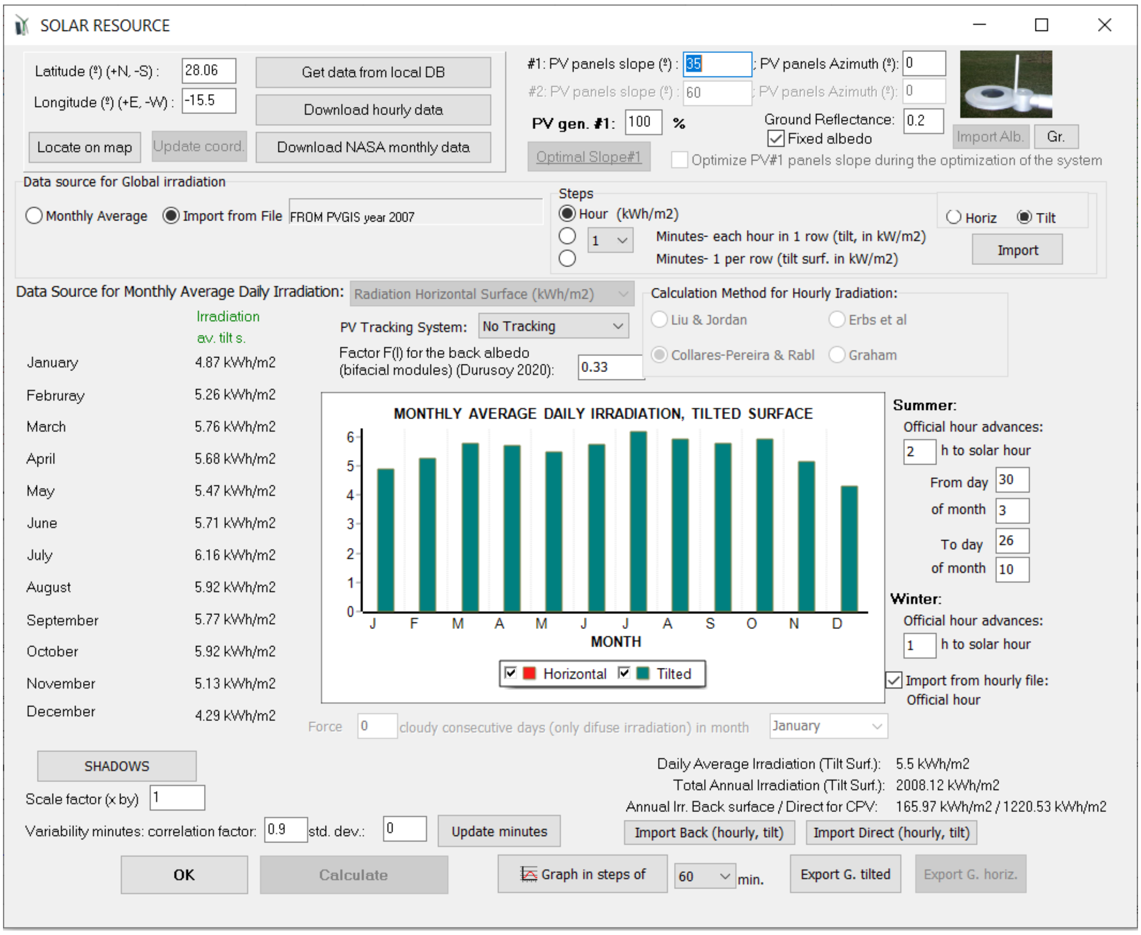
Save the project. Then save as with the name "Pr1-PVGIS".

Now we will download hourly data from PVGIS database. We can download data from any year, from 2007 to 2020, and there is no limit in the number of downloads per day. There is no data for extreme locations near the poles neither for the sea, check in https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

In the irradiation window, click in the button "**Download hourly Data**" and select PVGIS database, year 2007.

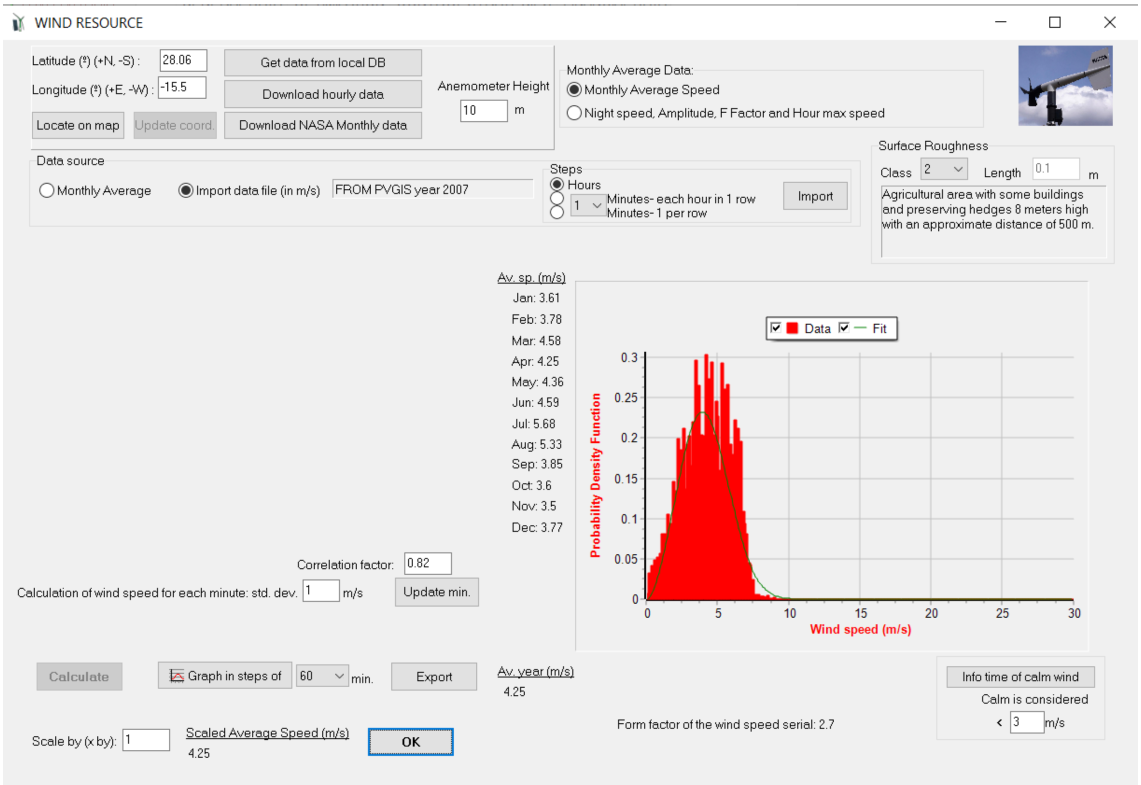


Click "**OK**" and the hourly data form PVGIS will be downloaded.

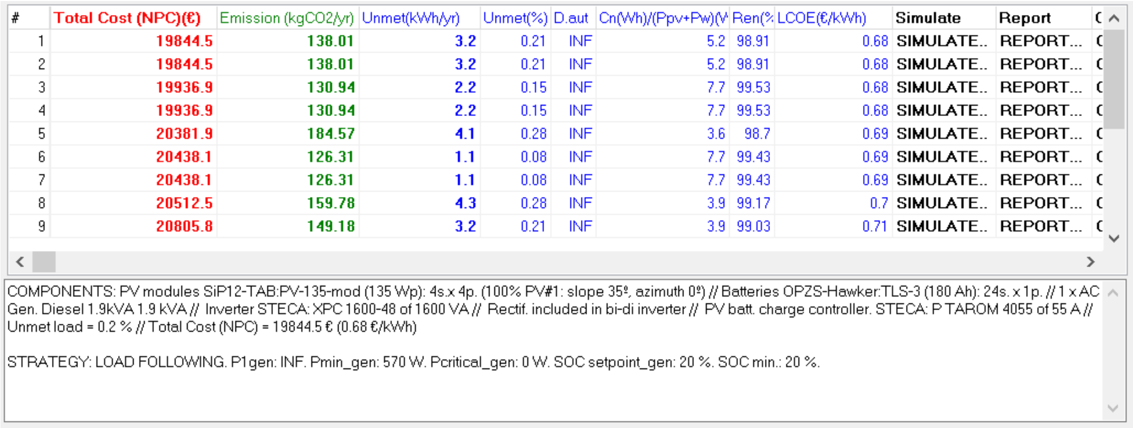


We can see that annual irradiation over the inclined surface is 2008 kWh/m2. Average daily irradiation in December is 4.29 kWh/m2. We accept clicking "**OK**".

In the Wind resource window, we can see the average wind speed is 4.25 m/s, with a Weibull form factor of 2.7. We accept clicking "**OK**".



We optimize the system and we obtain the following results:



#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	19844.5	138.01	3.2	0.21	INF	5.2	98.91	0.68	SIMULATE..	REPORT...	C
2	19844.5	138.01	3.2	0.21	INF	5.2	98.91	0.68	SIMULATE..	REPORT...	C
3	19936.9	130.94	2.2	0.15	INF	7.7	99.53	0.68	SIMULATE..	REPORT...	C
4	19936.9	130.94	2.2	0.15	INF	7.7	99.53	0.68	SIMULATE..	REPORT...	C
5	20381.9	184.57	4.1	0.28	INF	3.6	98.7	0.69	SIMULATE..	REPORT...	C
6	20438.1	126.31	1.1	0.08	INF	7.7	99.43	0.69	SIMULATE..	REPORT...	C
7	20438.1	126.31	1.1	0.08	INF	7.7	99.43	0.69	SIMULATE..	REPORT...	C
8	20512.5	159.78	4.3	0.28	INF	3.9	99.17	0.7	SIMULATE..	REPORT...	C
9	20805.8	149.18	3.2	0.21	INF	3.9	99.03	0.71	SIMULATE..	REPORT...	C

COMPONENTS: PV modules SiP12-TAB:PV-135-mod (135 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // Rectif. included in bi-di inverter // PV batt. charge controller. STECA: P TAROM 4055 of 55 A // Unmet load = 0.2 % // Total Cost (NPC) = 19844.5 € (0.68 €/kWh)

STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

NPC is higher as irradiation is lower than for Renewables Ninja.

We suggest the reader to repeat the optimization by using the NASA hourly data, and for different years.

We save and close the software. In the next steps we will continue using the original project Pr1.hoga.

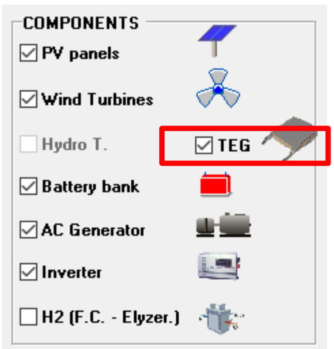
28. Including thermoelectric generator (TEG).

Next we will add in the Pr1.hoga the possibility to include TEG (thermoelectric generator to use the hot temperature of the exhaust gas of a cooking or heating stove to obtain electricity; more info in the user manual).

We open the project "Pr1.hoga" (**Project -> Open**).

Then we save the project with another name, **Project-> Save As**, let's save it as "**Pr1-TEG.hoga**".

We include the TEG, by checking "TEG" in the main screen:



Then we click the button "**TEG TEMP.**" in the main screen.

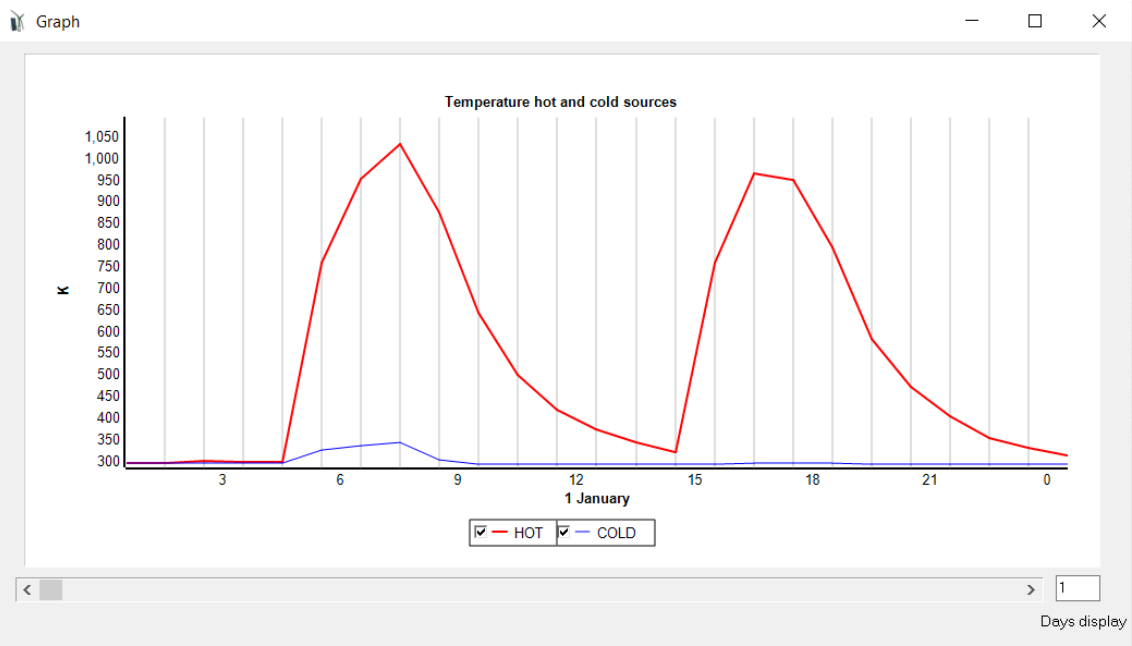
We will consider we have a cooking stove that works 6 hours, during 6 to 9 a.m. and also during all the days, and the temperature of the hot exchanger of the TEG is around 700ºC during that hours. We change the hot temperature from 6 to 9 a.m. and from 16 to 19 h to 700 ºC (change the first line, then click on the right or left cell to change all the cells of the column):

Temperature of HOT source (ºC) | Temperature of COLD source (ºC)

5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h	16-17h	17-18h	18-19h	19-20h	20-21h	21-22h
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20
20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20

We will leave the temperature of the cold source without changes.

Then we click the button "**Generate**" and then clicking in "**Graph in steps of**" we can see the graph of the temperatures of the hot and cold source (in K).

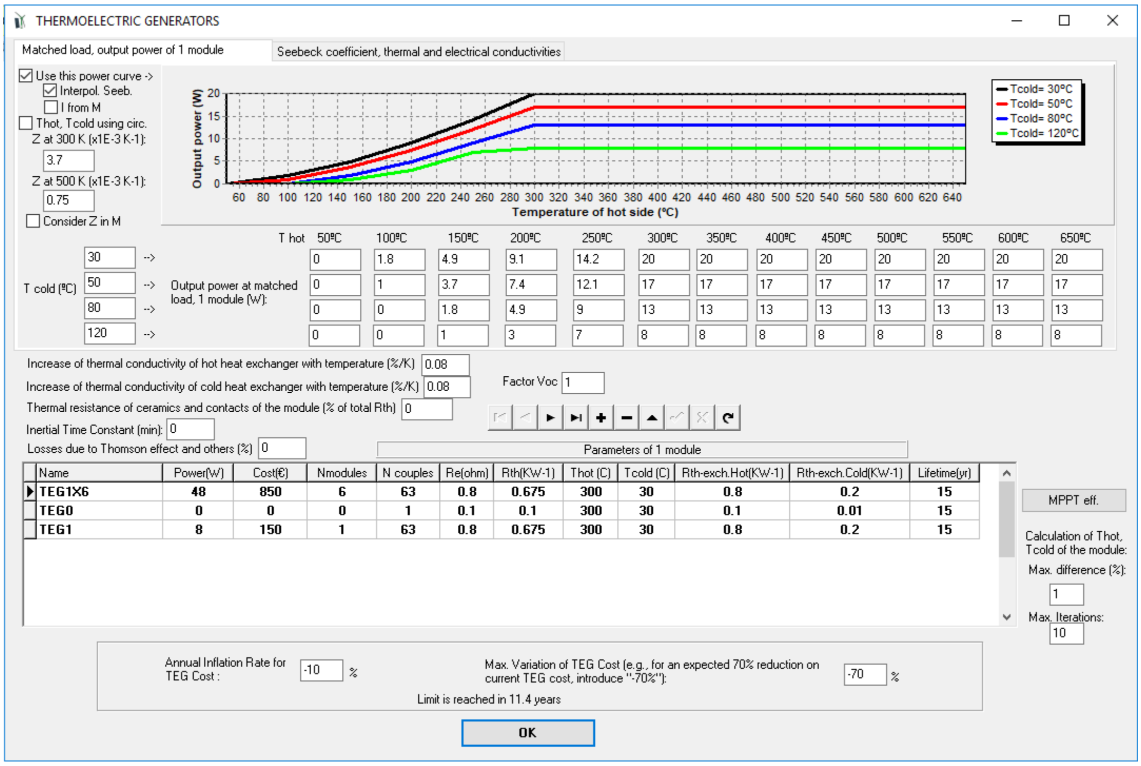


Clicking **OK** we return to the main screen.

Now we click the button "**TEG**" in the main screen.

Let's consider all the default data. iHOGA will use for the simulations the output power curve for 1 module shown and also the Seebeck coefficient, thermal and electrical conductivities shown in the right tab.

Default TEG considered are three: one of 0 W (that is, without TEG), another one of 1 module of 8 W (TEG1) and another one of 6 modules of 8 W, total 48 W (TEG1x6). For each one, cost and number of modules is shown, and also the parameters of 1 module (same parameters for TEG1 and for TEG1x6 because the module is the same).



T hot	50ºC	100ºC	150ºC	200ºC	250ºC	300ºC	350ºC	400ºC	450ºC	500ºC	550ºC	600ºC	650ºC
30	0	1.8	4.9	9.1	14.2	20	20	20	20	20	20	20	20
50	0	1	3.7	7.4	12.1	17	17	17	17	17	17	17	17
80	0	0	1.8	4.9	9	13	13	13	13	13	13	13	13
120	0	0	1	3	7	8	8	8	8	8	8	8	8

Name	Power(W)	Cost(€)	Nmodules	N couples	Re(ohm)	Rth(KW-1)	Thot (C)	Tcold (C)	Rth-exch.Hot(KW-1)	Rth-exch.Cold(KW-1)	Lifetime(yr)
TEG1X6	48	850	6	63	0.8	0.675	300	30	0.8	0.2	15
TEG0	0	0	0	1	0.1	0.1	300	30	0.1	0.01	15
TEG1	8	150	1	63	0.8	0.675	300	30	0.8	0.2	15

We click **OK** and we return to the main screen.

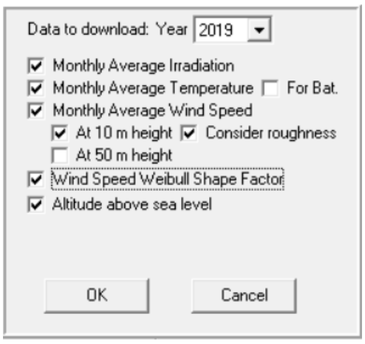
Save the project. We click "**CALCULATE**" button and the system is optimized (after several minutes), in this case considering also the possibility of TEG. However, the optimal system is the same as the one of Pr1 project, it does not include TEG (the optimal combination includes the one of 0 W, 0€). It is because in our case the PV is enough to cover the demand and including TEG would not reduce the NPC.

Variant: System in Norway:

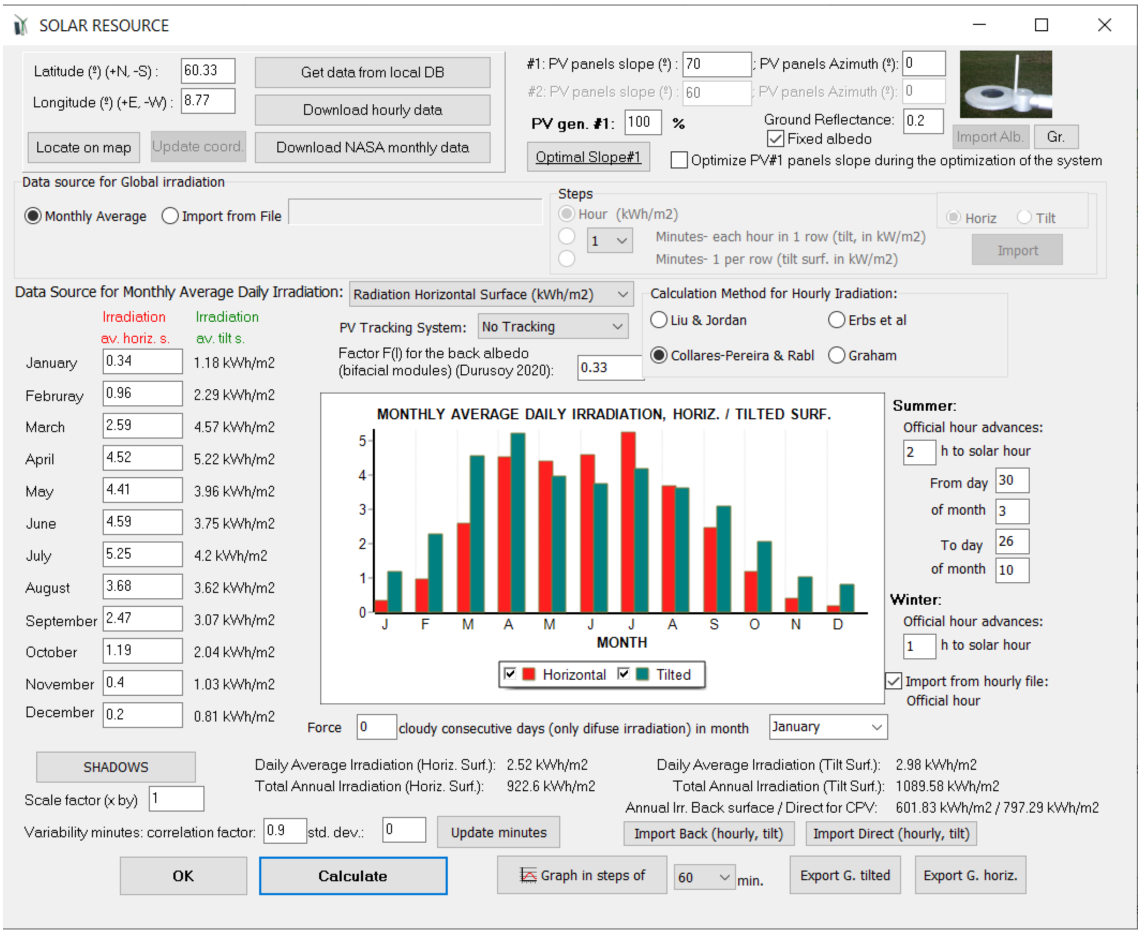
Now let's consider another location, in Norway, with much lower irradiation in winter. Let's suppose shadows are the same as previously (we won't change it).

In the **SOLAR** screen, we change latitude and longitude to 60.33º and 8.77º, respectively.

Now we click on "**Download NASA monthly data**" button.

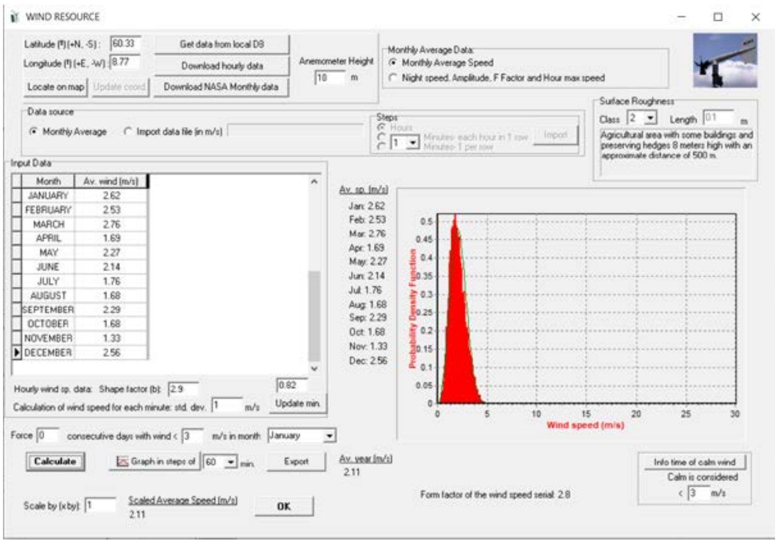


After downloading the NASA data, we change the PV panels slope to 70º (to maximize irradiation in winter) and press the button "**Calculate**". We see the irradiation in winter is quite low.



Then we can click in "**Graph in steps of**" button to see the new irradiation.

We return to the main screen. In the **WIND** screen (it was updated with the average monthly wind speed for the new location in Norway), we click "**Calculate**" to obtain the hourly values. We can see wind speed is quite low in that place.



We return to the main screen. We click “**TEG TEMP**.” and we access the TEG hot and cold source temperatures. We change the temperatures of the TEG as we consider a heating stove (instead of cooking stove) that works many hours in the day, see next figures (remember, you can change all the values of each column in just 1 click).

Hot source:

Temperature of HOT source (ºC) | Temperature of COLD source (ºC)

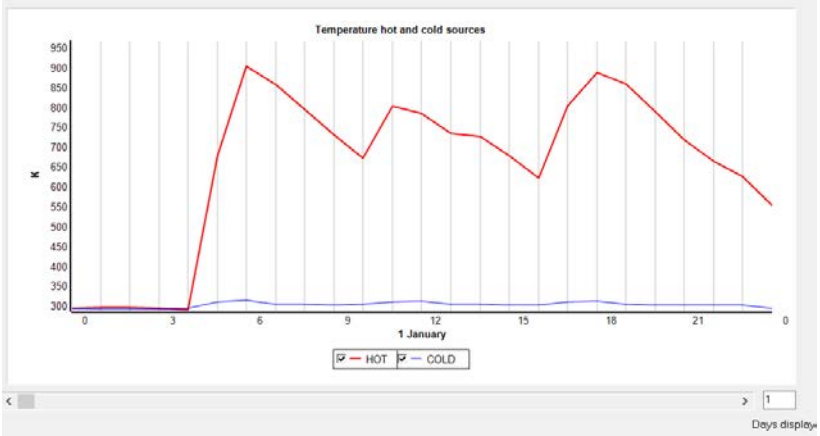
Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h	16-17h	17-18h	18-19h	19-20h	20-21h	21-22h	22-23h	23-24h
JANUARY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
FEBRUARY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
MARCH	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
APRIL	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
MAY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
JUNE	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
JULY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
AUGUST	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
SEPTEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
OCTOBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
NOVEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300
DECEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	300

Cold source:

Temperature of HOT source (ºC) | Temperature of COLD source (ºC)

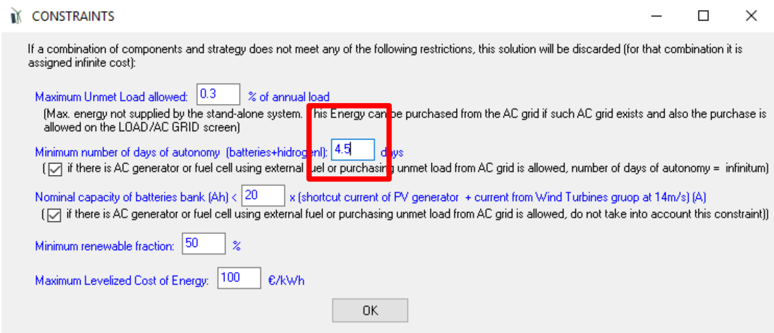
Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h	16-17h	17-18h	18-19h	19-20h	20-21h	21-22h	22-23h	23-24h
JANUARY	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
FEBRUARY	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
MARCH	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
APRIL	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
MAY	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
JUNE	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
JULY	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
AUGUST	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
SEPTEMBER	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
OCTOBER	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
NOVEMBER	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30
DECEMBER	20	20	20	20	20	40	40	30	30	30	30	40	40	30	30	30	30	40	40	30	30	30	30	30

Now we click on “**Generate**” button, we can see the hot and cold sources temperatures.

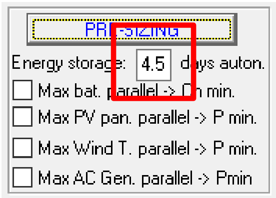


Click “**OK**” and then “**OK**” to return to the main screen.

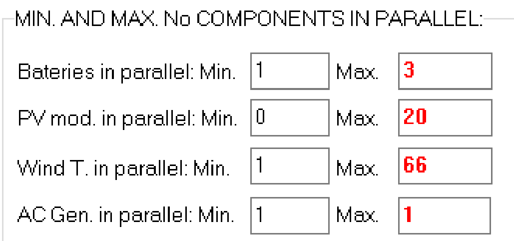
We return to the main screen. In the constraints, make sure the minimum number of autonomy days to 4.5 as it was in Pr1 project.



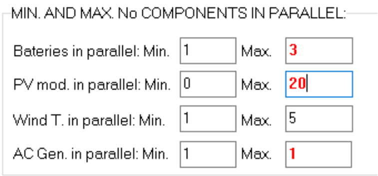
We also make sure in the PRE-SIZING:



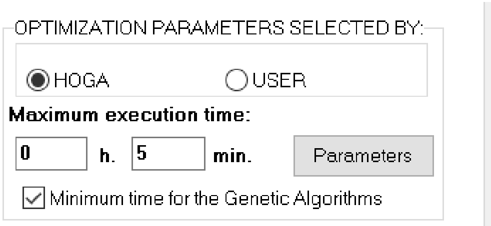
And then we click on “**PRE-SIZING**” button. The maximum number of components in parallel is updated, a big change is obtained for max. number of PV modules in parallel, as in winter irradiation is very low.



Now the number of possible combinations of components is too high, and it would take a lot of time to evaluate all of them. As wind speed is too low, it is likely that there will not be any wind turbine in the optimal system, we change to 5 max. wind turbines in parallel so that optimization time is reduced:



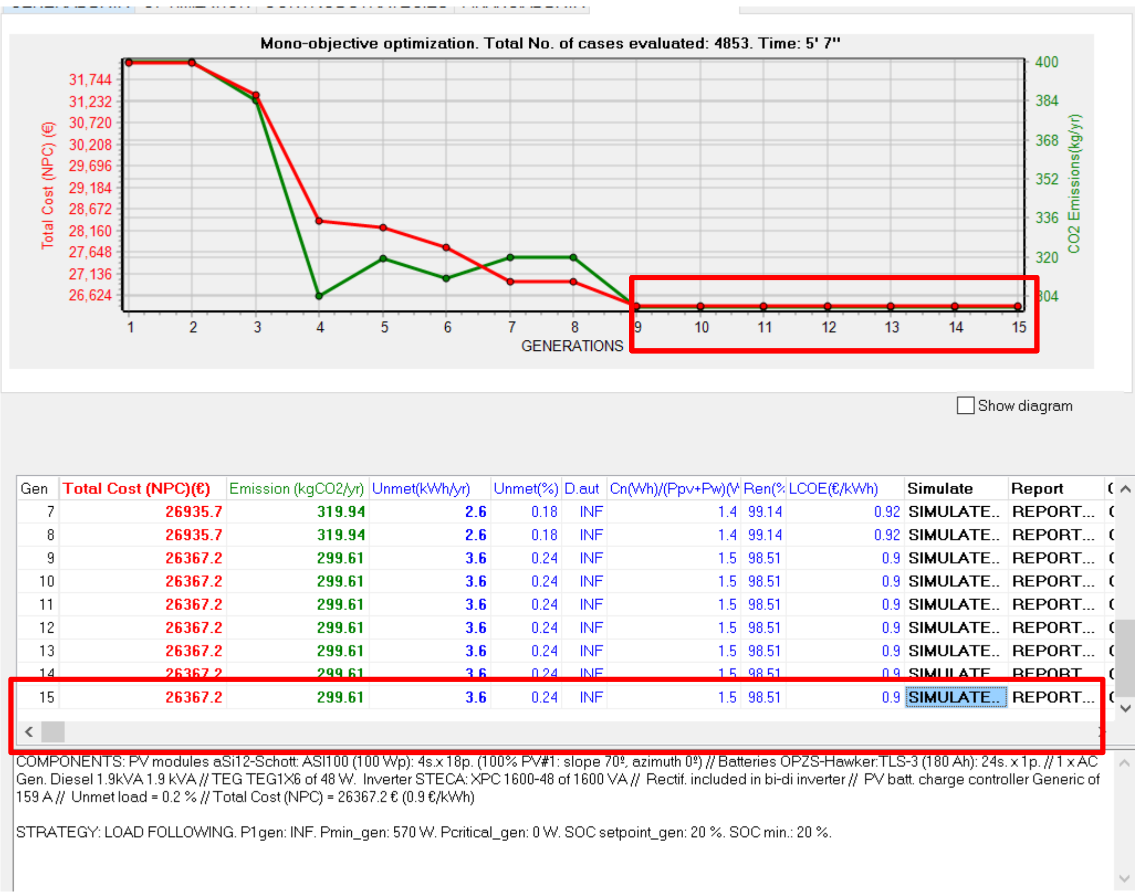
Optimization time, if evaluating all the combinations, would take near 1 hour. Let's suppose we want to optimize only in 5 minutes, then, in the main screen, "GENERAL DATA" tab, we change to that value in maximum execution time:



iHOGA will use genetic algorithms to optimize in that low time. Save the project. Now we **CALCULATE** again to optimize the hybrid system.

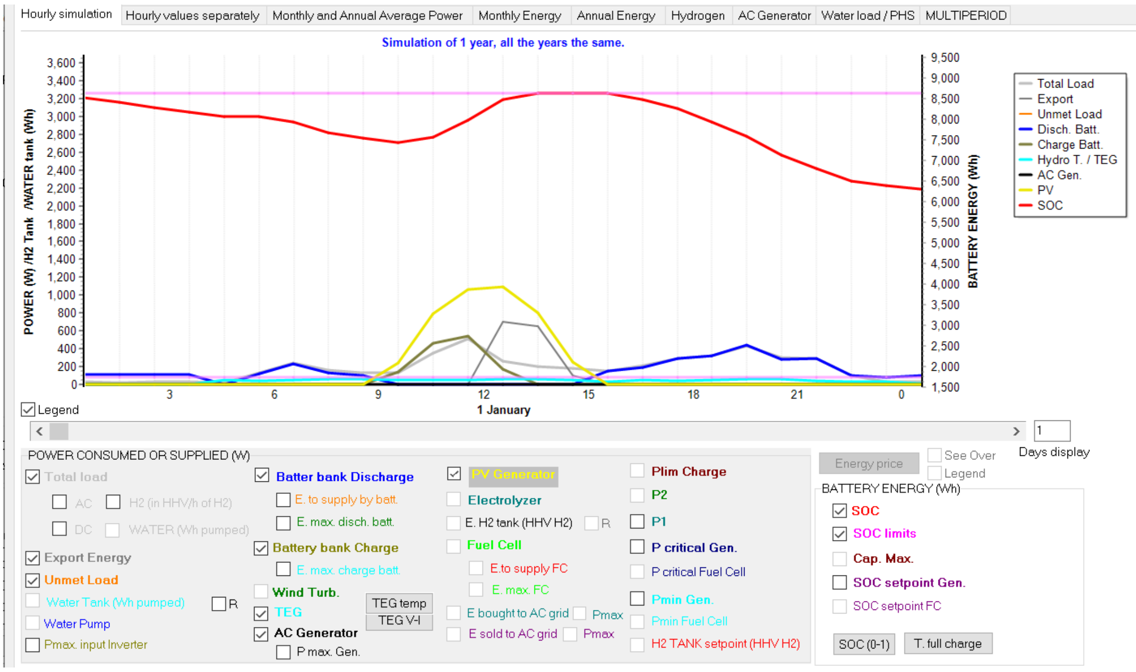
During the optimization, for the first generations we can see that for each generation of the genetic algorithm, the best combination found is better than the one of the previous generation. But after several generations, the optimal is the same, that is, we can see it is the true optimal (in a high probability).

When using genetic algorithms, the best combination found (lowest NPC) is the last, that is the one of the last generation (in this case from 9th to last generation the optimal is the same):

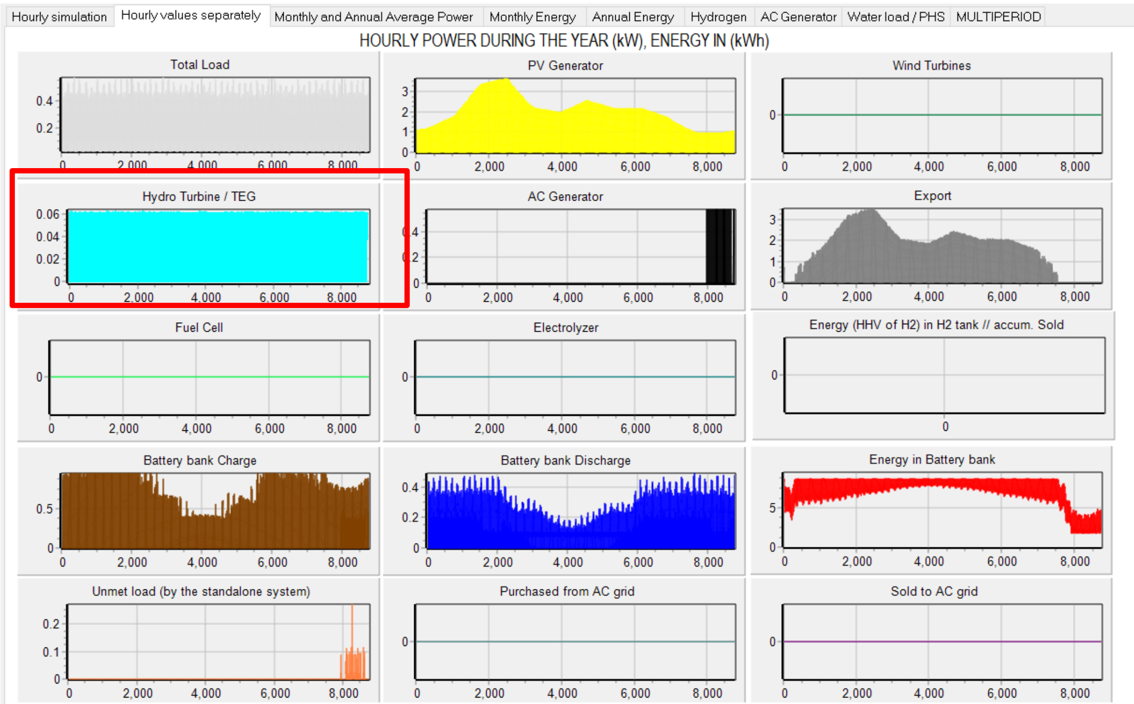


In this case the optimal combination is PV-Diesel-TEG-batteries, it includes TEG of 48 W (the highest one allowed).

In the simulation of the last generation (last row of the results table) we can see in light blue the generation of the TEG:



In the tab of hourly values separately we also can see it:



THE FOLLOWING CAN ONLY BE CARRIED OUT WITH PRO + VERSION

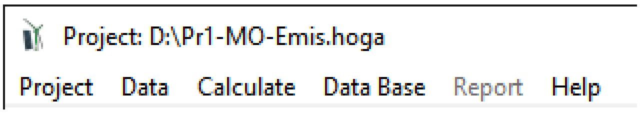
29. Multi-objective optimization.

Next we will carry out a multi-objective optimization project.

We open the project "Pr1.hoga" (**Project -> Open**).

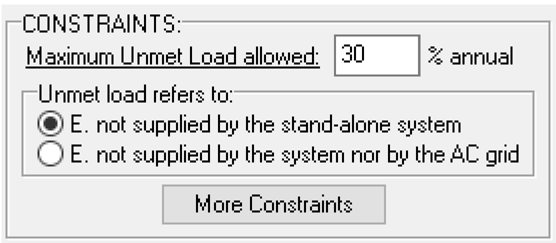
Then we save the project with another name. To do this, in the top menu of the main screen, we click **Project-> Save As** and the project will be saved with another name, preserving the original saved. Let's save it as "**Pr1-MO-Emis.hoga**".

Once saved as, the new name appears at the top of the screen:

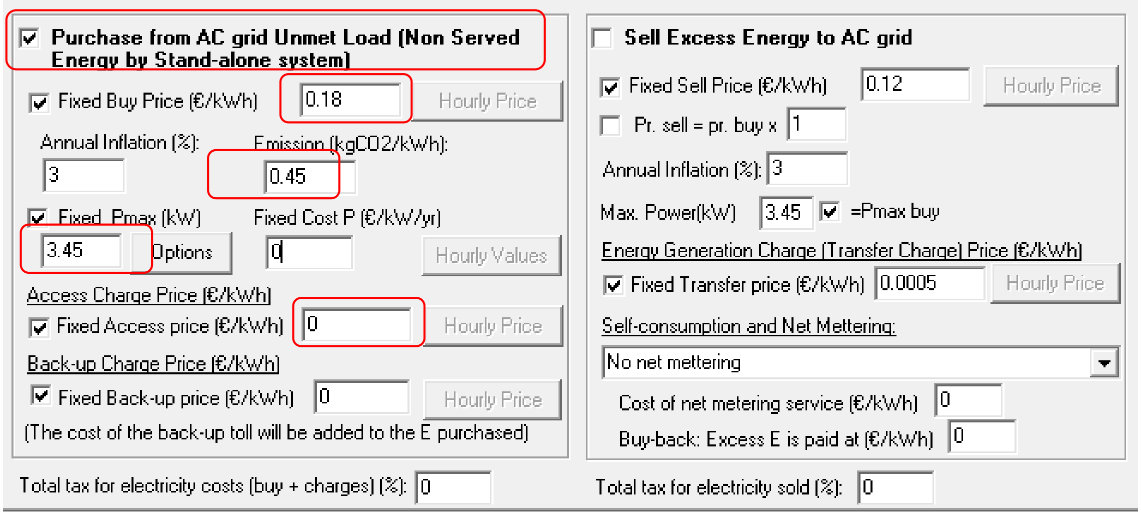


Let's suppose that we want to modify project Pr1 so that there is a connection to the AC electricity grid. We will specify a certain value of unmet load allowed (maximum energy that may not be supplied by the autonomous system, so it will be supplied by the AC grid). And we will make several multi-objective optimizations. We start with the multi-objective optimization NPC - CO_2 emissions.

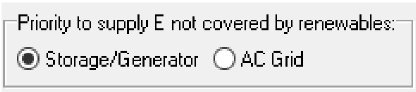
In the main screen of the program, "**GENERAL DATA**" tab, in "**CONSTRAINTS**" change the maximum unmet load allowed to 30% (in such a way that the system, without considering the AC grid, is obliged to supply at least 70% of the load, the rest will be supplied by the AC grid, if there is AC grid, as in this case):



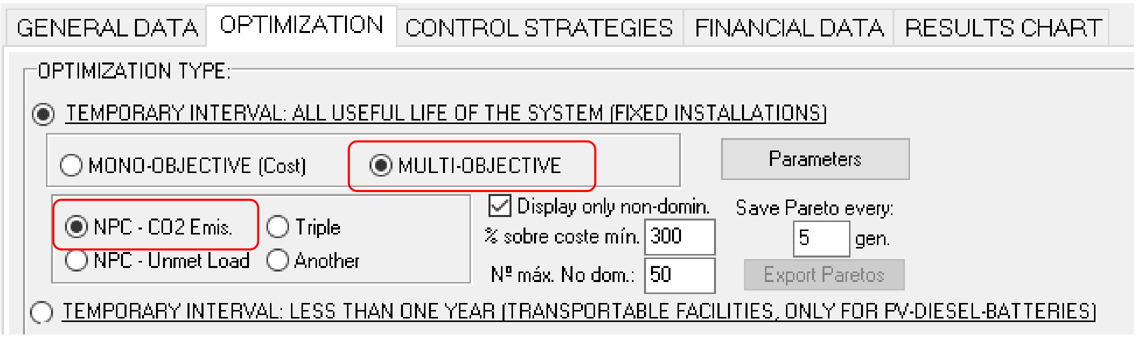
In the "**LOAD / AC GRID**" window, tab "**PURCHASE / SELL E.**", check the box "**Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system)**". Assume that the price of electricity purchased from the grid is 0.18 €/kWh (including access charge and taxes), the maximum power we can acquire from the grid is 3.45 kW and the emissions of the generated energy of the AC grid (national energy mix) is 0.45 kgCO_2/kWh:



We consider the priority to supply the energy not covered by the renewables the Storage (batteries) or the AC generator, as default:



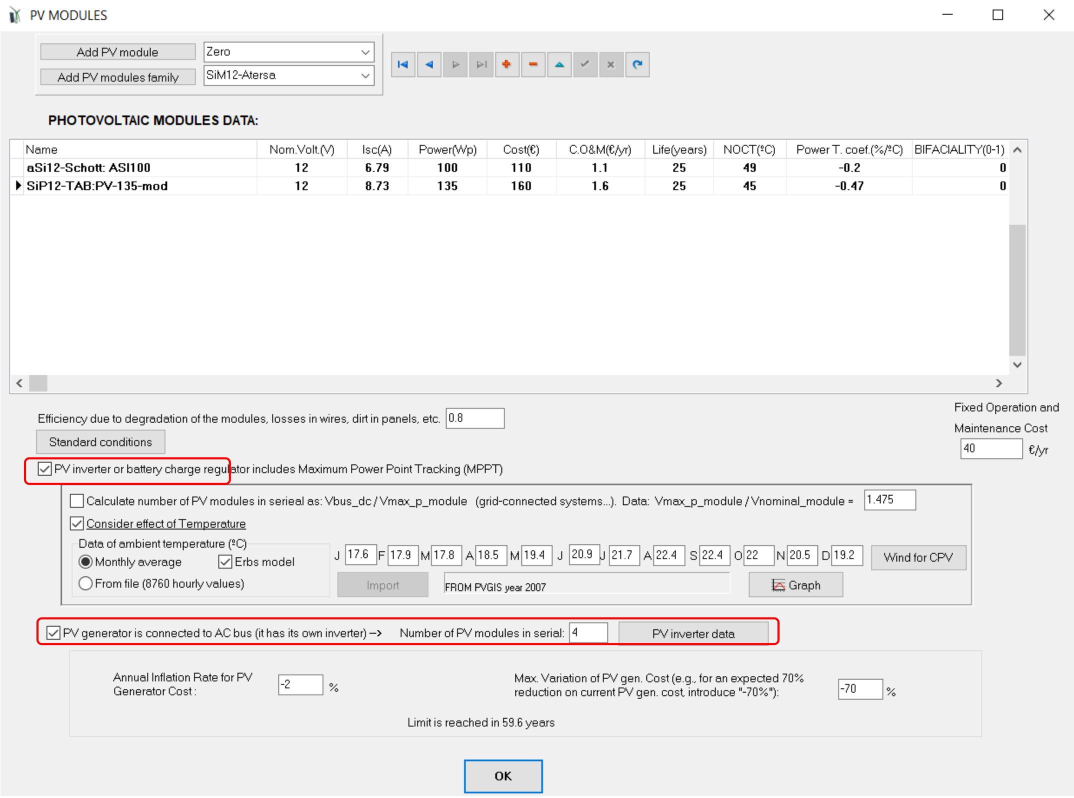
By clicking **OK** we return to the main screen, tab "**OPTIMIZATION**", and we mark "**MULTI-OBJECTIVE**", using the default optimization NPC-CO2 emission.



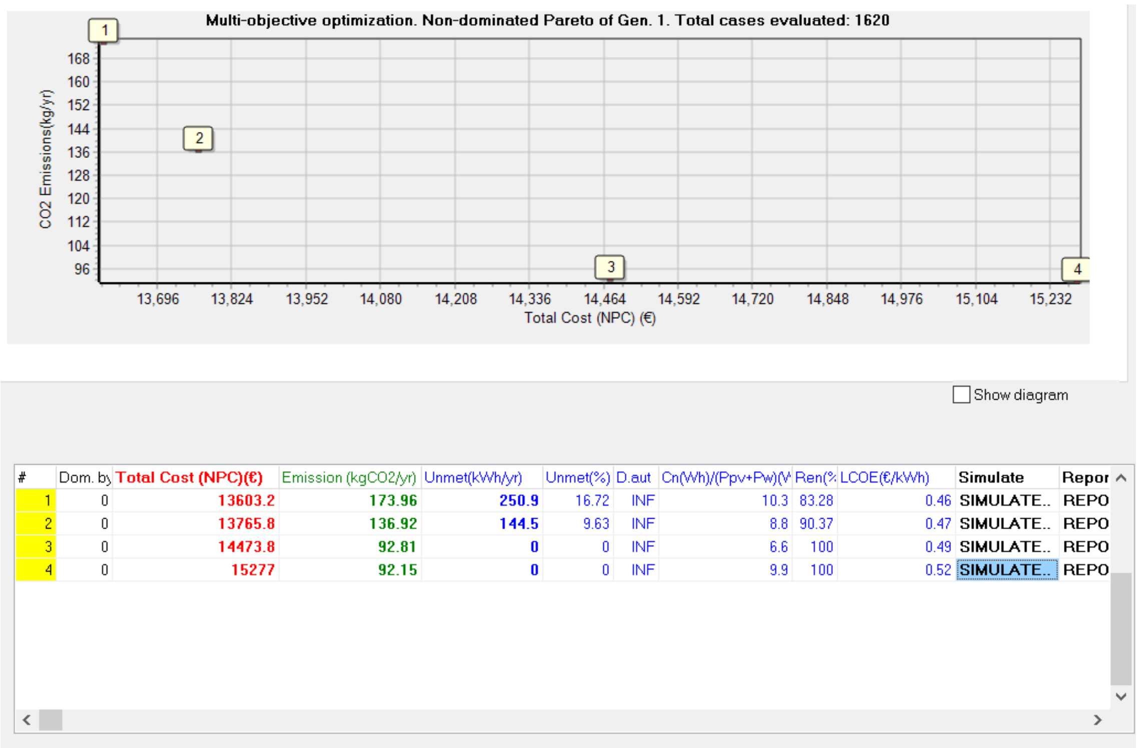
Let's suppose the PV has its own inverter, with MPPT, therefore the PV generation will be injected in the AC bus. In the PV modules window, check the boxes

and

The number of PV panels in series is 4 and the PV inverter rated power and efficiency are the default ones (clicking the button "PV inverter data") they are shown.

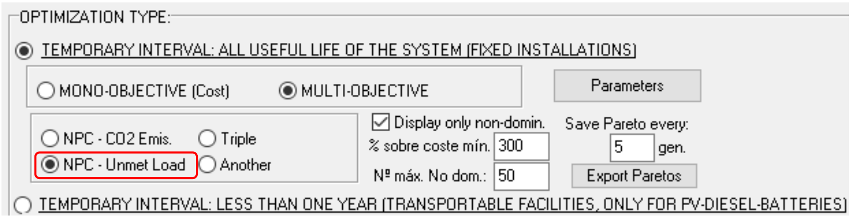


Save the project. We click on "**CALCULATE**" and we obtain the following results, where we have obtained four non-dominated solutions (called the “pareto front”), that is, none of the three is better than the remaining in both objectives at a time. Once obtained the “pareto front”, the designer will choose one of the non-dominated solutions for his/her project, considering NPC and CO_2 emissions.

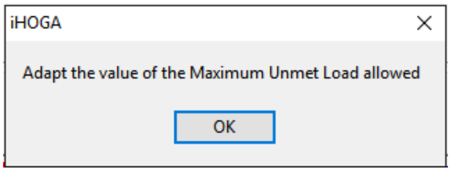


Variant: optimization NPC – Unmet load by the stand-alone system:

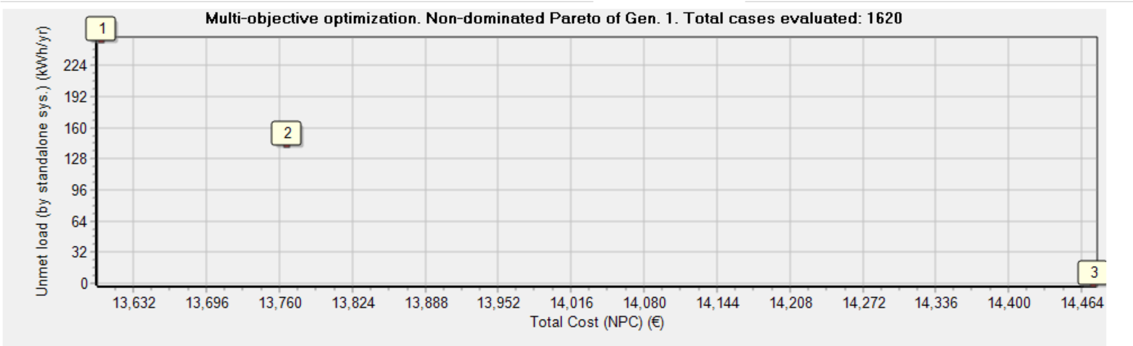
Next we save the project and save as with the name "**Pr1MO-Unmet.hoga**". We will perform the multi-objective optimization NPC – Unmet load (by the stand-alone system). We chose the type of multi-objective optimization "NPC – Unmet load".

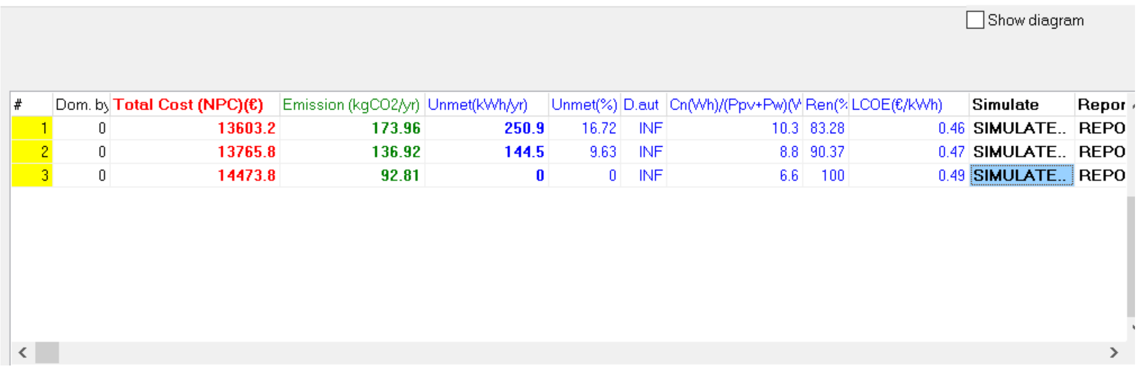


A screen appears informing us that we must adjust the value of the maximum unmet load allowed. We accept (we have already done so, leaving it at 30%).



Save the project. We recalculate and obtain the following results screen, in which three solutions are not dominated. None of the solutions is better than the others in both objectives at the same time (NPC and unmet load by the stand-alone system). The rest of solutions are not visualized because they are dominated, that is to say, at least one of the non-dominated is better in both objectives.

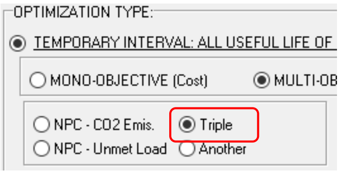




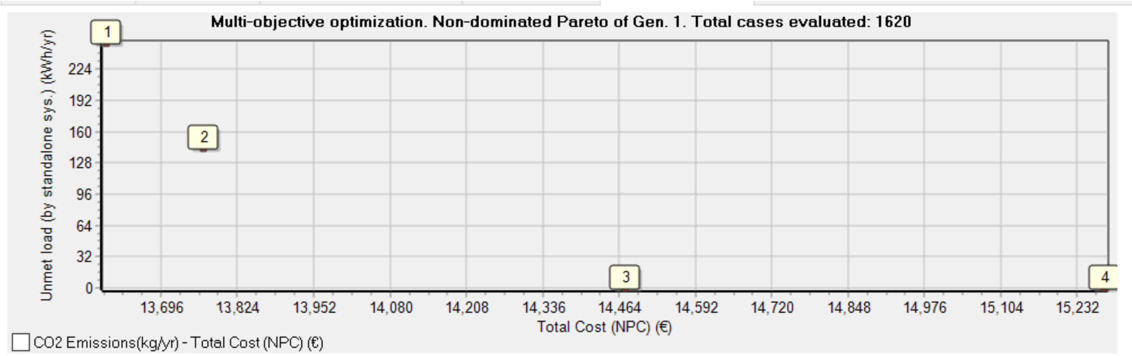
#	Dom. by	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Repor
1	0	13603.2	173.96	250.9	16.72	INF	10.3	83.28	0.46	SIMULATE..	REPO
2	0	13765.8	136.92	144.5	9.63	INF	8.8	90.37	0.47	SIMULATE..	REPO
3	0	14473.8	92.81	0	0	INF	6.6	100	0.49	SIMULATE..	REPO

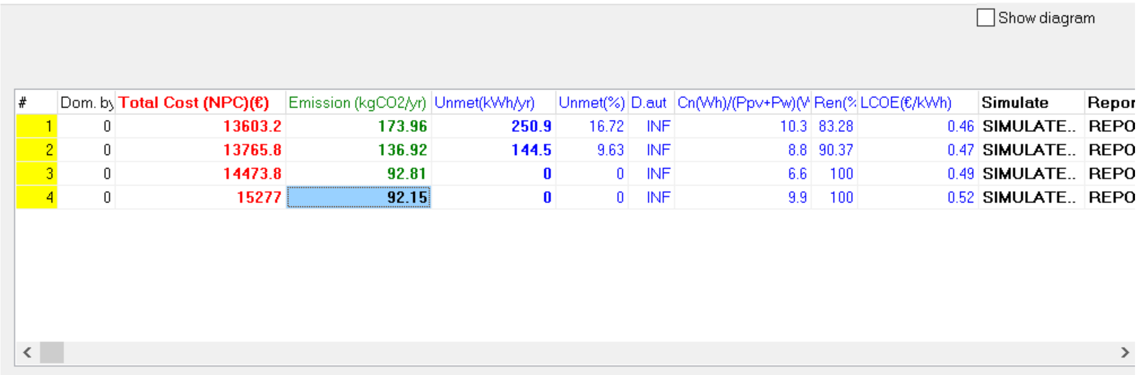
Variant: triple optimization (NPC - CO_2 emissions – Unmet load by the stand-alone system):

Next we save the project and save as with the name "**Pr1MO-Three.hoga**". We will perform the optimization of three objectives (NPC - CO_2 emissions – Unmet load by the stand-alone system). We chose the type of triple optimization:



We obtain nine non-dominated solutions (in this case, the same as in the case of cost-emission optimization, in other cases it can be different). The graph shows unmet load versus NPC.





#	Dom. by	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Repor
1	0	13603.2	173.96	250.9	16.72	INF	10.3	83.28	0.46	SIMULATE..	REPO
2	0	13765.8	136.92	144.5	9.63	INF	8.8	90.37	0.47	SIMULATE..	REPO
3	0	14473.8	92.81	0	0	INF	6.6	100	0.49	SIMULATE..	REPO
4	0	15277	92.15	0	0	INF	9.9	100	0.52	SIMULATE..	REPO

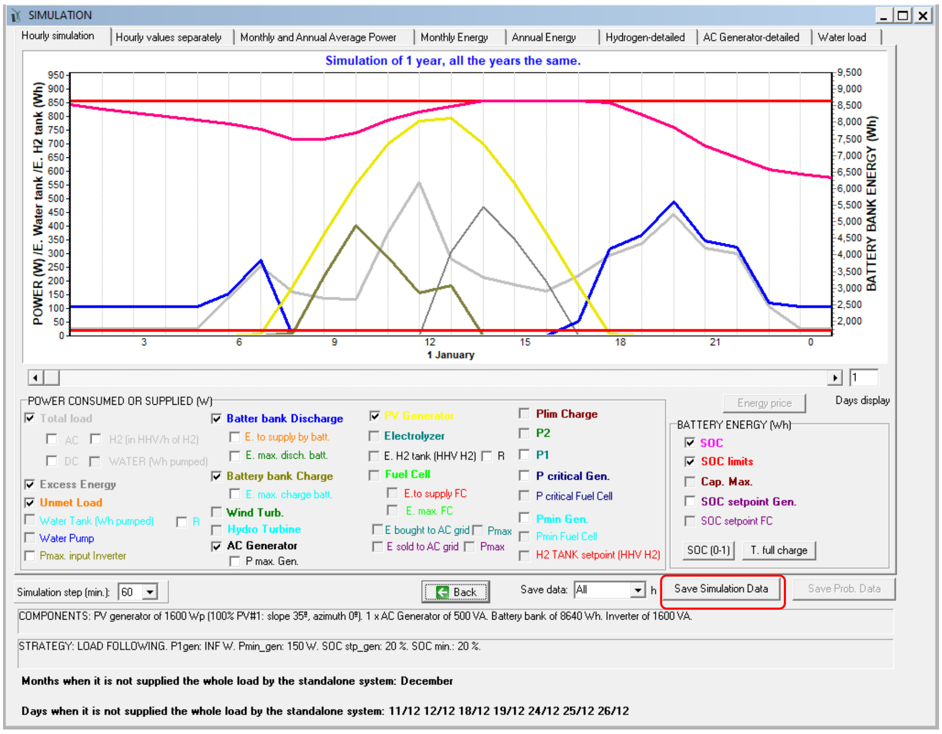
If we click on the lower left of the graph in the box "**CO2 Emissions ...**", the emission versus cost representation of the non-dominated solutions appears.

Finally, we save the project.

30. Save simulation data.

We open the project “Pr1.hoga” (in the top menu, **Project->Open**) and let's see how the simulation data can be saved in an Excel file.

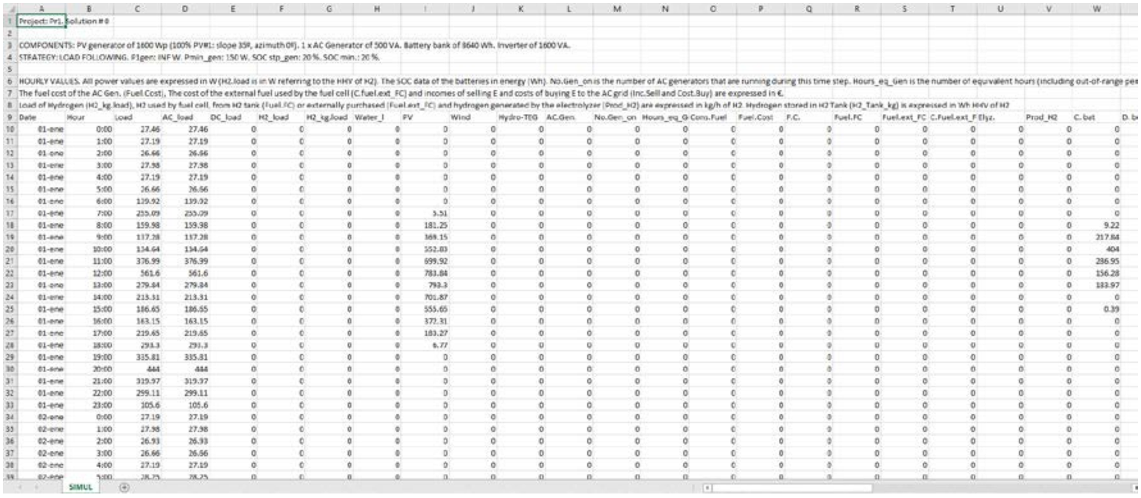
In the simulation screen of the optimal combination (by clicking on the first row of the table, in "**SIMULATE**"), we can save the simulation data in Microsoft Excel format.



To do this, click the "**Save Simulation Data**" button. Once the Excel file has been saved, when opening the Excel file, it warns us about opening the file, to which we respond "**Yes**".

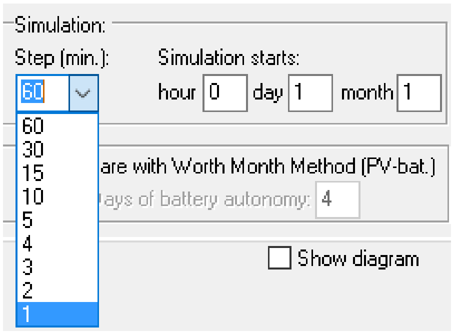
The Excel file opens perfectly, showing for each hour of the year the different power of the different components. At the end it shows the monthly and total annual values, the values of the purchase and sale of energy to the AC grid (if any), the cash flows of costs and revenues ...

We must save this file by the option "Save As" of Microsoft Excel in Excel file (*.xlsx) and the next time we open it, it will no longer show the previous warning.



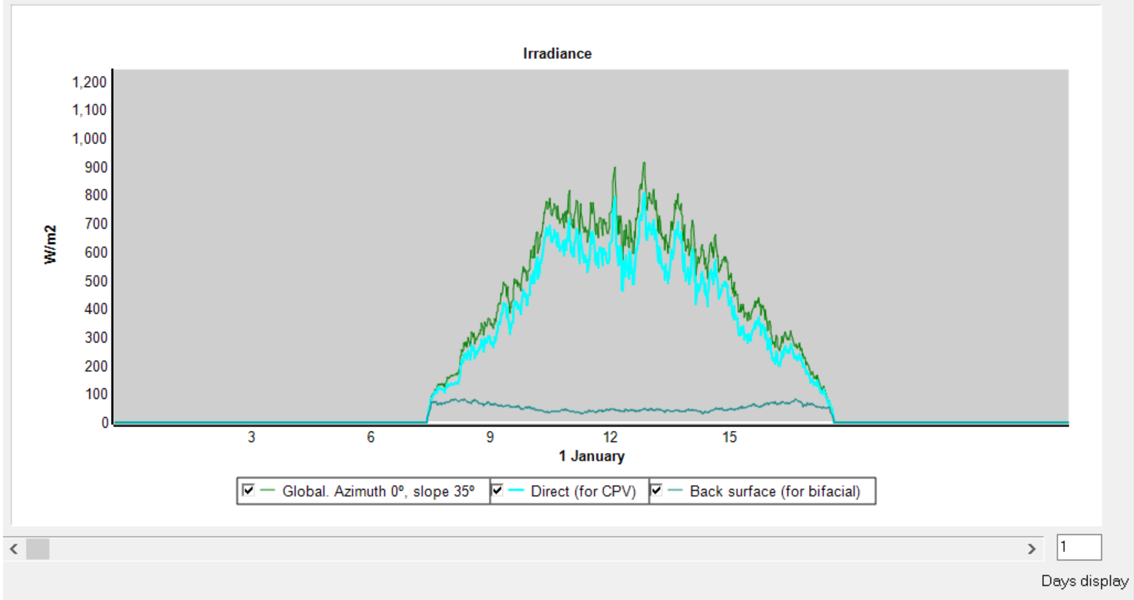
31. Simulation with time steps of less than 1 h.

In the main screen of the program, in the default tab "**GENERAL DATA**", we can change the steps of the simulation. Let's set time step of 1 minute:



To see the variability of the irradiance in steps of 1 minute, in the SOLAR window (click "**SOLAR**" button in the main window), we change std. dev. to 0.1.

Then in the solar window we click "**Calculate**" and the irradiation in steps of 1 minute has variability. In the graph, steps of 1 minute, we see:

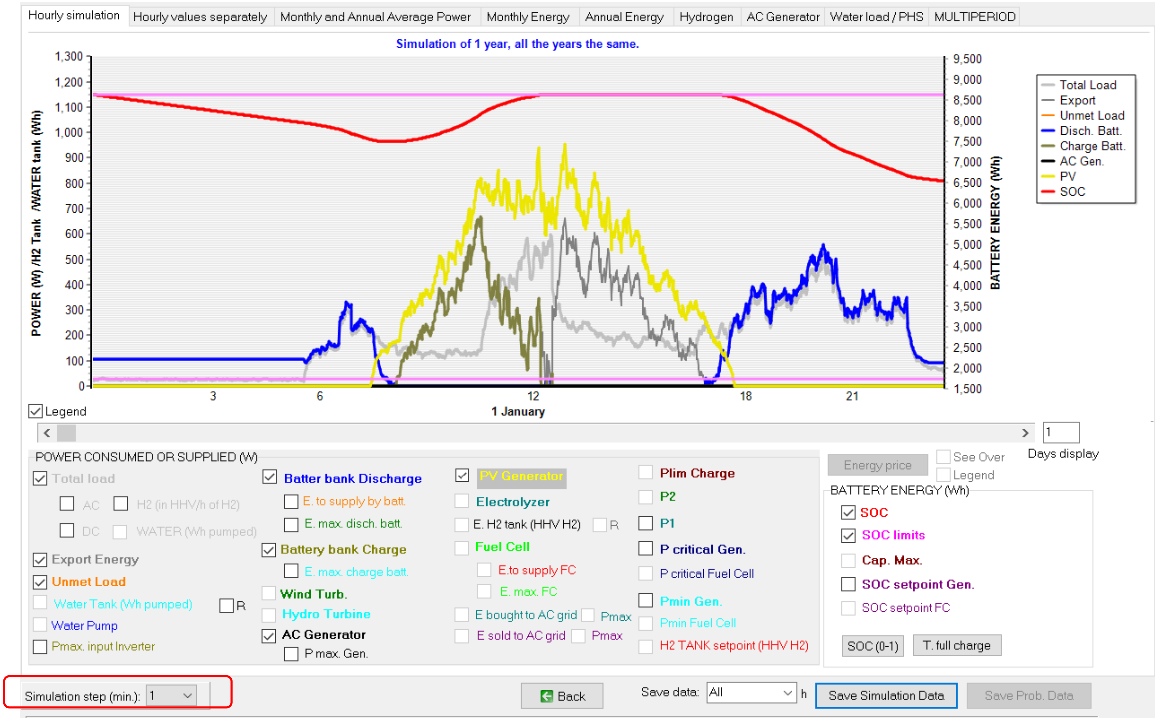


We can recalculate the optimization with time steps of 1 minute, but it will take a long time. At the moment we are not going to do it.

If we click in a row, the simulation of that combination will be performed with temporary steps of 1 minute and the results will be updated. Clicking on any cell of the first row, after some seconds, it updates the results for time steps of 1 minute, changing the result of the NPC to 14993.9 € (due to the randomness of the load and of the irradiation in 1-minute time steps, your results will be a bit different). In this case the change is very low, so in this case the value of the time step has little effect. However, in other cases it can affect much more.

Gen	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	14993.9	104.99	1.4	0.09	INF	6.6	99.71	0.51	SIMULATE..	REPORT...	(

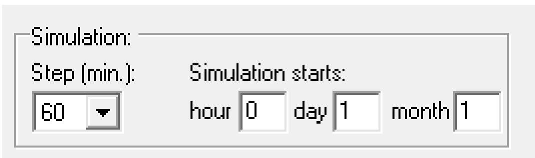
By clicking on the "SIMULATE" cell in the first row, we obtain the full year simulation in time steps of 1 minute (be patient, the simulation takes some seconds).



In the simulation screen, we can change the simulation time step, under the legend, in the left, and the simulation will be updated to the new time steps.

We go back with the button "**Back**" to the main screen.

In the main screen, we re-select 60 minutes as a time step:

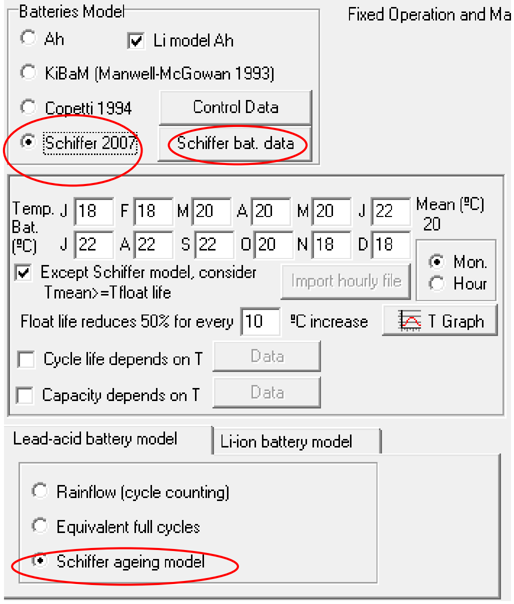


And, in the SOLAR screen, we change again the std. dev. to 0, to have same conditions as before, **Calculate** to update the irradiation and OK.

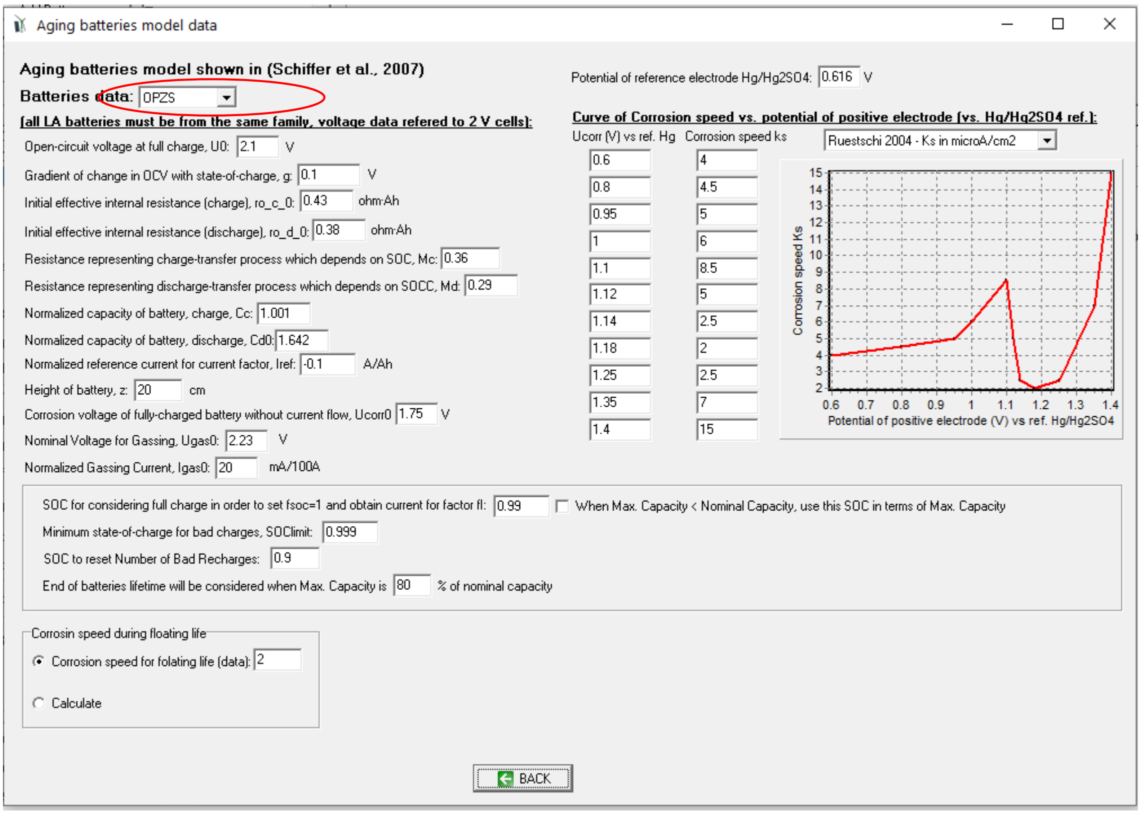
If we click again on the rows in the table of results that we had clicked in the case of 1 minute time step, they return to the results obtained with 60 minutes time step.

32. Advanced Schiffer ageing model for lead-acid batteries.

Save the project and then save as with the name "**Pr1-Sch.hoga**". Now in the new project (Pr1-Sch) we will modify the batteries lifetime model (model to estimate its lifespan) to the Schiffer et al. advanced ageing model. On the **BATTERY** screen, we modify the following:

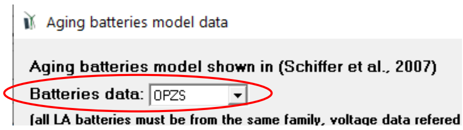


We click in the button “**Schieffer bat. data**”, seeing the data needed for this battery model:



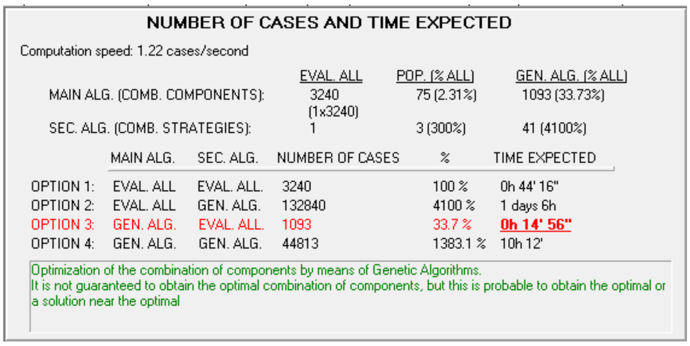
Ucorr (V) vs ref. Hg	Corrosion speed ks
0.6	4
0.8	4.5
0.95	5
1	6
1.1	8.5
1.12	5
1.14	2.5
1.18	2
1.25	2.5
1.35	7
1.4	15

In this window, there are many parameters that are usually unknown as they are not published by the batteries manufacturers. The default parameters were obtained from the publication of Schieffer et al., 2007 (see the user manual for reference). You should not change any value unless you know this. It is important that all the battery models considered in the battery screen table are of the same type, in our case it is true, all are OPZS-Hawker, TLS model. As they are OPZS, it is important to ensure that in the window of the Schieffer data, at the top it is selected OPZS:



We will leave all the default data and then we return to the battery screen by clicking on “**Back**”.

We return to the main screen (by clicking on "**OK**"). In the main screen, with the mouse over the area of the maximum and minimum allowed number of components (**GENERAL DATA** tab) something similar to the following is shown:



NUMBER OF CASES AND TIME EXPECTED

Computation speed: 1.22 cases/second

	EVAL. ALL	POP. (% ALL)	GEN. ALG. (% ALL)
MAIN ALG. (COMB. COMPONENTS):	3240 (1x3240)	75 (2.31%)	1093 (33.73%)
SEC. ALG. (COMB. STRATEGIES):	1	3 (300%)	41 (4100%)

	MAIN ALG.	SEC. ALG.	NUMBER OF CASES	%	TIME EXPECTED
OPTION 1:	EVAL. ALL	EVAL. ALL.	3240	100 %	0h 44' 16"
OPTION 2:	EVAL. ALL	GEN. ALG.	132840	4100 %	1 days 6h
OPTION 3:	GEN. ALG.	EVAL. ALL.	1093	33.7 %	0h 14' 56"
OPTION 4:	GEN. ALG.	GEN. ALG.	44813	1383.1 %	10h 12'

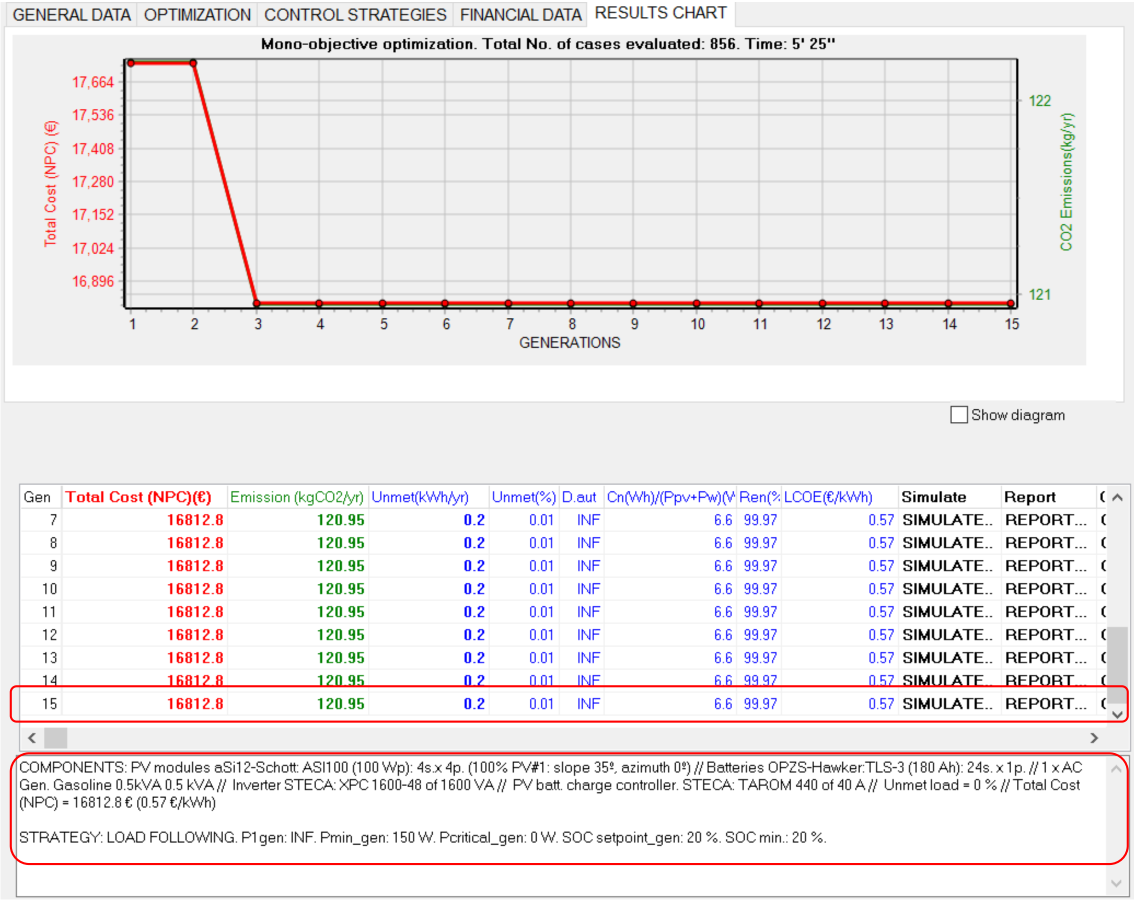
Optimization of the combination of components by means of Genetic Algorithms.
It is not guaranteed to obtain the optimal combination of components, but this is probable to obtain the optimal or a solution near the optimal

Depending on the speed of your computer, the data on this screen may be different, since it estimates the time it will take to evaluate the different combinations.

Now the optimization will take a lot more time, since the Schiffer et al. model, although much more accurate, is also much slower (it performs a vast quantity of calculations). A calculation speed of 1,22 cases per second is estimated, and the estimated optimization time using the enumerative method (all possible combinations) is 44'16". As we are only allowing 15 minutes of calculation, it chooses the method of **genetic algorithms** (marked in red).

It is possible that the actual calculation time is lower than the estimated one, since the Schiffer model implies simulating each combination of components during the life of the batteries, and since this depends on each combination of components (and control strategy), it cannot be previously known. Therefore, the simulations can last for more or less time and the total duration of the optimization may be significantly different from the estimated one. The estimate is quite conservative, that is, it is likely to take less time than expected.

Save the project. We click on "**CALCULATE**" and, after some minutes in the case of the computer where this guide has been done (much less than expected, due to the above), the optimization finishes, obtaining something like this:



__The last row (row 15, corresponding to the last generation evaluated by the genetic algorithms) shows the optimal solution found__. However, it can be seen that, in this case, already in the 3rd generation that solution has been found, and since then no better one has been found. Other tests have been performed and iHOGA obtain the same optimum around the 5th or 6th generation. As all possible combinations have not been evaluated, it is possible that the solution found is not optimal, but it is sure to be close to it. It is possible that the reader will see a different evolution throughout the generations, but it is very probable that in the 15th generation you have obtained the same optimal solution on your computer.

The characteristics of the optimal combination found are shown in the lower part. The optimal solution in this case is the same as in the previous project (with the battery model Ah and life estimate according to the Rainflow cycle count):

COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 16812.8 € (0.57 €/kWh)

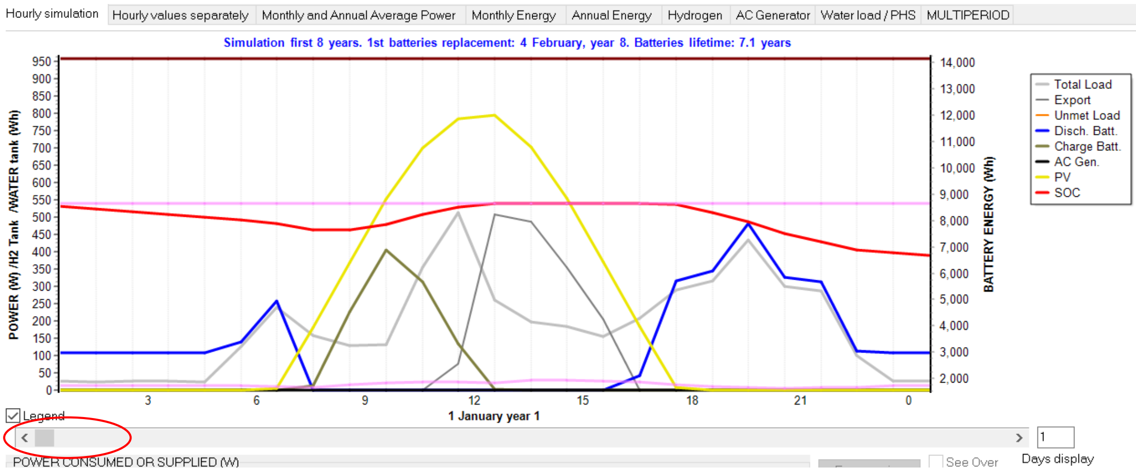
STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %

However, the estimated cost in this case is higher than that obtained in the previous project, because the estimation of the lifespan of the batteries is much more realistic with the Schiffer model: 7.09 years (compared to the 11.36 years estimated with the Ah model and cycle count ageing model, see section 22). Battery lifespan can be seen in the report or in the results table:

E gen (kWh)	E FC (kWh)	Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours Elyzer.	C. Fuel Gen.(€/yr)	C. Fuel FC
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	
0.3	0	1.63	7.09	3374.62	5308	0	0	0.4	

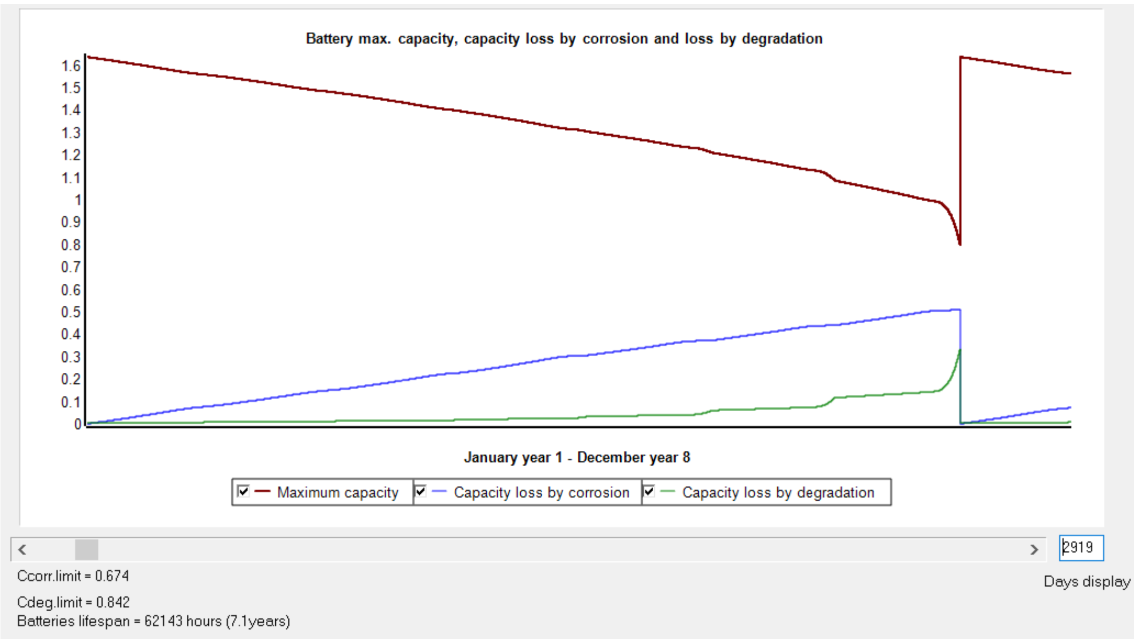
If we simulate the optimal combination, the simulation screen shows certain buttons with which we can visualize different results obtained with the Schiffer battery ageing model.

Clicking on the last row of results, in the "**SIMULATE**" button, after some seconds the following screen appears. _If, after 10 or 15 seconds, the mouse returns to the usual arrow and the simulation screen did not appear, click on the iHOGA icon on the taskbar at the bottom of the computer screen and the simulation screen will appear_.



By means of the bar under the graph, you can navigate in the simulation, seeing how the years pass and the remaining capacity of the batteries is reduced: brown curve, lower figure where we see the first 8 years (2920 days display), the batteries end their life when 7.09 years have passed.

You can also see the remaining capacity of the batteries by clicking the "**Capacity**" button on the right side of the simulation screen. If we indicate a high value of display days we get the following graph:



Where it is seen that the loss of capacity due to corrosion in this case is much higher than the loss due to degradation.

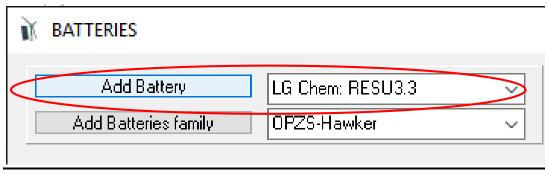
You can click the other buttons and see different parameters: battery voltage, battery current, factors used by the Schiffer model, unweighted and weighted cycles performed, bad charges, resistance, time since last complete charge and SOC.

33. Lithium batteries.

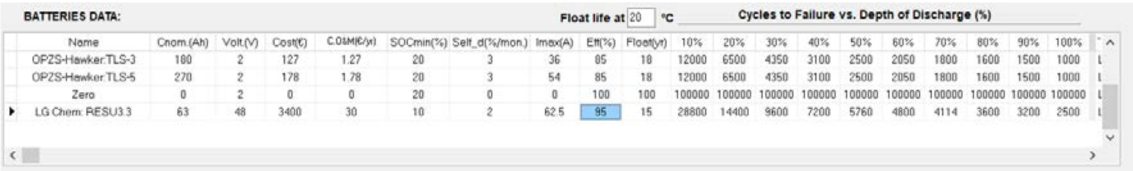
We save the project and then Save As, with the name "**Pr1-Li.hoga**".

Let's add a type of lithium battery, so that we will also consider it in the optimization. In this case the battery chosen is the LG Chem RESU3.3 (48 V).

On the battery screen, select this battery and click on "**Add Battery**"



It is added:

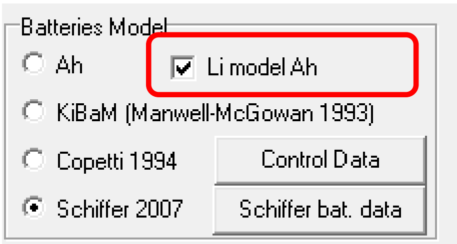


BATTERIES DATA: Float life at 20 °C — Cycles to Failure vs. Depth of Discharge (%)

Name	Cnom.(Ah)	Volt.(V)	Cost(€)	C.O&M(€/yr)	SOCmin(%)	Self_d(%/mon.)	Imax(A)	Eff(%)	Float(yr)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
OPZS-Hawker:TLS-3	180	2	127	1.27	20	3	36	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	1000
OPZS-Hawker:TLS-5	270	2	178	1.78	20	3	54	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	1000
Zero	0	2	0	0	20	0	0	100	100	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000
LG Chem: RESU3.3	63	48	3400	30	10	2	62.5	95	15	28800	14400	9600	7200	5760	4800	4114	3600	3200	2500

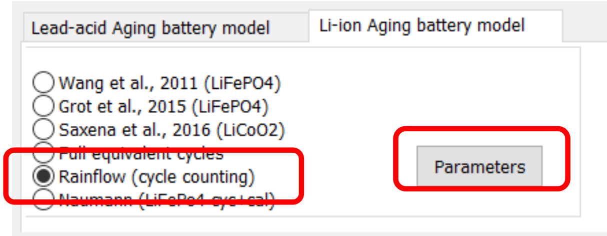
Maximum current is 62.5 A (approx. 1C), but many manufacturers recommend to limit current to 0.5 C, therefore we will change the name (adding "-mod") and later we change the Imax to 31.5 A:

For lithium-ion batteries, for the battery model, we must ensure that the checkbox "**Li-ion model Ah**" is checked because it is the most simple and adapts correctly to lithium-ion batteries.



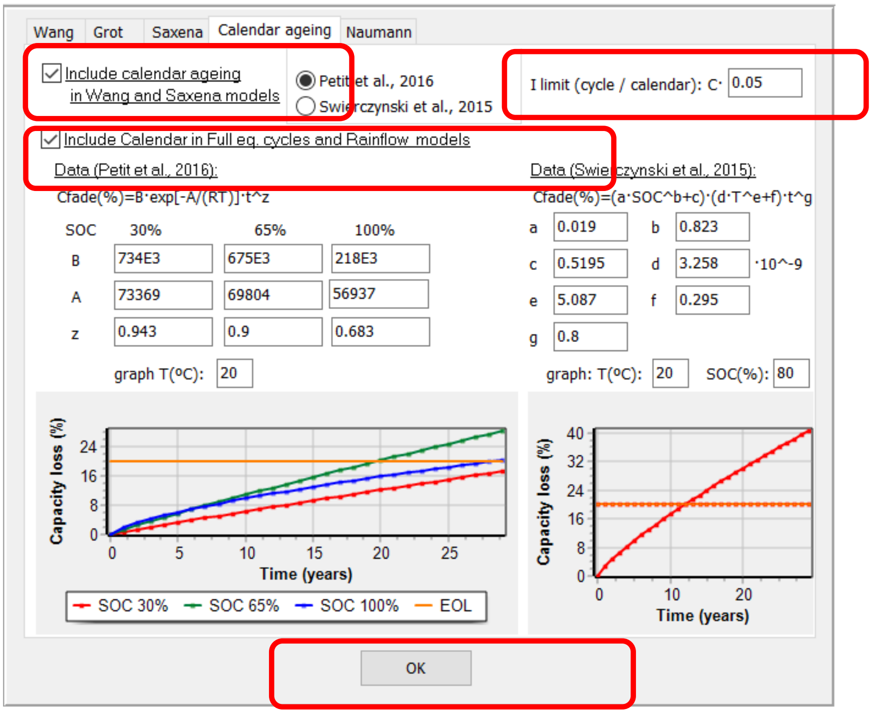
For the ageing model, you can select several models: Wang, Grot or Naumann for $LiFePO_4$, Saxena for $LiCoO_2$ or generic models (Full equivalent cycles or Rainflow). See the user manual for details.

It is important to say that Wang, Grot, Naumann and Saxena models were obtained by researchers by testing specific commercial batteries, so these models are only adequate for those commercial batteries tested and for the conditions they were tested. If you are not sure about if your battery is similar to the ones tested by these models, it would be better to select a generic model (Full equivalent cycles or Rainflow). In our case we select "Rainflow (cycle counting)" model (by default).



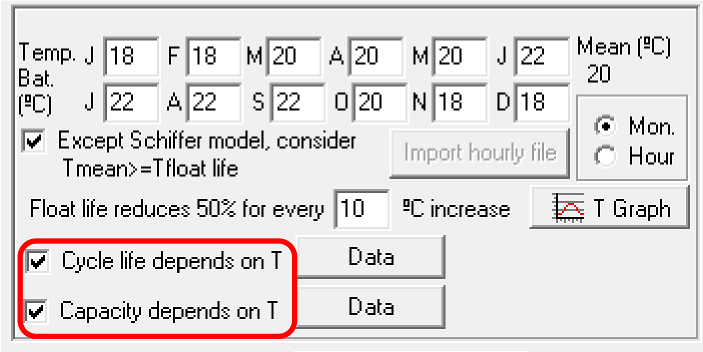
Full equivalent cycles or Rainflow models are generic models, and they consider the number of cycles to failure of the battery data.

After you select the model, click in "**Parameters**" button and **you should be sure that the calendar ageing model is included**, then both calendar and cycle degradation will be considered. In some cases (specially in stand-alone systems where cycling degradation is low), if you do not include calendar ageing you can obtain very high battery lifetime, which would be not real.



You should set a threshold limit to consider cycle or calendar ageing, by default a C-rate of 0.05 is the limit (we leave the default value). In the time steps when the C-rate is lower than this value calendar ageing will be considered and when it is higher cycle ageing will be considered. Then click "**OK**" to save the changes.

It is also important to select the checkboxes "**Cycle life depends on T**" and "**Capacity depends on T**", to consider the cycle life dependence on temperature and also the capacity dependence on temperature during each time step. With the button "**Data**" you can change that dependence, but we will leave the default values.

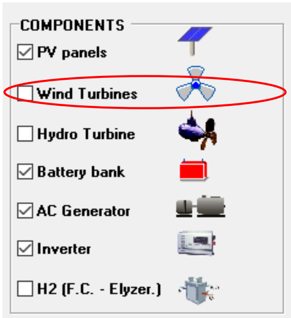


For lithium batteries it will use Rainflow life model (including cycle life dependence on temperature and calendar degradation) while for lead-acid batteries it will use the Schiffer model.

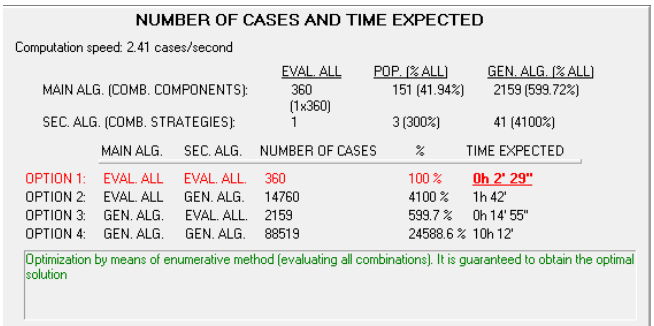
Click on "**OK**" and return to the main screen.

Since wind turbines have not been part of the optimum solution in the previous optimization, we will eliminate them to reduce the search space.

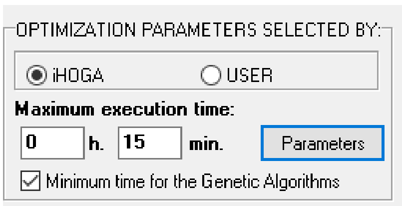
On the main screen, deselect the "Wind Turbines" box:



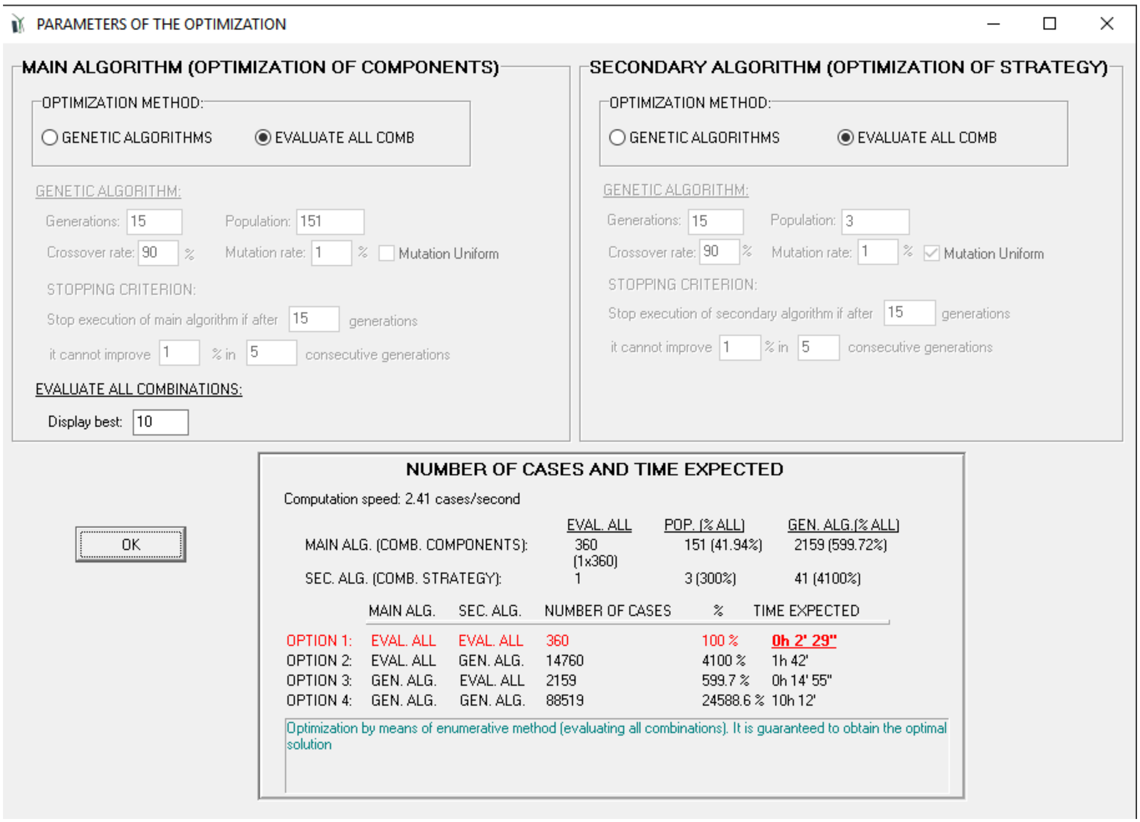
If we now move the mouse over the min. and max. number of components in parallel, we see the following screen, which indicates that in about 2 or 3 minutes it can be evaluate all the combinations.



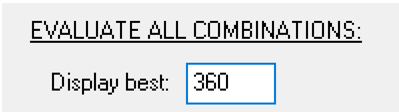
We see that there are 360 possible combinations. If we click on the "**Parameters**" button in the area of the selection of the optimization parameters:



The following screen appears:



If we change the value of "Display best" (default 10) by 360, when the optimization is finished we will see the results of all the combinations:

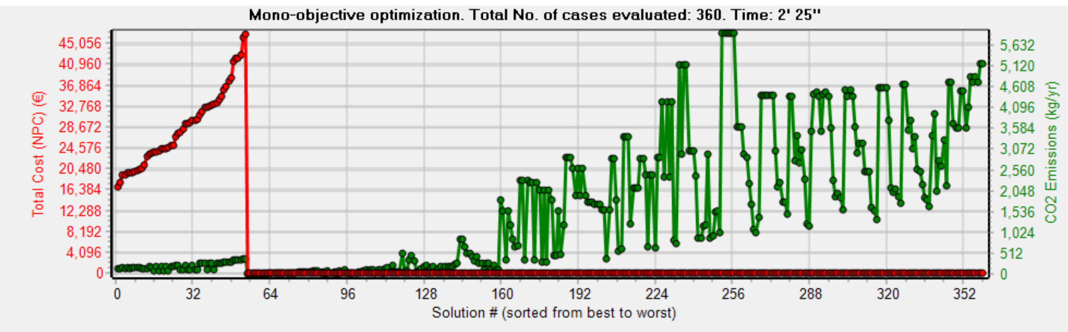


Then click on "OK" and return to the main screen.

Save the project and then click on the "**CALCULATE**" button to optimize the system, obtaining the results shown in the following figure, where you can see the 360 combinations and the optimum is the first row (since the enumerative method has been used). If we go down the table, it is observed that from solution 54 all have an "INFINITUM" cost, assigned to indicate that they do not satisfy all the constraints.

It is observed that the optimal solution (the first of the table, as all the combinations have been evaluated) is the same as in the previous case where we did not consider li-ion batteries.

The optimal solution found is shown in the next figure.



Show diagram

No.	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	16812.8	120.95	0.2	0.01	INF	6.6	99.97	0.57	SIMULATE..	REPORT...	(
2	17735	122.2	0.2	0.01	INF	6.6	99.96	0.6	SIMULATE..	REPORT...	(
3	19289.9	152.53	1	0.07	INF	6.9	99.81	0.66	SIMULATE..	REPORT...	(
4	19339.3	132.87	2.5	0.17	INF	2.3	98.88	0.66	SIMULATE..	REPORT...	(
5	19769.1	155.32	2.4	0.16	INF	2.3	97.07	0.67	SIMULATE..	REPORT...	(
6	19773.7	141.75	3.3	0.22	INF	2.4	98.7	0.67	SIMULATE..	REPORT...	(
7	19773.9	150.53	0	0	INF	9.9	100	0.67	SIMULATE..	REPORT...	(
8	19892.8	152.39	0.4	0.03	INF	6.9	99.73	0.68	SIMULATE..	REPORT...	(
9	20115.7	165.76	2.8	0.18	INF	2.4	96.7	0.68	SIMULATE..	REPORT...	(

COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 16812.8 € (0.57 €/kWh)

STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

Navigating the table, we can compare the first rows (the best solutions), seeing the components of each one. We can see that the third best solution includes li-ion batteries (in the table, go to the right with the scroll until you see the column of the nominal capacity of the battery, you can see the 4th row includes 1x1x63 Ah, that is, 1 serial (as the lithium battery nominal voltage is 48, same as the DC bus voltage) x 1 parallel x 63 Ah (the capacity of the lithium battery considered).

Report	Costs	HDI	Jobs	P. PV mod. (Wp)	Slope#1(º)	Cn Bat. (Ah)	P. Gen (W)	P. Inv (W)	P. Wind T. (W)	F. Turb (l/s)	P. F
REPORT...	COSTS...	0.525968	0.0048	4x4x100	35	24x1x180	1x500	1600	1x0	0	
REPORT...	COSTS...	0.525971	0.0048	4x4x100	35	24x1x180	1x1900	1600	1x0	0	
REPORT...	COSTS...	0.525916	0.00486	4x3x135	35	24x1x180	1x500	1600	1x0	0	
REPORT...	COSTS...	0.525818	0.004802	4x4x100	35	1x1x63	1x500	1600	1x0	0	
REPORT...	COSTS...	0.525824	0.004806	4x4x100	35	1x1x63	1x1900	1600	1x0	0	
REPORT...	COSTS...	0.525768	0.004862	4x3x135	35	1x1x63	1x500	1600	1x0	0	
REPORT...	COSTS...	0.525981	0.0048	4x4x100	35	24x1x270	1x500	1600	1x0	0	
REPORT...	COSTS...	0.525955	0.004861	4x3x135	35	24x1x180	1x1900	1600	1x0	0	
REPORT...	COSTS...	0.525801	0.004867	4x3x135	35	1x1x63	1x1900	1600	1x0	0	

The 4th best solution NPC is 19445.7 €, considerably higher than the best one.

No.	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	16812.8	120.95	0.2	0.01	INF	6.6	99.97	0.57	SIMULATE..	REPORT...	(
2	17735	122.2	0.2	0.01	INF	6.6	99.96	0.6	SIMULATE..	REPORT...	(
3	19289.9	152.53	1	0.07	INF	6.9	99.81	0.66	SIMULATE..	REPORT...	(
4	19339.3	132.87	2.5	0.17	INF	2.3	98.88	0.66	SIMULATE..	REPORT...	(

We can see that in this case, with the batteries and models selected, the optimal system includes lead-acid batteries and not lithium batteries. But in other cases it can be different, if the cost of the li-ion battery decreases or for places with different temperature.

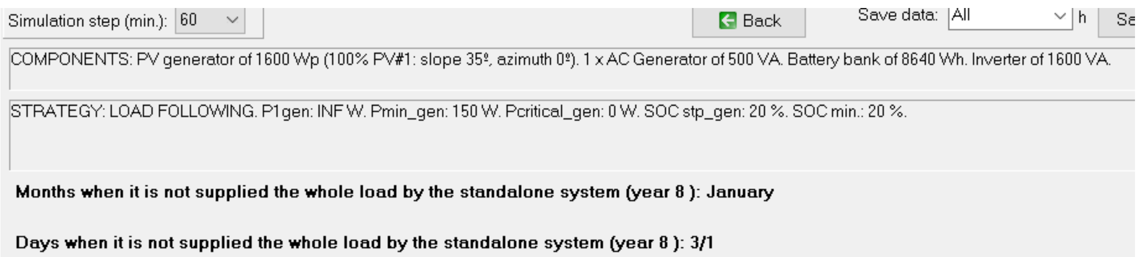
Lithium batteries can become competitive in some stand-alone systems, depending on costs, cycle life and working conditions.

More results can be compared, for example the hours of operation of the AC generator (gasoline or diesel): in cases with lithium batteries (third best solutions), it has to operate 98.01 h per year (equivalent hours, including equivalent hours due to the 5-minute penalty for each start as well as the life cycle penalty due to operating the generator out of its optimum range).

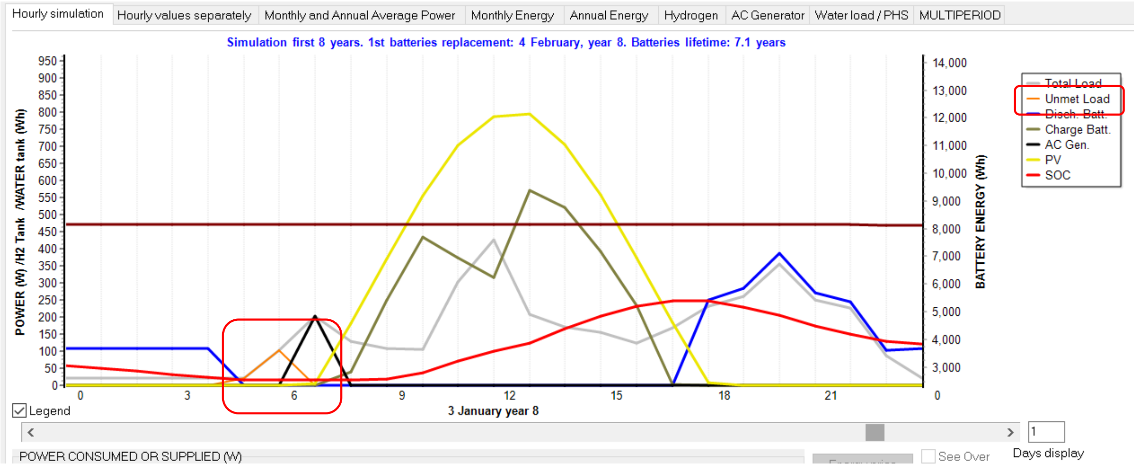
E disch. bat (kWh)	E elyzer. (kWh)	E gen (kWh)	E FC (kWh)	Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours E
928.3	0	0.3	0	1.63	7.09	3374.62	5308	0	
928.6	0	0.4	0	0.97	6.98	3394.71	5309.57	0	
928.8	0	1.8	0	10.71	5.11	3311.67	5347.33	0	
911.6	0	14.4	0	98.01	6.74	2923	5252	0	
909.9	0	41.6	0	98.85	6.73	2958	5230	0	
912.2	0	16.2	0	113.7	6.75	2960	5293	0	
929	0	0	0	0	7.43	3369.38	5313	0	
931	0	3.6	0	8.49	5.12	3315.5	5364	0	
911.6	0	46.7	0	111.0	6.73	2988	5279	0	

Comparing the 1st row (lead acid battery 180 Ah) with the 4th row (Lithium battery 63 Ah), being the total capacity of the lithium 1x1x63 Ah x 48 V = 3024 Wh, lower than that of lead-acid (24x1x180 Ah x 2V = 8640 Wh), in the case of Lithium (4th row) the generator must run for 98 hours during 1 year, while in the case of lead-acid (optimal solution, 1st row) it just work for 1.63 hours (this is the average during the 7.09 years of the battery lifetime, as Schiffer model was selected for lead-acid, the first years the generator doesn't run for any hour, the last years runs few hours). The total cost of the gasoline fuel and of replacement of the generator is higher than the savings in the batteries (total cost including their replacements), so in this case the combination with backup generator and lead-acid batteries is better. Smaller capacity lead-acid batteries could be added, and probably the optimal solution would have more difference in NPC, being lead-acid batteries the optimal in this case.

There is unmet load even though there is a backup generator in the system, which should supply all the missing energy. However, as we indicated on the AC generators screen that the availability of the gas generator is only from 7 am to 10 pm, during night hours it cannot run, so there are some hours when the batteries cannot deliver the energy during the night (because they are at minimum SOC) and also the gasoline generator is not allowed to run in those hours. If we see the simulation of the optimal solution, at the bottom of the simulation screen we are informed of the months and days when the demand is not covered (Year 8th, January the 3rd):



In the simulation we can see in orange the unmet load (energy not served) for the Year 8th, January the 3rd. At 6 a.m., the battery still has no energy to supply the load that is consumed at that hour, and the backup generator cannot run at this hour.



During these hours the generator cannot operate (unavailable at night), so there is some unmet load (orange).

Note that, in the tab "Hourly values separately", we see the simulation of the last year (8th year).

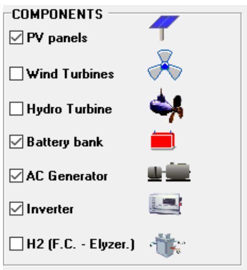
Finally, in the main screen of the program, we save the project with **Project-> Save**.

34. Probability analysis.

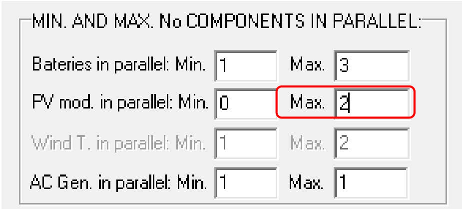
Next, we will perform, for a particular combination, the analysis of probability of variation of load, irradiation and inflation rate of the price of gasoline. Thus we will see how the variations of these variables affect the system.

We open the project "Pr1" (top menu, **Project-> Open**) and, once opened, we save it with another name **(Project-> Save as**), in this case we give it the name "**Pr1-Prob.hoga**".

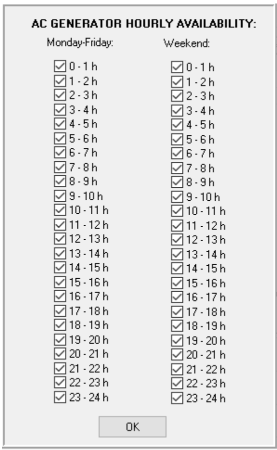
Next we eliminate the possibility of wind turbines, (deselecting the box "Wind turbines" of the main screen) to reduce the space of search (since we have seen that they do not appear in the optimal solution):



To better see the effect of the gasoline price inflation rate variable, we will limit the size of the photovoltaic generator, so that the gasoline generator will have to run more hours and the gas price effect will be better shown in the analysis of probability. To do this, we set a maximum of 2 branches of PV modules in parallel:

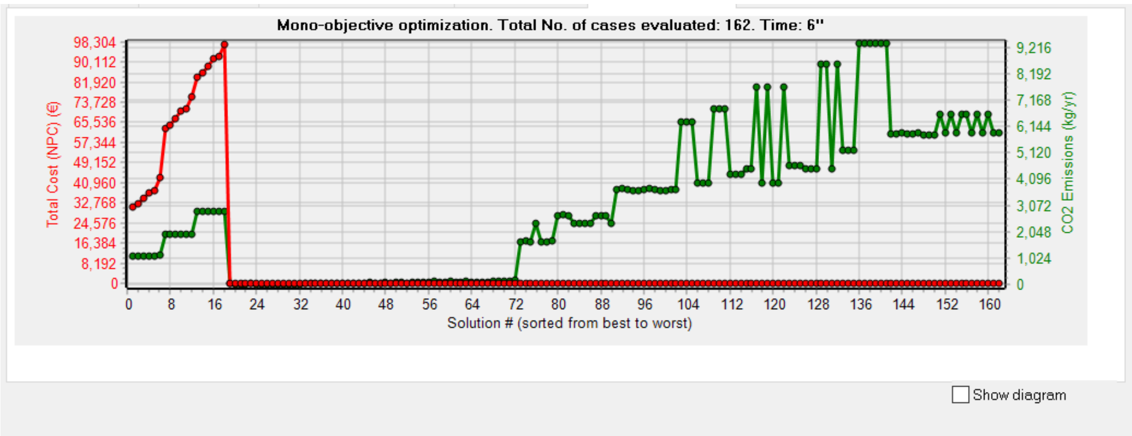


In the AC generators screen, we eliminate the availability restriction, that is, we leave the AC generator available during all hours of the day (see section 12):



We have 162 possible combinations, clicking on the "**Parameters**" button on the main screen, tab "**GENERAL DATA**" (see section 30), a screen appears where we must change the number 10 of "**Display best**" by 162. Then after the optimization we will see all the possible combinations:

Save the project. Then click on "**CALCULATE**" on the main screen, and perform the optimization again:



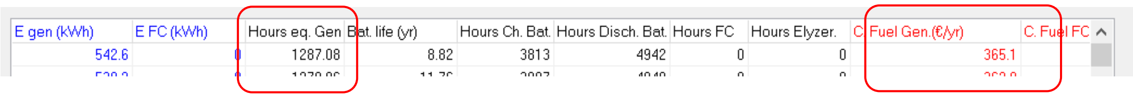
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	31105	1123.87	0.2	0.01	INF	10.3	63.83	1.06	SIMULATE..	REPORT...	C
2	32226.2	1124.09	0.2	0.01	INF	15.5	64.06	1.09	SIMULATE..	REPORT...	C
3	34457.6	1124.53	0.2	0.01	INF	20.6	64.28	1.17	SIMULATE..	REPORT...	C
4	36969.2	1124.18	0.2	0.01	INF	30.9	64.7	1.26	SIMULATE..	REPORT...	C
5	37897.6	1124.18	0.2	0.01	INF	30.9	64.7	1.29	SIMULATE..	REPORT...	C
6	43251.2	1144.2	0.2	0.01	INF	46.4	65.39	1.47	SIMULATE..	REPORT...	C
7	62966.2	1941.23	1.4	0.09	INF	10.3	71.05	2.14	SIMULATE..	REPORT...	C
8	64427.7	1941.16	1.4	0.09	INF	15.5	71.24	2.19	SIMULATE..	REPORT...	C
9	66953.3	1943.07	1.4	0.09	INF	20.6	71.42	2.28	SIMULATE..	REPORT...	C

The optimal one is shown in the first row (as all the combinations have been evaluated):

COMPONENTS: PV modules SiP12-TAB:PV-135-mod (135 Wp): 4s.x 2p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 kVA // Inverter STECA: XPC 1600-48 of 1600 VA // Rectif. included in bi-di inverter // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 31105 € (1.06 €/kWh)

STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

The cost is significantly higher than the case of Pr1, since we have now do not allow more than 2 branches of photovoltaic modules in parallel, which implies that to supply all the energy the AC generator (in this case diesel, since in the optimum solution appears Diesel 1.9 kVA) has to work many hours a year (1272.08 equivalent hours, including start-up and operating outside the optimum range penalties). Thereforem the cost of diesel fuel is high (365.1 €/year), and also the generator must be replaced every few years (the generator lasts 10,000 hours, so every 10000/1272.08 = 7.86 years you have to replace it). The results table shows the average hours per year the diesel runs and the fuel cost:

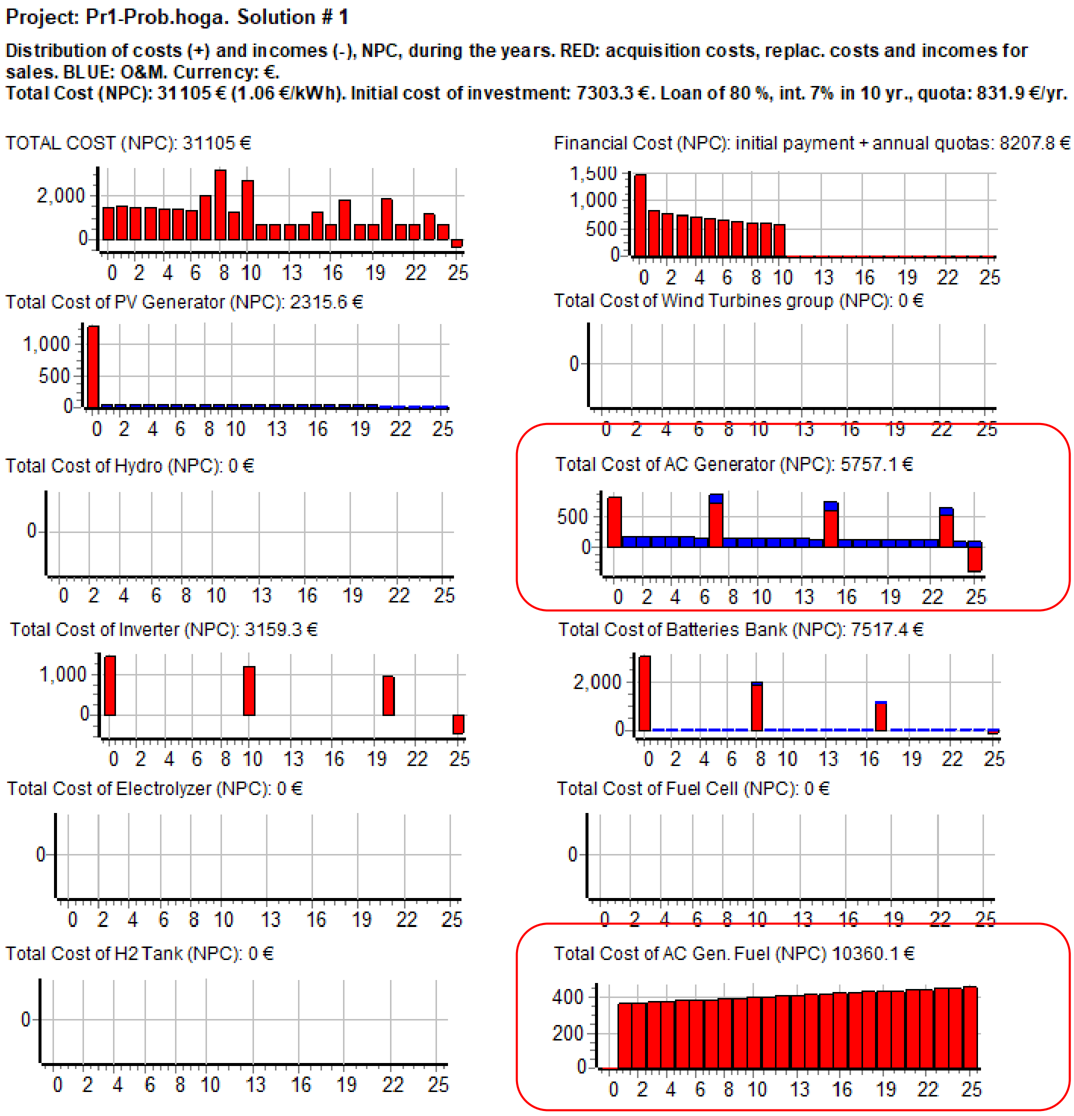


E gen (kWh)	E FC (kWh)	Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours Elyzer.	C	Fuel Gen.(€/yr)	C. Fuel FC
542.6	0	1287.08	8.82	3813	4942	0	0		365.1	

By clicking on the cell "**COSTS**" of the first row of the table we can see the different costs, where in the AC generator we see the replacement costs every 7 or 8 years (see next figure).

In the figure, below, we see the cost of the fuel, it increases every year due to fuel inflation (5%), although the cost that is displayed is the one transferred to the initial moment of the installation: annual_cost * (1 + inflation)^{year} / (1 + Interest) ^{year}. Where Interest is the nominal discount rate defined in the FINANCIAL DATA of the main screen (4%).

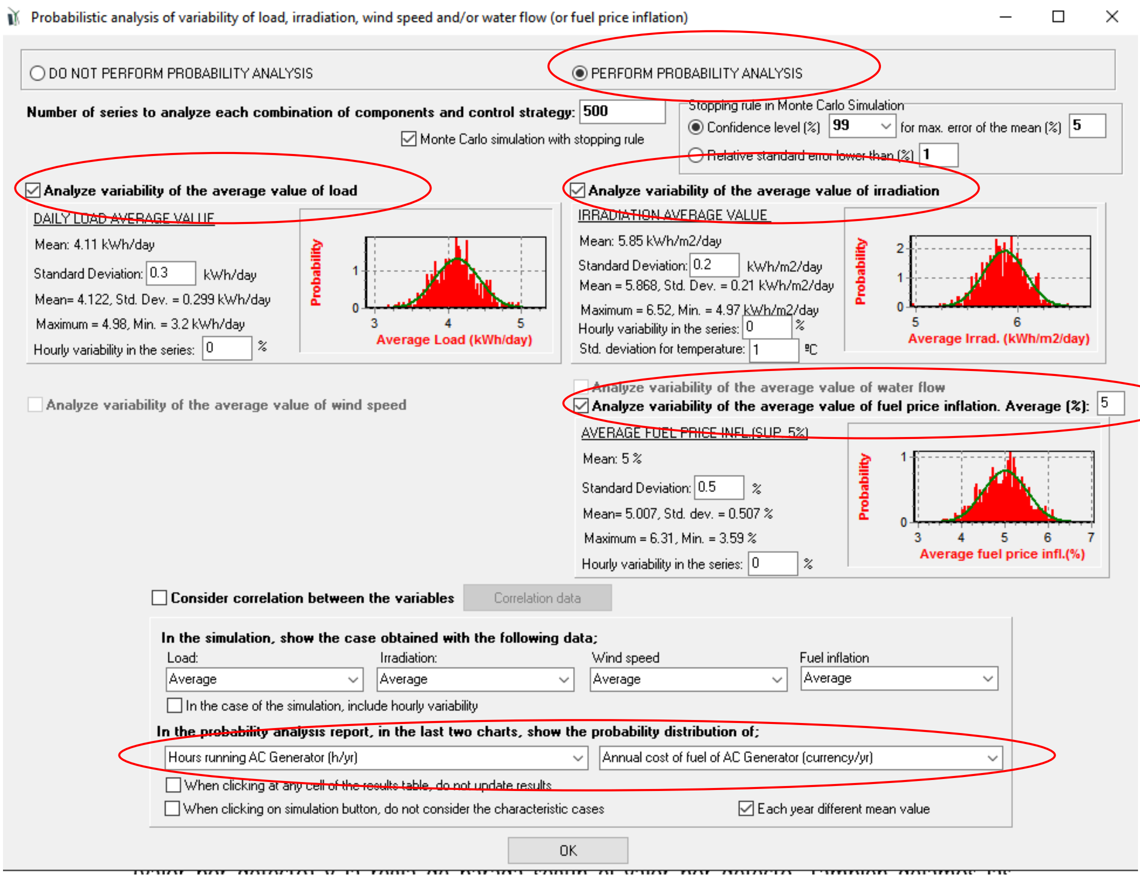
We see that the total cost of fuel over the useful life (NPC) is 10360.1 €. It is affected by the inflation rate of the price of fuel (fixed at 5% annual on the screen of AC generators) and interest rate (4%, fixed in the main screen of the program, tab "**FINANCIAL DATA**").



If we change the fuel inflation, the total cost NPC of the system will be modified.

Let's see below the probability analysis in which we will see the effect of irradiation, load and fuel price inflation.

In the main screen, click the "**Probability Analysis**" button (above the calculate button):

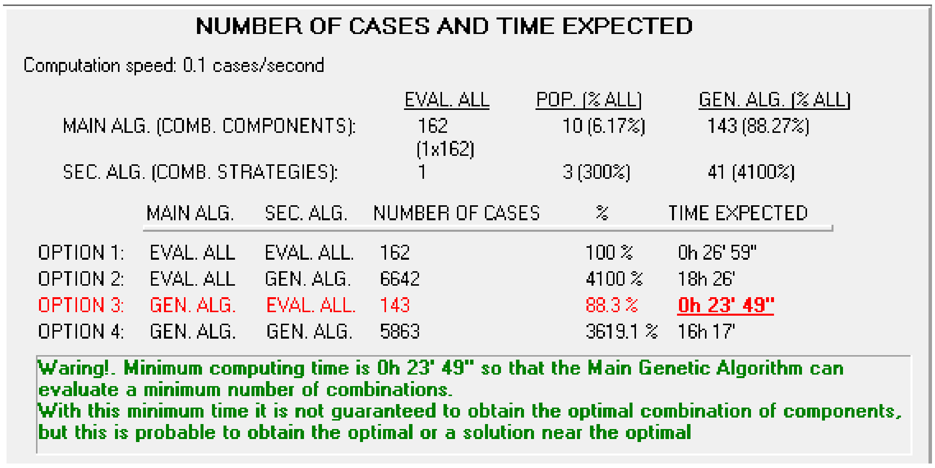


We select "**PERFORM PROBABILITY ANALYSIS**", and also "**Analyze the variability of the average value of load**", "**Analyze the variability of the average value of irradiation**" and "**Analyze the variability of the average value of fuel price inflation**". We leave the number of series to be performed for each component combination and control strategy in 500 (default) and the stop rule according to the default value. We also leave the standard deviations that appear by default (for load 0.3 kWh/day, for irradiation 0.2 kWh/m2/ day together with the temperature affecting the modules 1°C and for inflation of the price of fuel 0.5%).

Make sure that in the two drop-downs menus at the bottom appears "**Hours running AC Generator (h/year)**" and "**Annual cost of fuel AC generator (currency/year)**", respectively.

Click on "**OK**" and return to the main screen.

If we pass with the mouse over the area where the minimum and maximum number of parallel components are indicated, a window similar to the following appears:

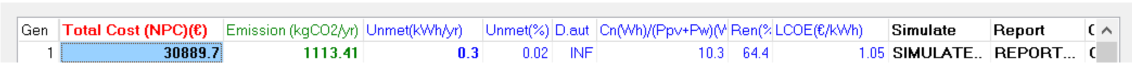


Indicating that the calculation speed is now 0.1 cases/second (approximately 500 times lower than before, since each case is evaluated up to a maximum of 500 times with different load and irradiation values, obtained randomly from their probability curves, whose mean values follow a normal distribution as we have seen). iHOGA would need at least 23' to perform the optimization.

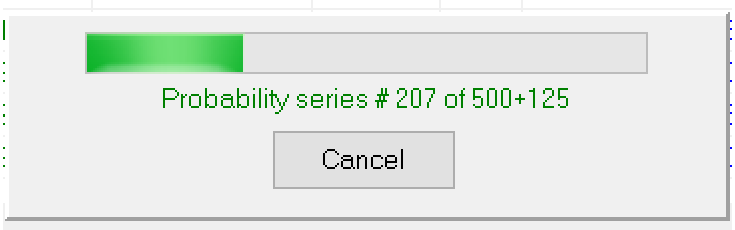
In our case we will not perform the optimization including the probability analysis. What we are going to do is simply to see the effect of the variation of the irradiation, the load and the inflation of the price of the fuel in a concrete case. For example, if we want to see how the probability analysis affects the best solution found, **simply click on the first row of the table** (where the best solution is indicated).

The following window appears, indicating that you are performing the 500 probability analysis combinations for the selected combination (although it will stop earlier if the stop criterion is reached before):

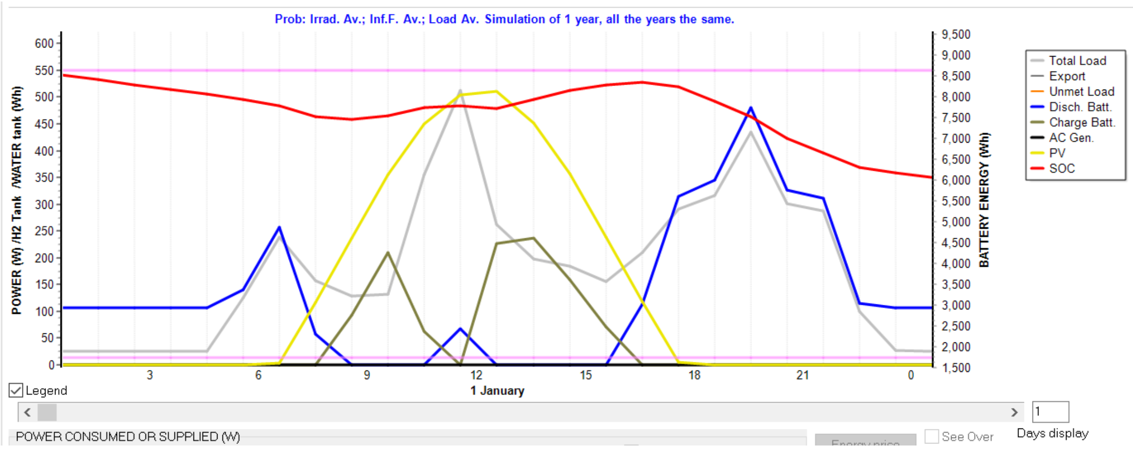
After a few seconds, that screen disappears and the results in the 1st row of the table are updated, but now the results we see in the 1st row are the average values of the combinations of probability analysis evaluated (500 or less if reached the stopping criterion). In our case, the average results are slightly different from the original result. Each time we click on the table, it will slightly change the result, because a new analysis of probability is performed and therefore new average values are obtained.



If we click again on the 1st row, but now in the "**SIMULATE**" cell, the following box appears, which indicates that you are doing the analysis of 500 probability combinations again (or less if the stop criterion is met), plus other 5 typical cases (combinations of mean, mean + standard deviation, mean-standard deviation, mean + 3 standard deviation, mean - 3 standard deviation), as there are 2 variables in the probability analysis (wind speed), 5^1 = 5 typical cases of combinations are evaluated, in addition to the 500 (or less if the stop criterion is met) random combinations.

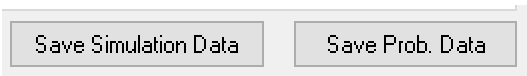


After some seconds the simulation screen appears:



The simulation of the case of average irradiation (Irrad. AV), average inflation of fuel price (Inf.F. Av.) and average load (Load Av.) is visualized. By default, the average case is displayed, but we could have chosen to display another combination, for example, the worst extreme, which would be the case of average load + 3·standard deviation, average inflation fuel price + 3·standard deviation and average irradiation - 3·standard deviation), the case being displayed must be indicated before on the probability analysis screen as shown below:

In the simulation screen, clicking the "**Save Simulation Data**" button saves the time data of the simulation case being displayed (in our case, the average case).



By clicking the "**Save Prob. Data**" button, the results of the probability analysis are stored in an Excel file. If you open the saved Excel file, something similar to this is shown:

Project: Pr1-Prob. Solution # 0
COMPONENTS: PV generator of 1080 Wp (100% PV#1: slope 35º, azimuth 0º). 1 x AC Generator of 1900 VA. Battery bank of 8640 Wh. Inverter of 1600 VA.
STRATEGY: LOAD FOLLOWING. P1gen: INF W. Pmin_gen: 570 W. SOC stp_gen: 20 %. SOC min.: 20 %.

RESULTS FOR THE DIFFERENT COMBINATIONS OF THE PROBABILITY ANALYSIS:
First 500 rows are the results corresponding to random data series. Next 125 rows correspond to characteristical cases. Next row correspond to the case shown in simulation. Finally MINIMUM, MAXIMUM, AVE

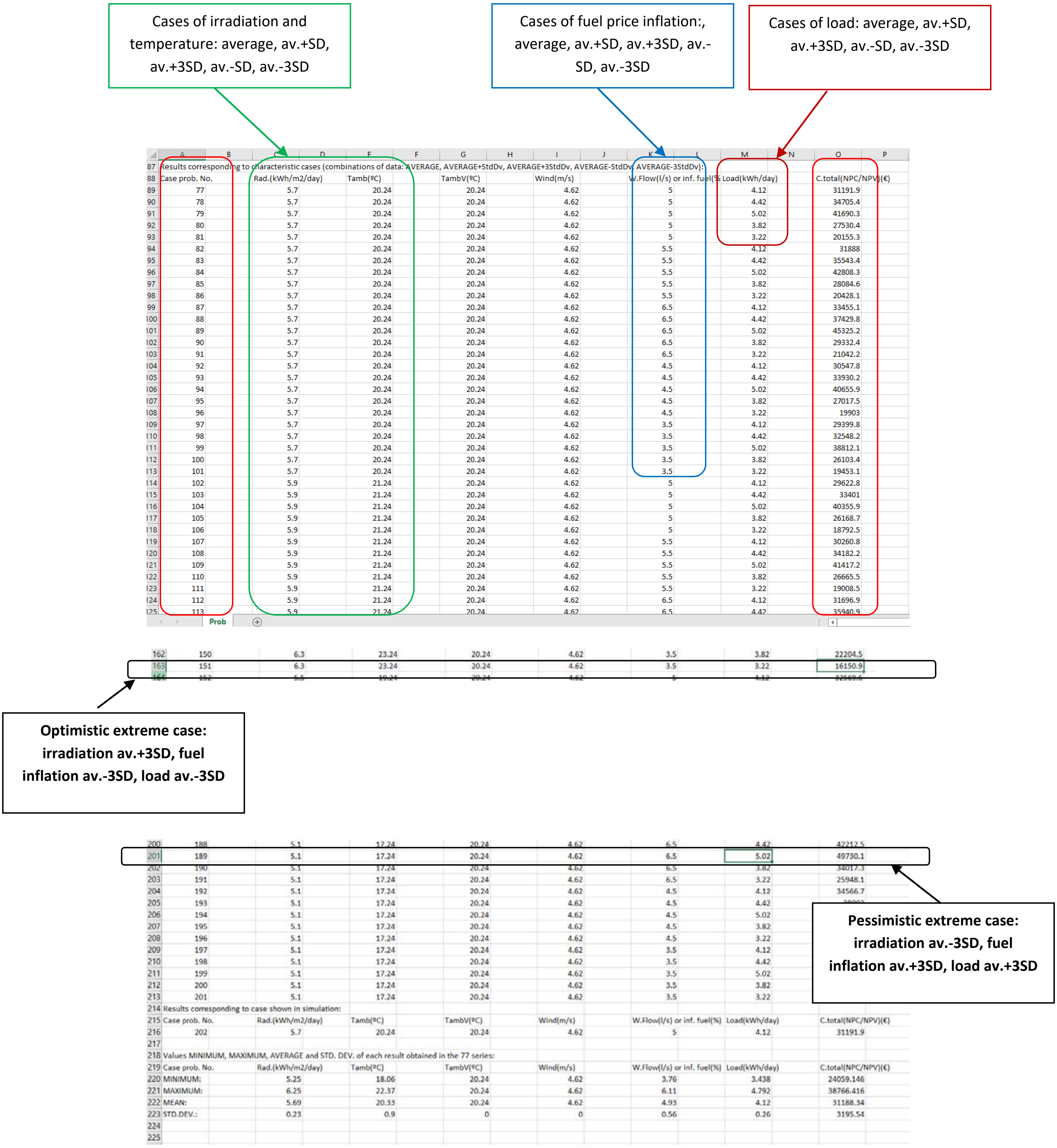
Results corresponding to random data series:

Case prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambV(ºC)	Wind(m/s)	W.Flow(l/s) or inf. fuel(%	Load(kWh/day)	C.total(NPC/NPV)(€)
0	5.7	20.24	20.24	4.62	5	4.12	31191.9
1	5.73	20.16	20.24	4.62	5	4.52	35885.2
2	5.25	19.09	20.24	4.62	5.36	4.08	34444.3
3	5.63	21	20.24	4.62	5.83	3.44	24059.1
4	5.68	19.89	20.24	4.62	6.08	4.2	34034.4
5	5.71	19.23	20.24	4.62	4.36	4.09	29956.9
6	5.75	20.74	20.24	4.62	4.75	3.89	27780.5
7	5.56	19.77	20.24	4.62	4.64	4.33	34097.7
8	5.7	20.23	20.24	4.62	3.76	4.14	29977.9
9	5.77	20.75	20.24	4.62	6.11	3.69	26505.5
10	5.55	21.23	20.24	4.62	5.99	3.96	31711.9
11	5.81	22.13	20.24	4.62	4.35	4.22	30696.5
12	5.79	20.24	20.24	4.62	4.77	4.25	31883.9
13	5.77	19.67	20.24	4.62	4.6	3.87	27281.5
14	5.74	20.42	20.24	4.62	4.24	4.29	31921.1
15	5.74	18.84	20.24	4.62	4.77	4.1	30478.4
16	5.55	20.44	20.24	4.62	5.23	4.24	33942.9
17	5.68	22.21	20.24	4.62	4.14	4.58	35440.3
18	6.03	21.25	20.24	4.62	4.6	4.42	31957.9
19	5.53	19.65	20.24	4.62	4.13	3.96	29518.6
20	6.04	20.11	20.24	4.62	4.87	4.43	32349.6
21	5.51	21.07	20.24	4.62	4.96	3.7	27437.6
22	5.87	20.62	20.24	4.62	4.71	4.32	31958
23	5.43	20.09	20.24	4.62	4.76	4.02	31557.8
24	5.42	20.23	20.24	4.62	5.71	4.04	33304.5
25	5.45	20.18	20.24	4.62	3.88	4.62	36743.4
26	5.41	20.87	20.24	4.62	4.75	4.47	37014
27	5.97	19.97	20.24	4.62	5.09	3.99	27831.7
28	6.25	20.99	20.24	4.62	5.38	4.2	28624.8
29	5.49	19.42	20.24	4.62	5.6	3.79	29411.5

Prob

In this case we see the 77 rows corresponding to the random probability cases, one in each row of the table (cases 0 to 76, since 500 cases have not been reached because the stopping rule of the Monte Carlo Simulation was met, the reader may see another number of rows since it is unlikely that the random analysis has been the same). In each case the average irradiance, temperature, fuel price inflation and average load are random (following their probability curves defined in the probability analysis screen). In each case (each row of the table) the results of this case are shown: total NPC cost, energy price, emissions, unmet load, renewable fraction, etc.

After the first rows, the results for 5^3 = 125 typical cases of combinations of irradiation, fuel price inflation and load (cases 163 to 258), including the average case, the most optimistic (mean irradiation + 3DT, mean consumption - 3DT) and More pessimistic (mean irradiation-3DT, mean consumption + 3DT):



87 Results corresponding to characteristic cases (combinations of data: AVERAGE, AVERAGE+StdDv, AVERAGE+3StdDv, AVERAGE-StdDv, AVERAGE-3StdDv):

Row	Case prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambV(ºC)	Wind(m/s)	W.Flow(l/s) or inf. fuel(%	Load(kWh/day)	C.total(NPC/NPV)(€)
89	77	5.7	20.24	20.24	4.62	5	4.12	31191.9
90	78	5.7	20.24	20.24	4.62	5	4.42	34705.4
91	79	5.7	20.24	20.24	4.62	5	5.02	41690.3
92	80	5.7	20.24	20.24	4.62	5	3.82	27530.4
93	81	5.7	20.24	20.24	4.62	5	3.22	20155.3
94	82	5.7	20.24	20.24	4.62	5.5	4.12	31888
95	83	5.7	20.24	20.24	4.62	5.5	4.42	35543.4
96	84	5.7	20.24	20.24	4.62	5.5	5.02	42808.3
97	85	5.7	20.24	20.24	4.62	5.5	3.82	28084.6
98	86	5.7	20.24	20.24	4.62	5.5	3.22	20428.1
99	87	5.7	20.24	20.24	4.62	6.5	4.12	33455.1
100	88	5.7	20.24	20.24	4.62	6.5	4.42	37429.8
101	89	5.7	20.24	20.24	4.62	6.5	5.02	45325.2
102	90	5.7	20.24	20.24	4.62	6.5	3.82	29332.4
103	91	5.7	20.24	20.24	4.62	6.5	3.22	21042.2
104	92	5.7	20.24	20.24	4.62	4.5	4.12	30547.8
105	93	5.7	20.24	20.24	4.62	4.5	4.42	33930.2
106	94	5.7	20.24	20.24	4.62	4.5	5.02	40655.9
107	95	5.7	20.24	20.24	4.62	4.5	3.82	27017.5
108	96	5.7	20.24	20.24	4.62	4.5	3.22	19903
109	97	5.7	20.24	20.24	4.62	3.5	4.12	29399.8
110	98	5.7	20.24	20.24	4.62	3.5	4.42	32548.2
111	99	5.7	20.24	20.24	4.62	3.5	5.02	38812.1
112	100	5.7	20.24	20.24	4.62	3.5	3.82	26103.4
113	101	5.7	20.24	20.24	4.62	3.5	3.22	19453.1
114	102	5.9	21.24	20.24	4.62	5	4.12	29622.8
115	103	5.9	21.24	20.24	4.62	5	4.42	33401
116	104	5.9	21.24	20.24	4.62	5	5.02	40355.9
117	105	5.9	21.24	20.24	4.62	5	3.82	26168.7
118	106	5.9	21.24	20.24	4.62	5	3.22	18792.5
119	107	5.9	21.24	20.24	4.62	5.5	4.12	30260.8
120	108	5.9	21.24	20.24	4.62	5.5	4.42	34182.2
121	109	5.9	21.24	20.24	4.62	5.5	5.02	41417.2
122	110	5.9	21.24	20.24	4.62	5.5	3.82	26665.5
123	111	5.9	21.24	20.24	4.62	5.5	3.22	19008.5
124	112	5.9	21.24	20.24	4.62	6.5	4.12	31696.9
125	113	5.9	21.24	20.24	4.62	6.5	4.42	35940.9

162	150	6.3	23.24	20.24	4.62	3.5	3.82	22204.5
163	151	6.3	23.24	20.24	4.62	3.5	3.22	16150.9
164	152	5.5	19.24	20.24	4.62	5	4.12	32569.6

200	188	5.1	17.24	20.24	4.62	6.5	4.42	42212.5
201	189	5.1	17.24	20.24	4.62	6.5	5.02	49730.1
202	190	5.1	17.24	20.24	4.62	6.5	3.82	34017.3
203	191	5.1	17.24	20.24	4.62	6.5	3.22	25948.1
204	192	5.1	17.24	20.24	4.62	4.5	4.12	34566.7
205	193	5.1	17.24	20.24	4.62	4.5	4.42	[illegible]
206	194	5.1	17.24	20.24	4.62	4.5	5.02	[illegible]
207	195	5.1	17.24	20.24	4.62	4.5	3.82	[illegible]
208	196	5.1	17.24	20.24	4.62	4.5	3.22	[illegible]
209	197	5.1	17.24	20.24	4.62	3.5	4.12	[illegible]
210	198	5.1	17.24	20.24	4.62	3.5	4.42	[illegible]
211	199	5.1	17.24	20.24	4.62	3.5	5.02	[illegible]
212	200	5.1	17.24	20.24	4.62	3.5	3.82	[illegible]
213	201	5.1	17.24	20.24	4.62	3.5	3.22	[illegible]

214 Results corresponding to case shown in simulation:

Row	Case prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambV(ºC)	Wind(m/s)	W.Flow(l/s) or inf. fuel(%)	Load(kWh/day)	C.total(NPC/NPV)(€)
216	202	5.7	20.24	20.24	4.62	5	4.12	31191.9

218 Values MINIMUM, MAXIMUM, AVERAGE and STD. DEV. of each result obtained in the 77 series:

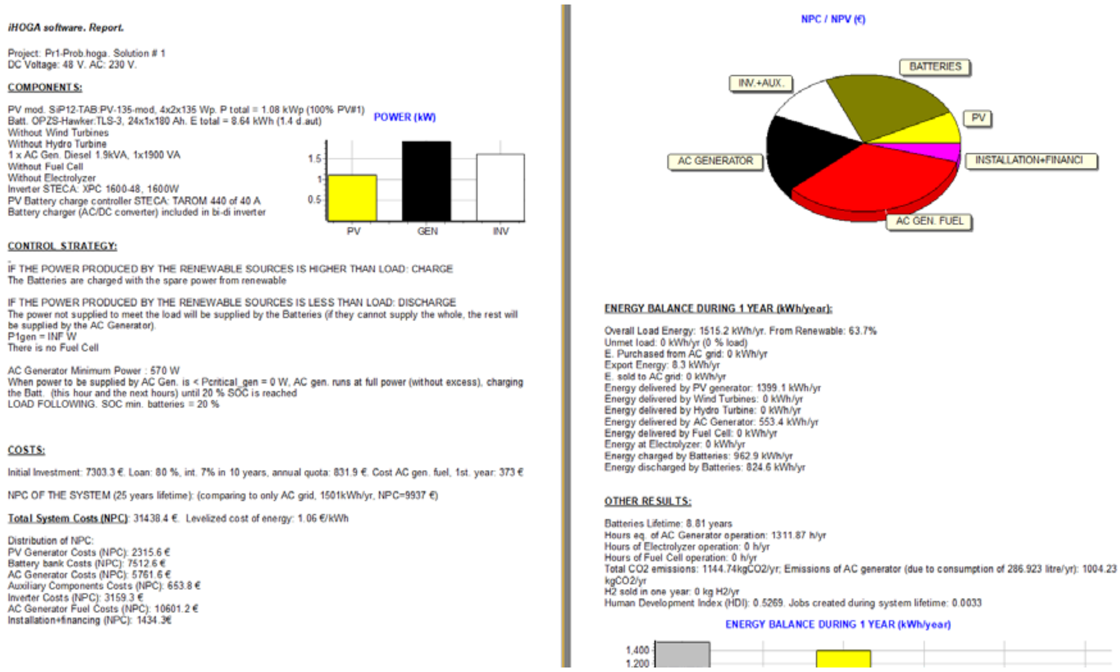
Row	Case prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambV(ºC)	Wind(m/s)	W.Flow(l/s) or inf. fuel(%)	Load(kWh/day)	C.total(NPC/NPV)(€)
220	MINIMUM:	5.25	18.06	20.24	4.62	3.76	3.438	24059.146
221	MAXIMUM:	6.25	22.37	20.24	4.62	6.11	4.792	38766.416
222	MEAN:	5.69	20.33	20.24	4.62	4.93	4.12	31188.34
223	STD.DEV.:	0.23	0.9	0	0	0.56	0.26	3195.54

It is observed that, in this case, the optimistic extreme case (irradiation average+3SD, fuel inflation average-3SD, load average-3SD) it has a NPC of 16150.9 €. The pessimistic extreme case (irradiation average-3SD, fuel inflation average+3SD, load average+3SD) has a NPC of € 49730.1

The next line (case 202) shows the case that is represented graphically in the simulation (mean values of the variables).

The following lines show the minimum, maximum, mean, and standard deviation values for each column (from the 0 to 76 cases, i.e., the random cases).

If we return to the main screen of iHOGA and click on the first row of the table, in the cell "**REPORT**", after a few seconds the report appears, which shows the average results of the analysis of probability of that combination of components and strategy:


iHOGA software. Report.

Project: Pr1-Prob.hoga. Solution # 1
DC Voltage: 48 V. AC: 230 V.

COMPONENTS:

PV mod. SiP12-TAB:PV-135-mod, 4x2x135 Wp. P total = 1.08 kWp (100% PV#1)
Batt. OPZS-Hawker:TLS-3, 24x1x180 Ah. E total = 8.64 kWh (1.4 d.aut)
Without Wind Turbines
Without Hydro Turbine
1 x AC Gen. Diesel 1.9kVA, 1x1900 VA
Without Fuel Cell
Without Electrolyzer
Inverter STECA: XPC 1600-48, 1600W
PV Battery charge controller STECA: TAROM 440 of 40 A
Battery charger (AC/DC converter) included in bi-di inverter

CONTROL STRATEGY:

IF THE POWER PRODUCED BY THE RENEWABLE SOURCES IS HIGHER THAN LOAD: CHARGE
The Batteries are charged with the spare power from renewable

IF THE POWER PRODUCED BY THE RENEWABLE SOURCES IS LESS THAN LOAD: DISCHARGE
The power not supplied to meet the load will be supplied by the Batteries (if they cannot supply the whole, the rest will be supplied by the AC Generator).
P1gen = INF W
There is no Fuel Cell

AC Generator Minimum Power : 570 W
When power to be supplied by AC Gen. is < Pcritical_gen = 0 W, AC gen. runs at full power (without excess), charging the Batt. (this hour and the next hours) until 20 % SOC is reached
LOAD FOLLOWING. SOC min. batteries = 20 %

COSTS:

Initial Investment: 7303.3 €. Loan: 80 %, int. 7% in 10 years, annual quota: 831.9 €. Cost AC gen. fuel, 1st. year: 373 €

NPC OF THE SYSTEM (25 years lifetime): (comparing to only AC grid, 1501kWh/yr, NPC=9937 €)

Total System Costs (NPC): 31438.4 €. Levelized cost of energy: 1.06 €/kWh

Distribution of NPC:
PV Generator Costs (NPC): 2315.6 €
Battery bank Costs (NPC): 7512.6 €
AC Generator Costs (NPC): 5761.6 €
Auxiliary Components Costs (NPC): 653.8 €
Inverter Costs (NPC): 3159.3 €
AC Generator Fuel Costs (NPC): 10601.2 €
Installation+financing (NPC): 1434.3€

ENERGY BALANCE DURING 1 YEAR (kWh/year):

Overall Load Energy: 1515.2 kWh/yr. From Renewable: 63.7%
Unmet load: 0 kWh/yr (0 % load)
E. Purchased from AC grid: 0 kWh/yr
Export Energy: 8.3 kWh/yr
E. sold to AC grid: 0 kWh/yr
Energy delivered by PV generator: 1399.1 kWh/yr
Energy delivered by Wind Turbines: 0 kWh/yr
Energy delivered by Hydro Turbine: 0 kWh/yr
Energy delivered by AC Generator: 553.4 kWh/yr
Energy delivered by Fuel Cell: 0 kWh/yr
Energy at Electrolyzer: 0 kWh/yr
Energy charged by Batteries: 962.9 kWh/yr
Energy discharged by Batteries: 824.6 kWh/yr

OTHER RESULTS:

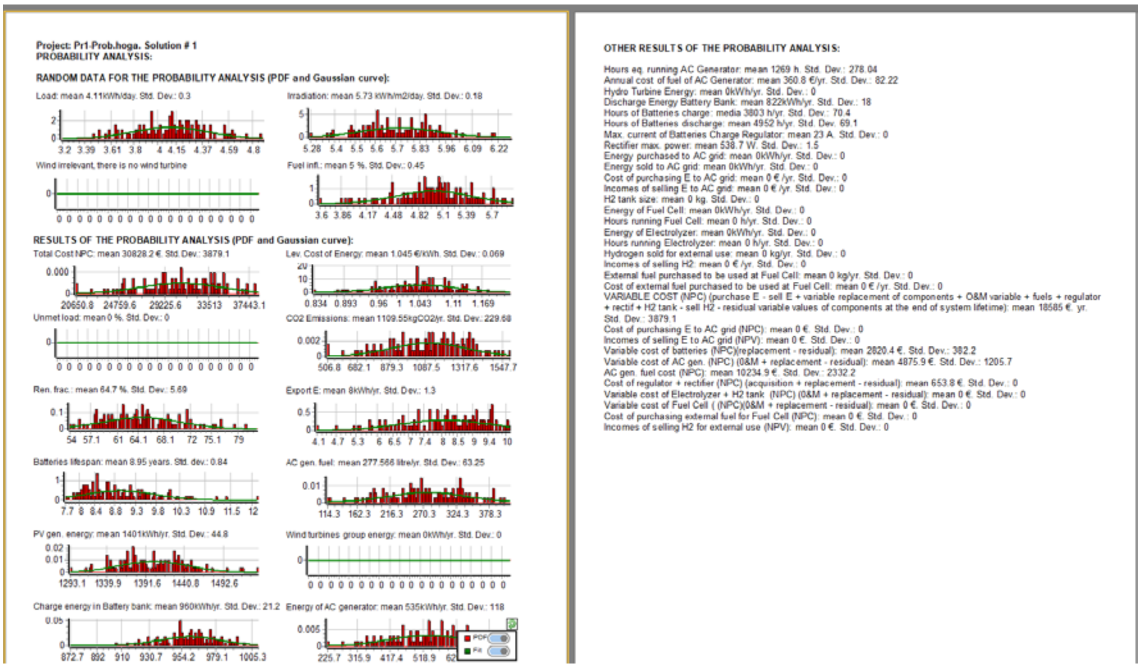
Batteries Lifetime: 8.81 years
Hours eq. of AC Generator operation: 1311.87 h/yr
Hours of Electrolyzer operation: 0 h/yr
Hours of Fuel Cell operation: 0 h/yr
Total CO2 emissions: 1144.74kgCO2/yr; Emissions of AC generator (due to consumption of 286.923 litre/yr): 1004.23 kgCO2/yr
H2 sold in one year: 0 kg H2/yr
Human Development Index (HDI): 0.5269. Jobs created during system lifetime: 0.0033

Click on "**Close**" (upper area of the report) and after selecting or not to download the .rtf file, after few seconds the report of the probability analysis of this case appears.

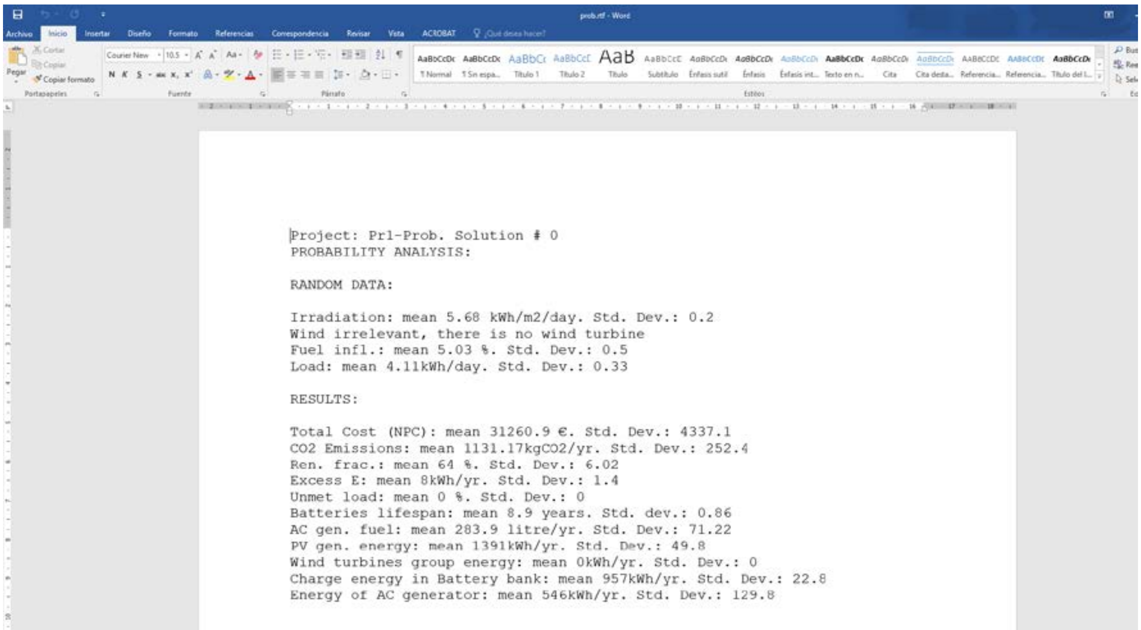
This report is of several pages, you move from one to the other with the arrow buttons at the top.

You can print or create a PDF file, selecting the printer (physical or pdf creator) and then you can print or create the PDF.

The first page shows the probability representation of the most representative results, marked in red the columns of the probability distribution obtained and the green curve is the one that best fits that distribution. The second page shows the results of other less important variables (only the mean and standard deviation) and then the results of the characteristic cases are shown (the 125 cases mentioned above, which include the mean and the optimistic and pessimistic extremes).



To close the report we click "**Close**" and we are asked if we want to save the results of the analysis of probability in a .rtf file (which can be open by Microsoft Word). We agree, download the file and open it with Microsoft Word:


Project: Pr1-Prob. Solution # 0
PROBABILITY ANALYSIS:

RANDOM DATA:

Irradiation: mean 5.68 kWh/m2/day. Std. Dev.: 0.2
Wind irrelevant, there is no wind turbine
Fuel infl.: mean 5.03 %. Std. Dev.: 0.5
Load: mean 4.11kWh/day. Std. Dev.: 0.33

RESULTS:

Total Cost (NPC): mean 31260.9 €. Std. Dev.: 4337.1
CO2 Emissions: mean 1131.17kgCO2/yr. Std. Dev.: 252.4
Ren. frac.: mean 64 %. Std. Dev.: 6.02
Excess E: mean 8kWh/yr. Std. Dev.: 1.4
Unmet load: mean 0 %. Std. Dev.: 0
Batteries lifespan: mean 8.9 years. Std. dev.: 0.86
AC gen. fuel: mean 283.9 litre/yr. Std. Dev.: 71.22
PV gen. energy: mean 1391kWh/yr. Std. Dev.: 49.8
Wind turbines group energy: mean 0kWh/yr. Std. Dev.: 0
Charge energy in Battery bank: mean 957kWh/yr. Std. Dev.: 22.8
Energy of AC generator: mean 546kWh/yr. Std. Dev.: 129.8

Finally we save the project.

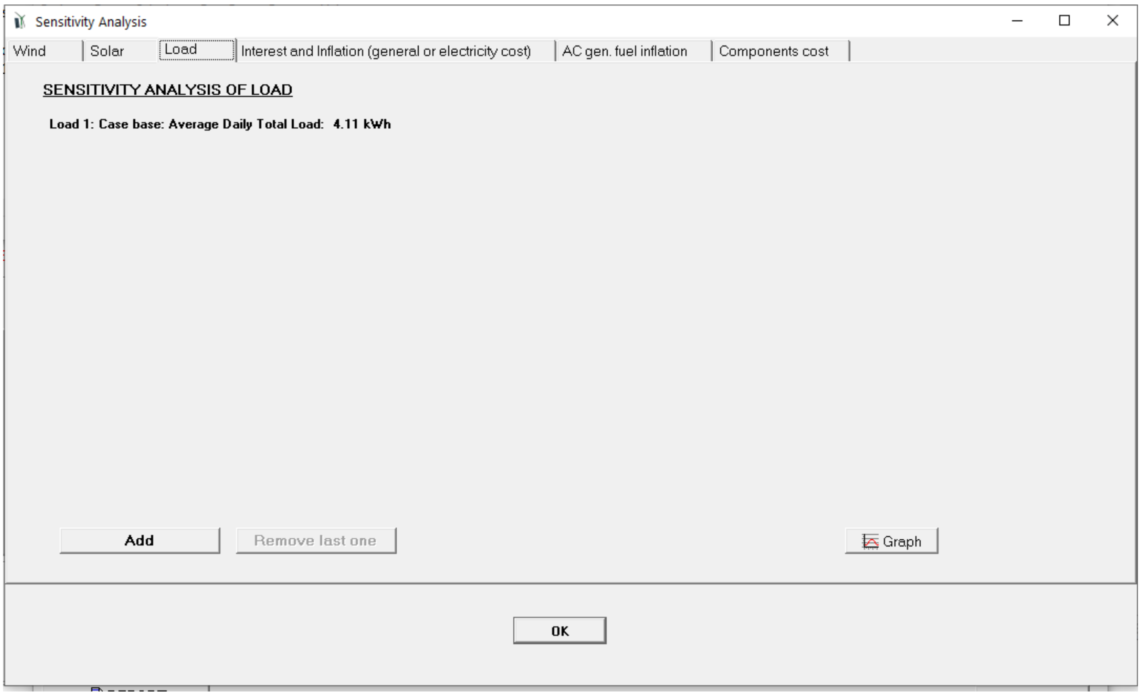
35. Sensitivity analysis.

Now we will perform the sensitivity analysis in the Pr1.hoga original project.

We open the Pr1.hoga project and save it as "**Pr1-Sens.hoga**".

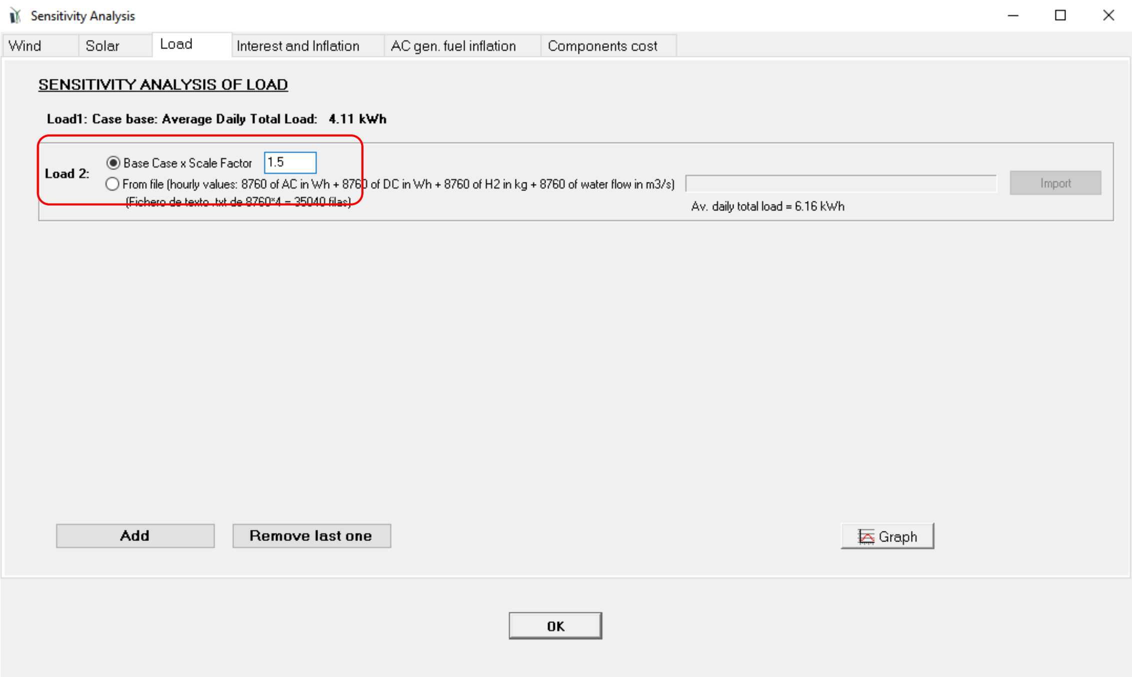
Click the "**Sensitivity Analysis**" button on the main screen (above "Probability Analysis").

A screen appears whose default tab is the sensitivity analysis of load:



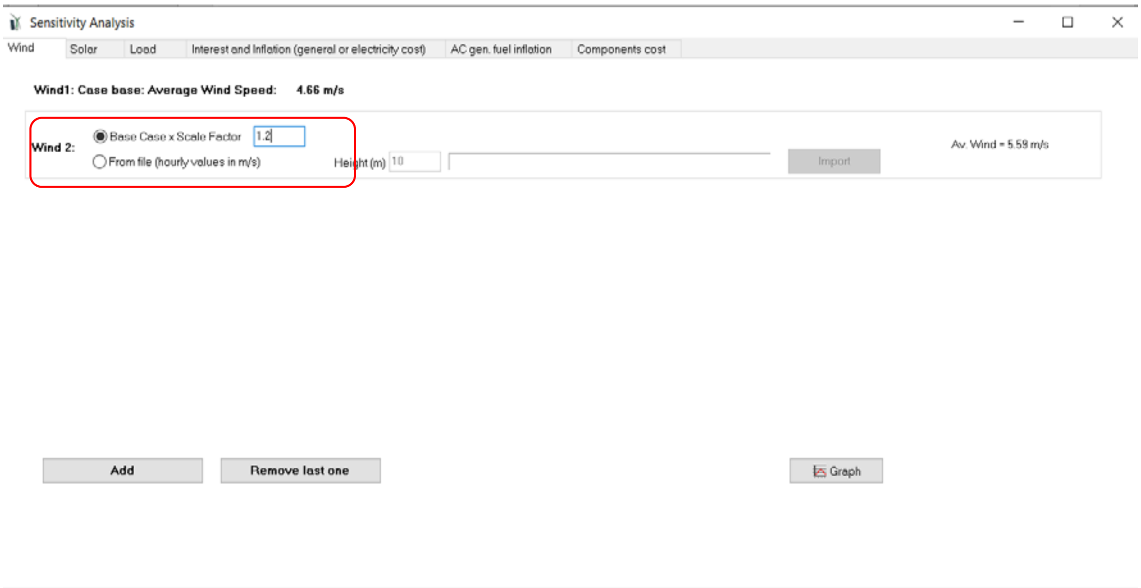
Case Load1 is the load defined in the screen **LOAD / AC GRID**.

Click on "**Add**" and a few fields appear to add a second consumption, Load2:

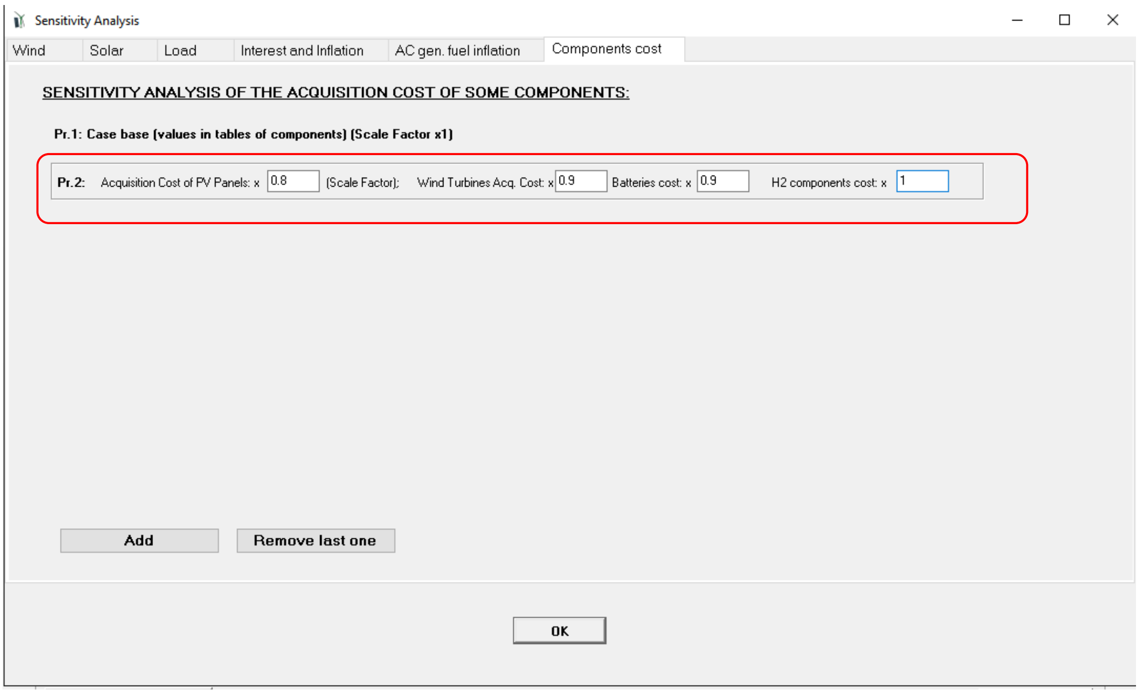


In "**Base Case x Scale factor**" indicate 1.5, this way we will consider cases with the base load and other cases with a consumption 50% higher.

Click on the "**Wind**" tab and add to consider cases with a wind 20% higher than defined on the wind resource screen:



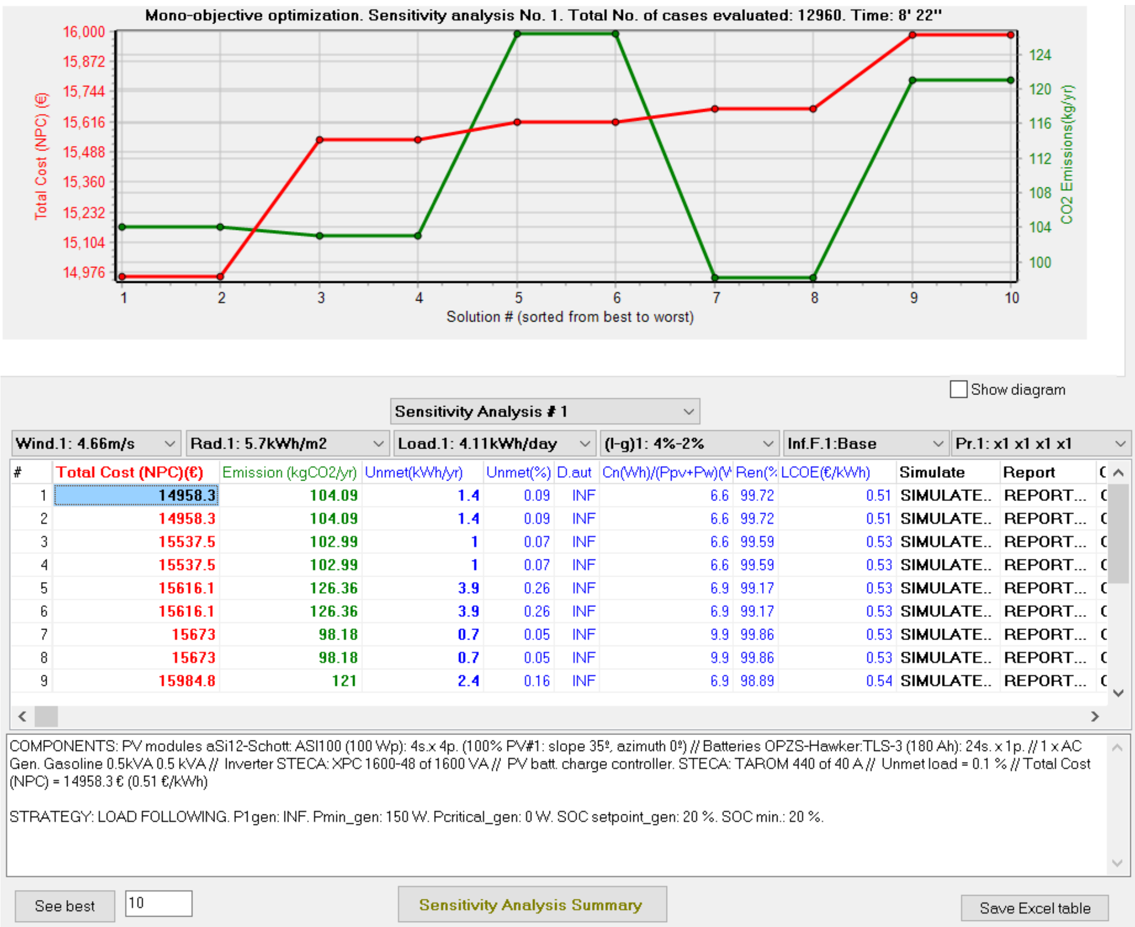
Then click on the tab "**Components cost**" to consider costs other than those defined in the screens of the components: Photovoltaic modules 80% of the defined cost, wind turbines 90%, batteries 90%:



We could also define sensitivity analysis of irradiation, interest (price of money) and inflation (general or inflation of electricity cost).

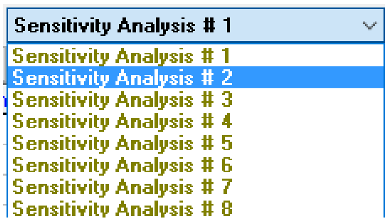
Click on "**OK**", save the project and then "**CALCULATE**" in the main screen.

After a few minutes the sensitivity analysis ends. We have analyzed 2 cases of load x 2 cases of wind x 2 cases of costs = 8 projects.

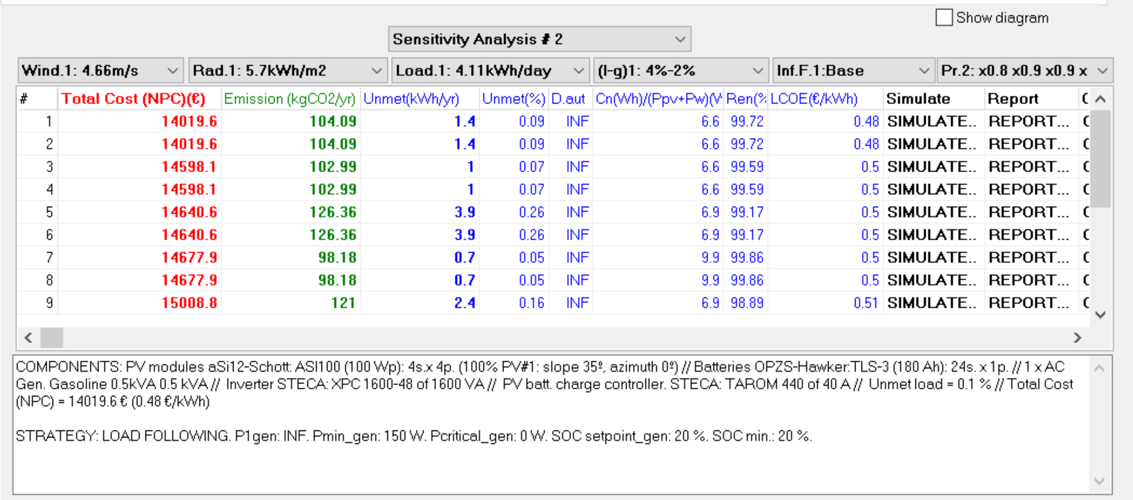


By default, the sensitivity analysis #1 is shown, corresponding to the base case (same result as in the Pr1.hoga Project).

We can select another project by clicking on the drop-down box "Sensitivity analysis #" (above the results table):



For example, if we choose # 2, the results of sensitivity analysis #2 appear:



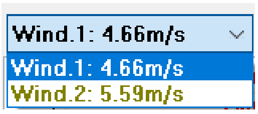
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	14019.6	104.09	1.4	0.09	INF	6.6	99.72	0.48	SIMULATE..	REPORT...	(
2	14019.6	104.09	1.4	0.09	INF	6.6	99.72	0.48	SIMULATE..	REPORT...	(
3	14598.1	102.99	1	0.07	INF	6.6	99.59	0.5	SIMULATE..	REPORT...	(
4	14598.1	102.99	1	0.07	INF	6.6	99.59	0.5	SIMULATE..	REPORT...	(
5	14640.6	126.36	3.9	0.26	INF	6.9	99.17	0.5	SIMULATE..	REPORT...	(
6	14640.6	126.36	3.9	0.26	INF	6.9	99.17	0.5	SIMULATE..	REPORT...	(
7	14677.9	98.18	0.7	0.05	INF	9.9	99.86	0.5	SIMULATE..	REPORT...	(
8	14677.9	98.18	0.7	0.05	INF	9.9	99.86	0.5	SIMULATE..	REPORT...	(
9	15008.8	121	2.4	0.16	INF	6.9	98.89	0.51	SIMULATE..	REPORT...	(

COMPONENTS: PV modules aSi12-Schott ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0.1 % // Total Cost (NPC) = 14019.6 € (0.48 €/kWh)

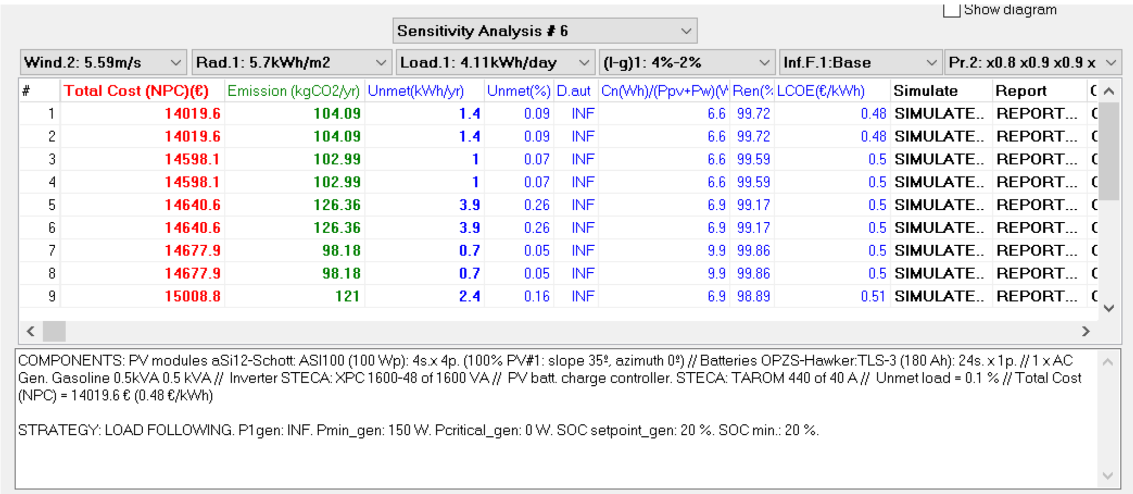
STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

We see that it corresponds to the base wind (Wind1), base load (Load1), components cost 2 (Pr.2). As the costs are lower, the optimum has a lower cost than in the base case.

We can also modify directly the drop-down box of each variable. For example, if we change the wind drop-down box and select Wind2:



We see that analysis number 6 appears, where the optimum found is the same as in analysis number 2 (since in both cases no wind turbines were selected in the optimum solution):

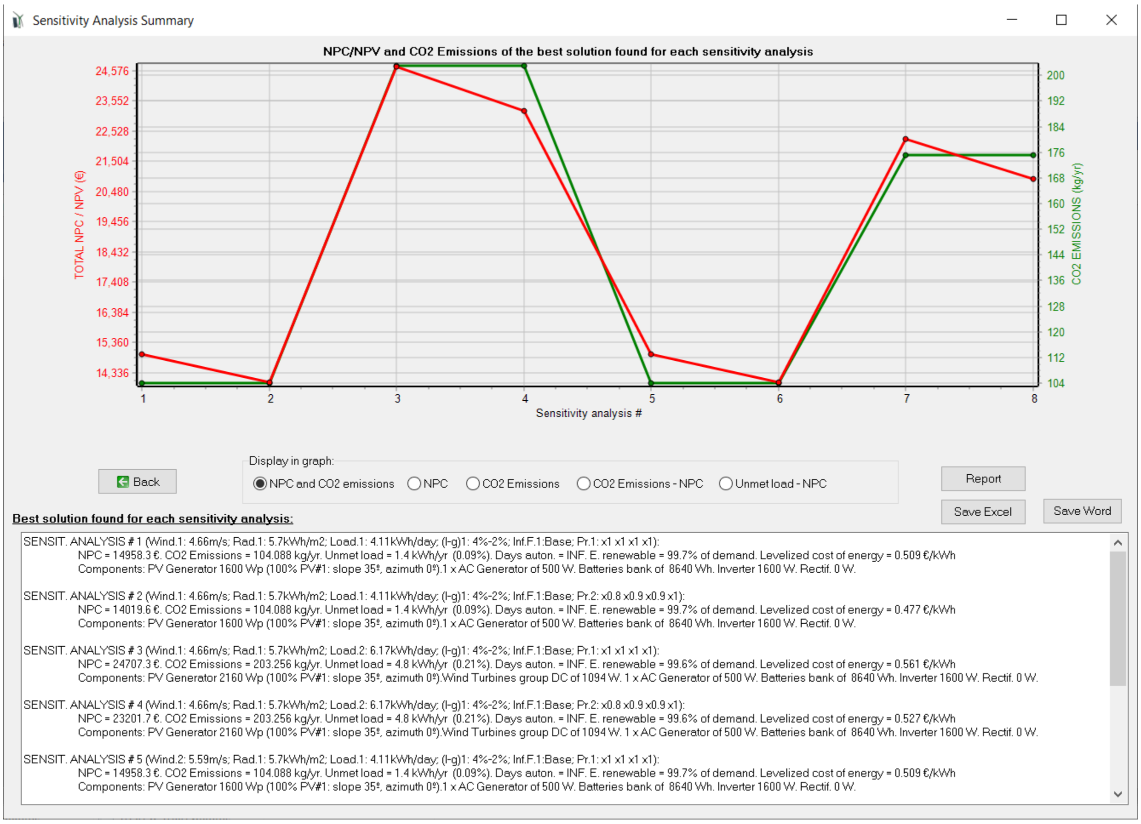


#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(
1	14019.6	104.09	1.4	0.09	INF	6.6	99.72	0.48	SIMULATE..	REPORT...	(
2	14019.6	104.09	1.4	0.09	INF	6.6	99.72	0.48	SIMULATE..	REPORT...	(
3	14598.1	102.99	1	0.07	INF	6.6	99.59	0.5	SIMULATE..	REPORT...	(
4	14598.1	102.99	1	0.07	INF	6.6	99.59	0.5	SIMULATE..	REPORT...	(
5	14640.6	126.36	3.9	0.26	INF	6.9	99.17	0.5	SIMULATE..	REPORT...	(
6	14640.6	126.36	3.9	0.26	INF	6.9	99.17	0.5	SIMULATE..	REPORT...	(
7	14677.9	98.18	0.7	0.05	INF	9.9	99.86	0.5	SIMULATE..	REPORT...	(
8	14677.9	98.18	0.7	0.05	INF	9.9	99.86	0.5	SIMULATE..	REPORT...	(
9	15008.8	121	2.4	0.16	INF	6.9	98.89	0.51	SIMULATE..	REPORT...	(

COMPONENTS: PV modules aSi12-Schott ASI100 (100 Wp): 4s.x 4p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 kVA // Inverter STECA XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0.1 % // Total Cost (NPC) = 14019.6 € (0.48 €/kWh)

STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

If we click on "**Sensitivity Analysis Summary**" (below the table) a comparative chart of the 8 analyzes projects appears, indicating below the optimal solution of each one:

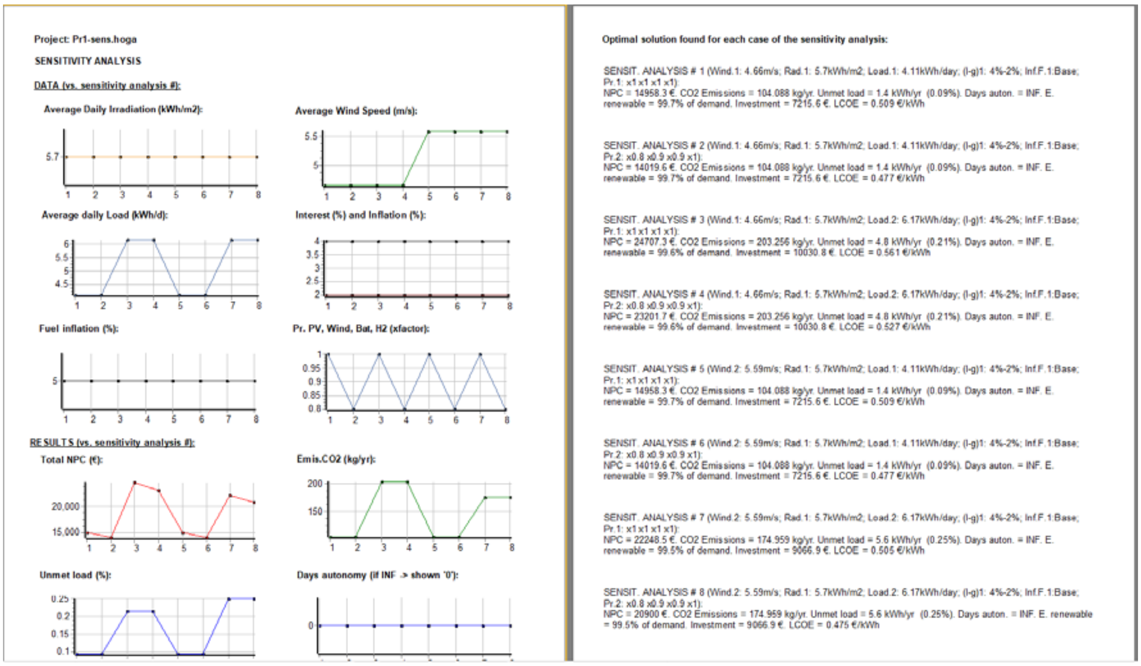


Clicking the "**Save Excel**" button it saves an Excel file where the optimal solution for each of the sensitivity analysis projects appears:

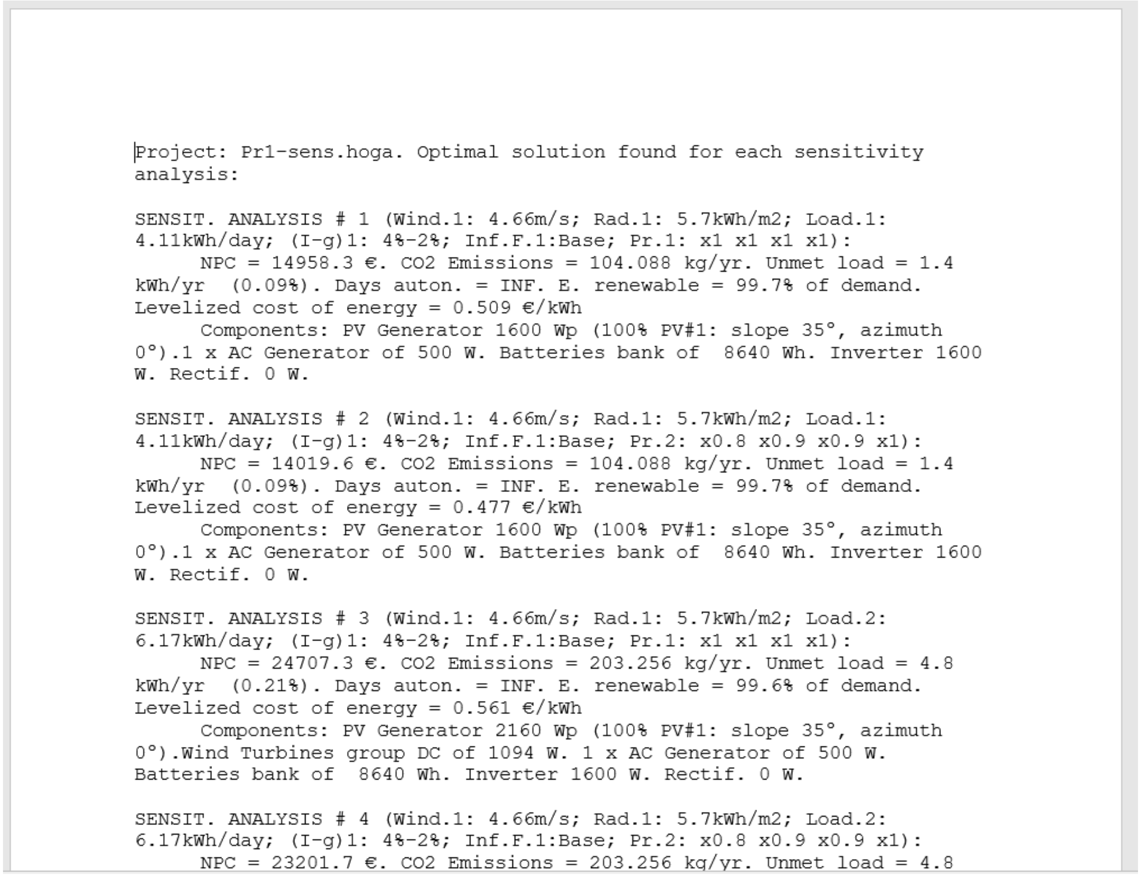
Project: Pr1-sens.hoga. Best system found for each case of the sensitivity analysis

Sens.#	Wind (m/s)	Rad(kWh/m2/d)	Load(kWh/d)	Interest(%)	Inflation(%)	Infla.Fuel(%)	Pr.PV(x)	Pr.W.T.(x)
1	4.66	5.7	4.11	4	2	5	1	1
2	4.66	5.7	4.11	4	2	5	0.8	0.9
3	4.66	5.7	6.17	4	2	5	1	1
4	4.66	5.7	6.17	4	2	5	0.8	0.9
5	5.59	5.7	4.11	4	2	5	1	1
6	5.59	5.7	4.11	4	2	5	0.8	0.9
7	5.59	5.7	6.17	4	2	5	1	1
8	5.59	5.7	6.17	4	2	5	0.8	0.9

If we click on the "**Report**" button a report of the sensitivity analysis appears, that can be printed or saved in PDF.



If we click on the "**Save Word**" button a report of the sensitivity analysis appears.



```
Project: Pr1-sens.hoga. Optimal solution found for each sensitivity
analysis:

SENSIT. ANALYSIS # 1 (Wind.1: 4.66m/s; Rad.1: 5.7kWh/m2; Load.1:
4.11kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.1: x1 x1 x1 x1):
     NPC = 14958.3 €. CO2 Emissions = 104.088 kg/yr. Unmet load = 1.4
kWh/yr  (0.09%). Days auton. = INF. E. renewable = 99.7% of demand.
Levelized cost of energy = 0.509 €/kWh
     Components: PV Generator 1600 Wp (100% PV#1: slope 35°, azimuth
0°).1 x AC Generator of 500 W. Batteries bank of  8640 Wh. Inverter 1600
W. Rectif. 0 W.

SENSIT. ANALYSIS # 2 (Wind.1: 4.66m/s; Rad.1: 5.7kWh/m2; Load.1:
4.11kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.2: x0.8 x0.9 x0.9 x1):
     NPC = 14019.6 €. CO2 Emissions = 104.088 kg/yr. Unmet load = 1.4
kWh/yr  (0.09%). Days auton. = INF. E. renewable = 99.7% of demand.
Levelized cost of energy = 0.477 €/kWh
     Components: PV Generator 1600 Wp (100% PV#1: slope 35°, azimuth
0°).1 x AC Generator of 500 W. Batteries bank of  8640 Wh. Inverter 1600
W. Rectif. 0 W.

SENSIT. ANALYSIS # 3 (Wind.1: 4.66m/s; Rad.1: 5.7kWh/m2; Load.2:
6.17kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.1: x1 x1 x1 x1):
     NPC = 24707.3 €. CO2 Emissions = 203.256 kg/yr. Unmet load = 4.8
kWh/yr  (0.21%). Days auton. = INF. E. renewable = 99.6% of demand.
Levelized cost of energy = 0.561 €/kWh
     Components: PV Generator 2160 Wp (100% PV#1: slope 35°, azimuth
0°).Wind Turbines group DC of 1094 W. 1 x AC Generator of 500 W.
Batteries bank of  8640 Wh. Inverter 1600 W. Rectif. 0 W.

SENSIT. ANALYSIS # 4 (Wind.1: 4.66m/s; Rad.1: 5.7kWh/m2; Load.2:
6.17kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.2: x0.8 x0.9 x0.9 x1):
     NPC = 23201.7 €. CO2 Emissions = 203.256 kg/yr. Unmet load = 4.8
```

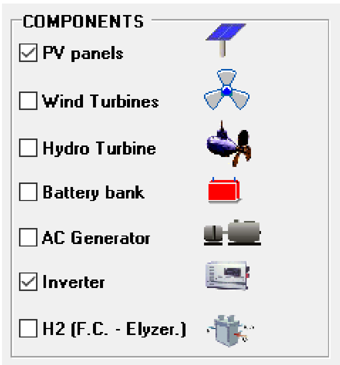
Finally, we return to the main screen ("**Back**") and save the project.

36. Net metering in grid-connected systems.

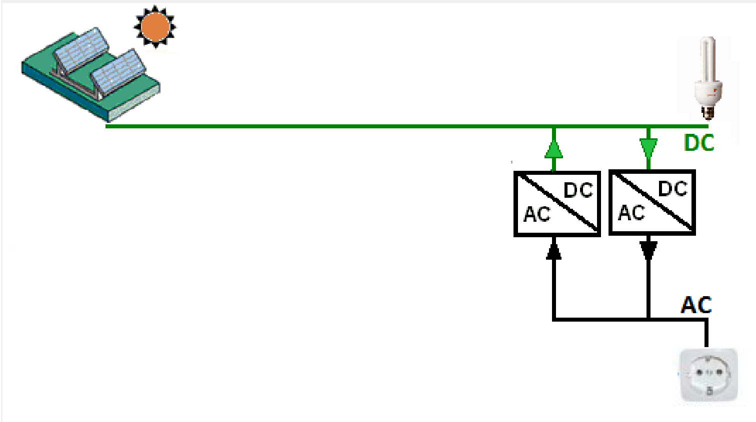
Next we are going to carry out a project to consider net metering in grid-connected systems.

We open the Pr1.hoga project and then save it as "**NetMet.hoga**".

We remove all components except the photovoltaic modules and the inverter:

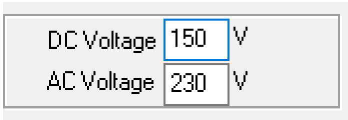


The scheme is now:

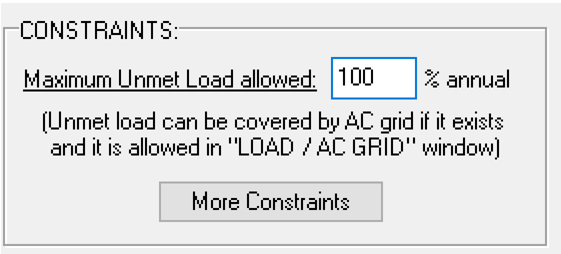


Even if a rectifier appears in the diagram, as there will be no DC loads or batteries, it will not be considered (its cost is 0).

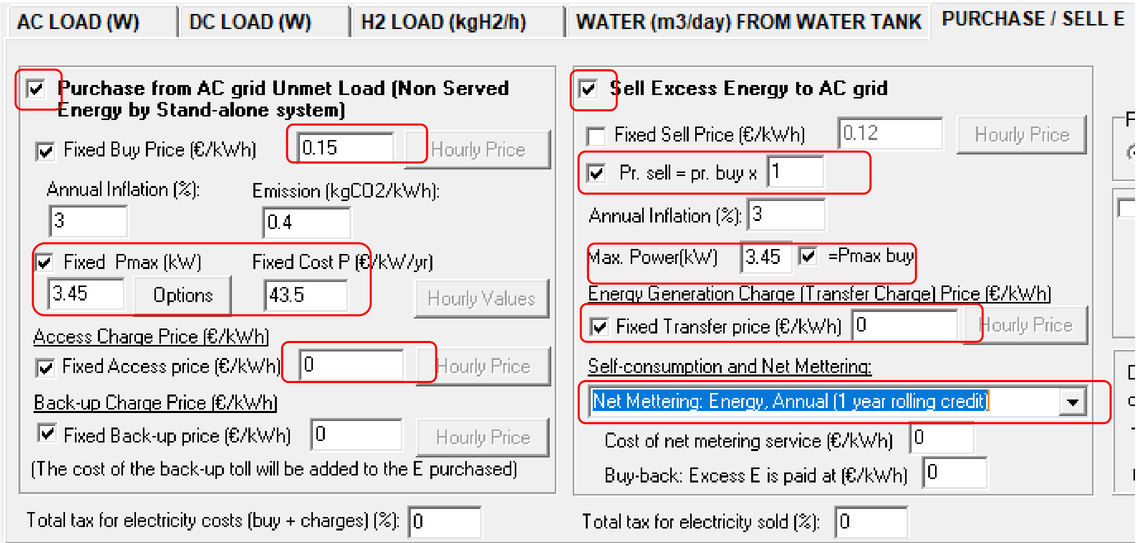
We change the DC voltage to 150 V (main screen, left), more common for the DC voltage of the grid-connected inverters.



We change the value of maximum unmet load allowed (by the stand-alone system) to 100%, since having AC grid connection we can buy from the electrical grid up to the total load.

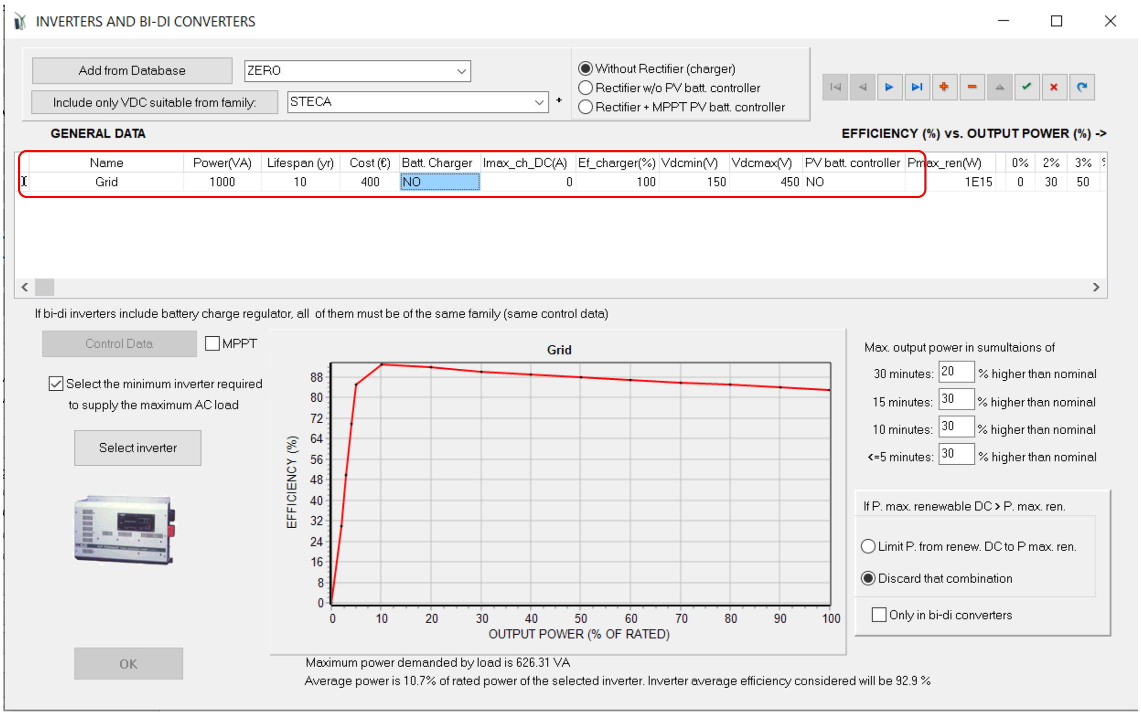


In the **LOAD / AC GRID** screen, **PURCHASE / SELL E**. tab, check the boxes to buy to the AC grid and sell to the AC grid. Suppose the price of electricity (including charges and taxes) is 0.15 €/kWh, the contracted power 3.45 kW (same to purchase or to inject) and the cost of the power term 43.5 €/kW/year (including taxes). Suppose we have the possibility of net metering as there is in some states of USA (net metering of energy with 1 year rolling credit), so the purchase price will be equal to the sale price.



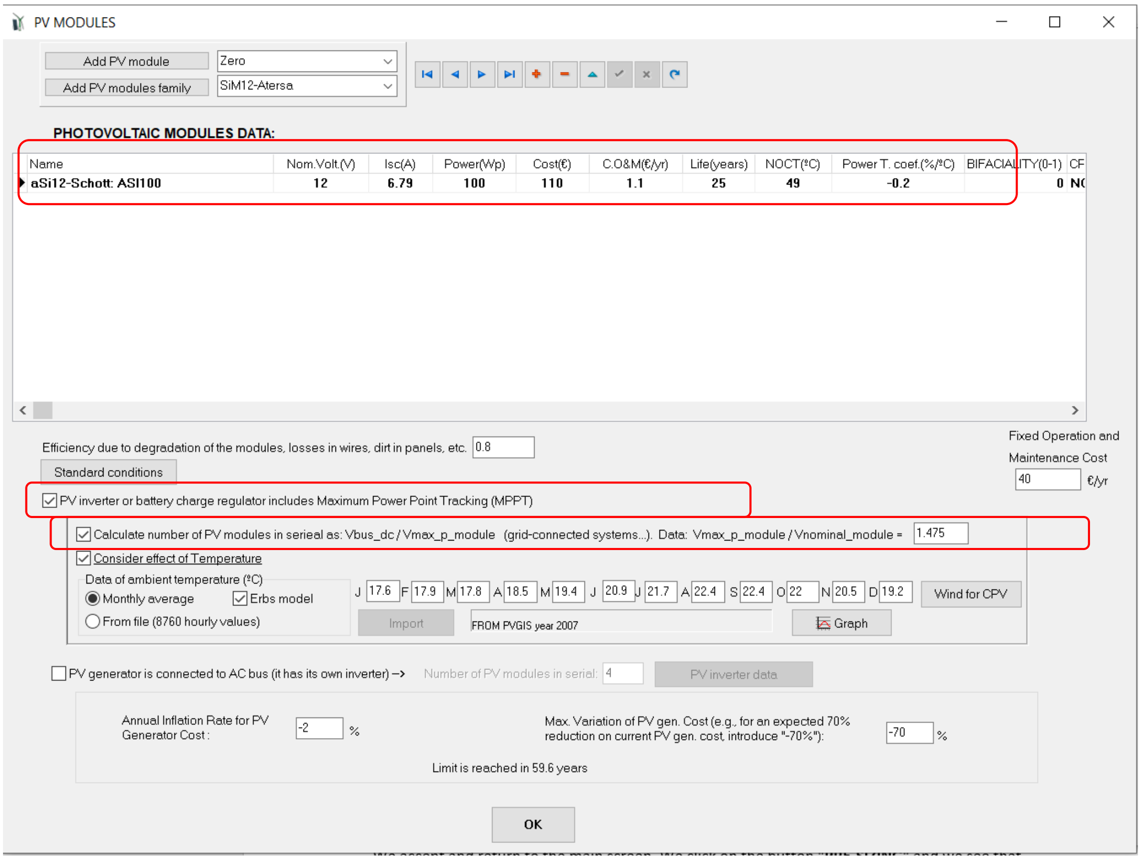
We accept and a warning appears about the voltage of the inverters that it is not adequate, we accept it (we will change now the inverter).

In the **INVERTERS** screen, we change the inverter by another one suitable for grid-connection. First change the name to “Grid” and then the voltage (VDCmin 150 V, VDCmax 450 V), power (1000 VA), price (400 €) and the other characteristics as shown in the next figure:



Then click on “**Select inverter**” button and then in “**OK**”.

In the **PV MODULES** screen, remove the second row, leaving only the Schott panel of 100 Wp. Check the option "**PV battery charge regulator includes ...**" and in the panel that appears, "**Calculate number of PV modules...**":

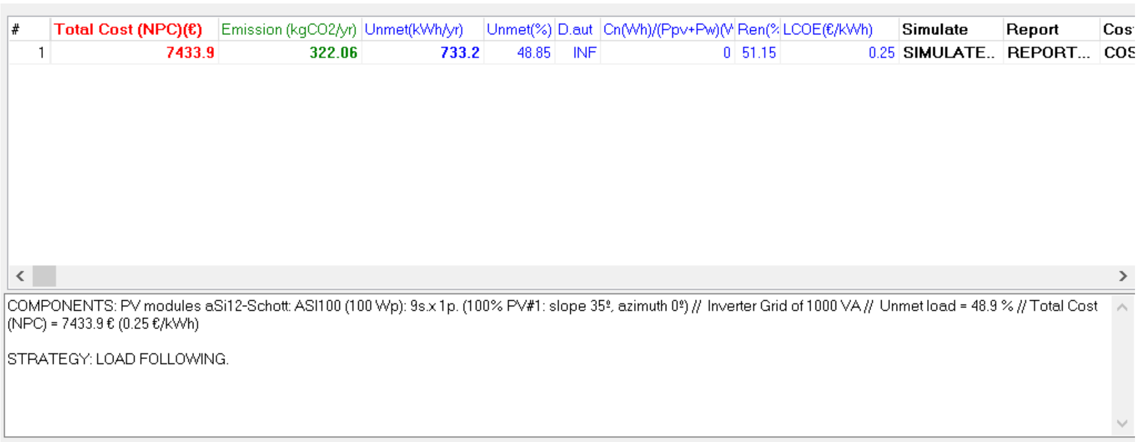


We assume that the voltage of maximum power of the modules is 12 * 1.475 = 17.7 V. Therefore iHOGA will calculate the serial number as 150 V / 17.7 = 8.47 -> 9 in series.

We accept and return to the main screen. We click on the button "**PRE-SIZING**" and we see that the maximum number of parallel modules becomes 2. However, we change it manually setting min. = max = 1, allowing just one in parallel:

Therefore, the power of the PV generator will be 100 Wp x 9 serial x 1 parallel = 900 Wp.

Return to the main screen, save the project and click "**CALCULATE**", obtaining the following results:



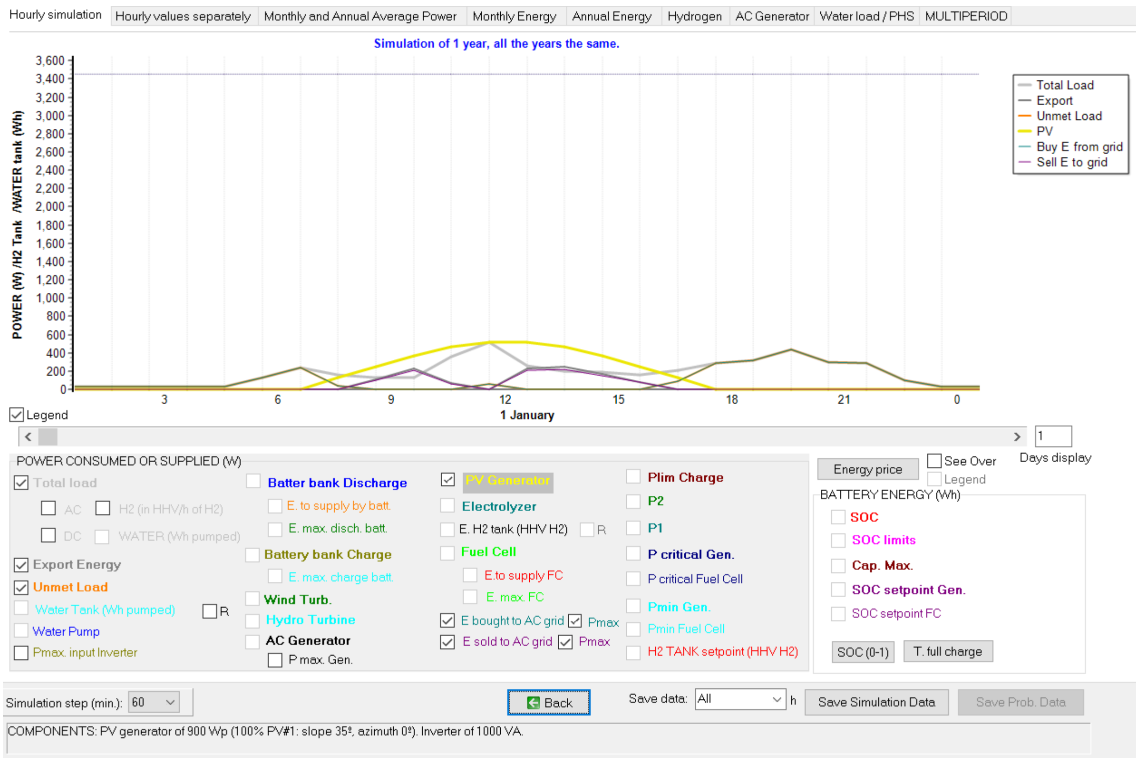
The optimal solition is obviously the only one evaluated:

COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 9s.x 1p. (100% PV#1: slope 35º, azimuth 0º) // Inverter Grid of 1000 VA // Unmet load = 48.9 % // Total Cost (NPC) = 7433.9 € (0.25 €/kWh)

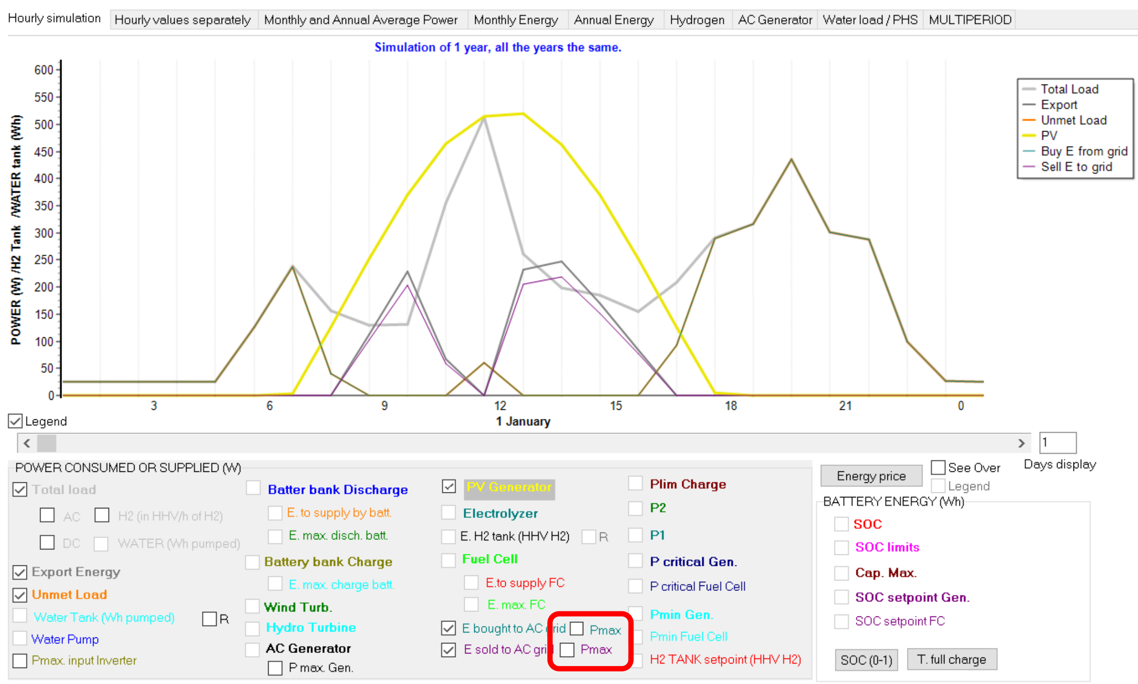
We see that the load consumption is 1500.8 kWh/year, the energy generated by the PV modules 1430.7 kWh/year, the export energy (excess energy which cannot be used by the load) 579.1 kWh/year, of that excess 513 kWh/year are sold to the AC grid (the rest is lost in the inverter), and 733 kWh/year are purchased from the AC grid.

Etotal(kWh)	Eren(kWh)	Epv(kWh)	Ew(kWh)	Et(kWh)	E export(kWh)	E Sell(kWh)	E Buy(kWh)	E ch. bat(kWh)	E
1500.8	1430.7	1430.7	0	0	579.1	513	733	0	

If we see the simulation:



We can see it better if we uncheck both “Pmax” checkboxes:



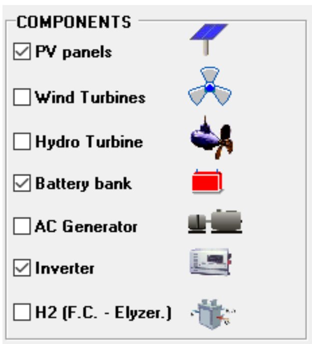
It shows that in each hour the energy sold is less than the excess, since the excess is the excess of energy before passing through the inverter, that is, not counting the losses in the inverter.

<u>37. Grid-connected systems with batteries.</u>

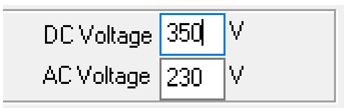
Next we are going to create a project to simulate batteries connected to the AC grid together with photovoltaic. It will only be allowed to buy energy from the network, not to sell it. With the batteries (charge/discharge) we can manage the energy that is purchased from the network.

Save the previous project and then save as "**BatGrid.hoga**".

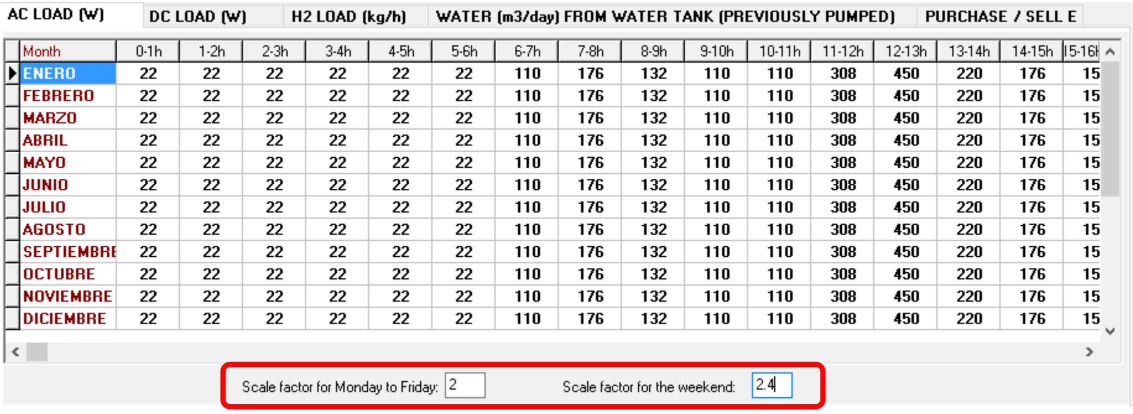
Include batteries:



The batteries to be used will be the Tesla Powerwall DC 2 (we will see it later), which voltage is 350 V DC. So we will change the DC bus voltage to 350 V:



Suppose that the AC load in this case is twice that previously considered. In the "**LOAD / AC GRID**" screen, in the "**AC LOADS (W)**" tab change the load scale factors to 2 and 2.4:

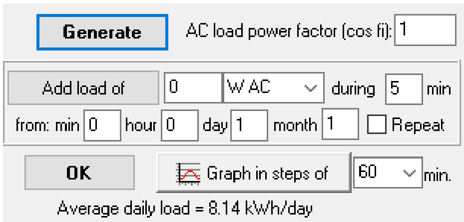


AC LOAD (W) | DC LOAD (W) | H2 LOAD (kg/h) | WATER (m3/day) FROM WATER TANK (PREVIOUSLY PUMPED) | PURCHASE / SELL E

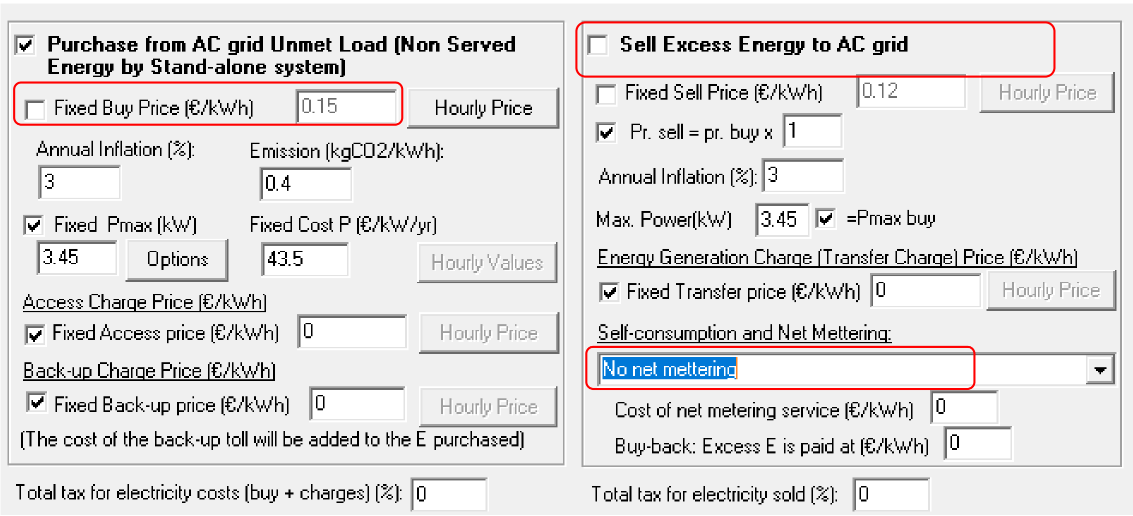
Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16l
ENERO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
FEBRERO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
MARZO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
ABRIL	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
MAYO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
JUNIO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
JULIO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
AGOSTO	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
SEPTIEMBRE	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
OCTUBRE	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
NOVIEMBRE	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15
DICIEMBRE	22	22	22	22	22	22	110	176	132	110	110	308	450	220	176	15

Scale factor for Monday to Friday: 2 Scale factor for the weekend: 2.4

We click on "**Generate**" and we obtain an average daily consumption of 8.14 kWh / day, more suitable to use the Tesla batteries.

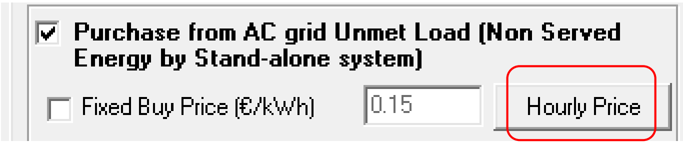


In the same window, in the "**PURCHASE / SELL E**" tab, change the following: the purchase price of the E is no longer fixed, there is no possibility to sell E surplus to the AC grid (we suppose it is not allowed) and there is no net metering:

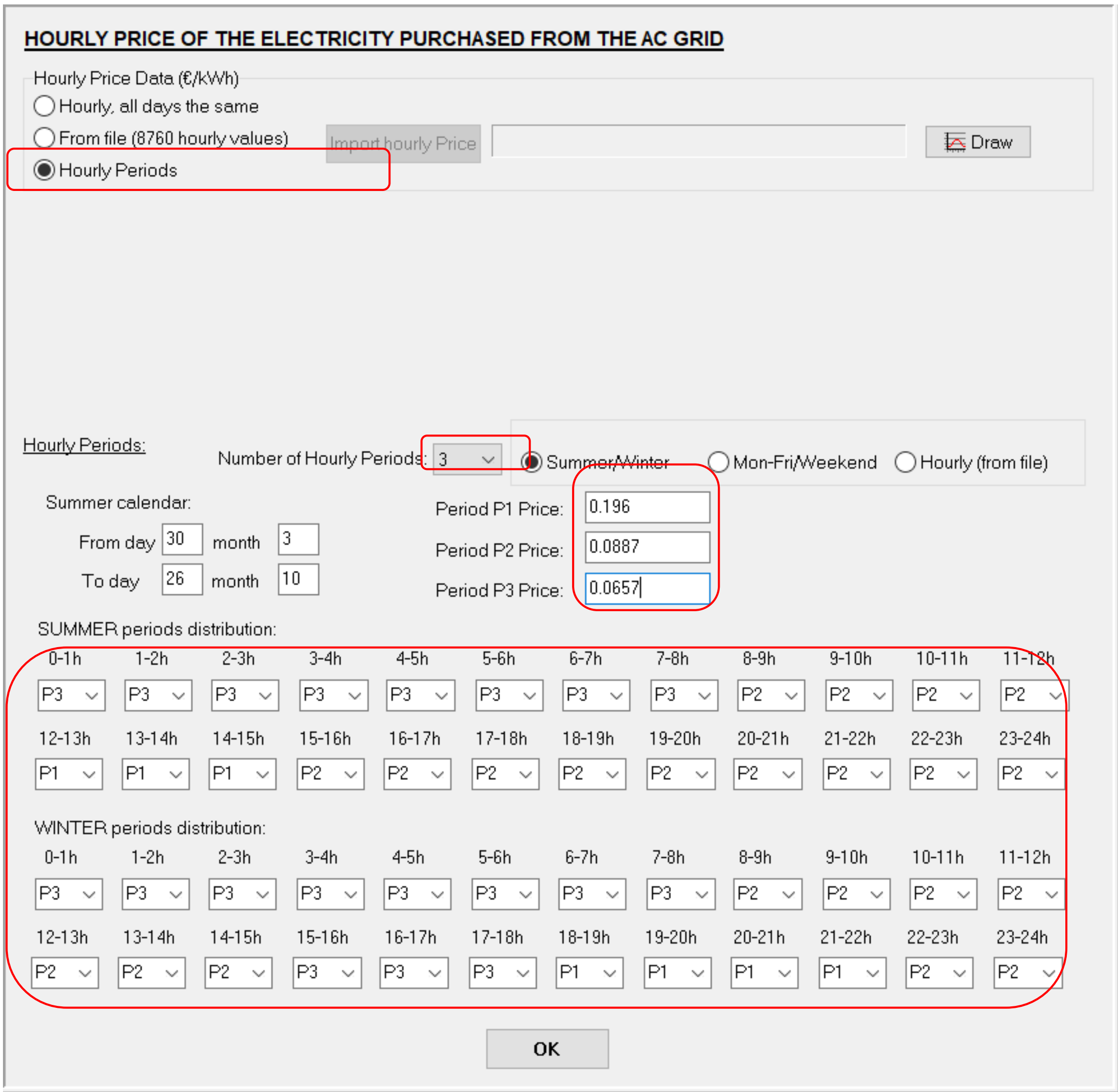


In addition, change the priority of the supply of energy not covered by renewables to "**AC Grid**" (in this way, the AC grid will be used primarily to cover the demand that has not been covered by renewable sources, instead of using batteries or diesel generator):

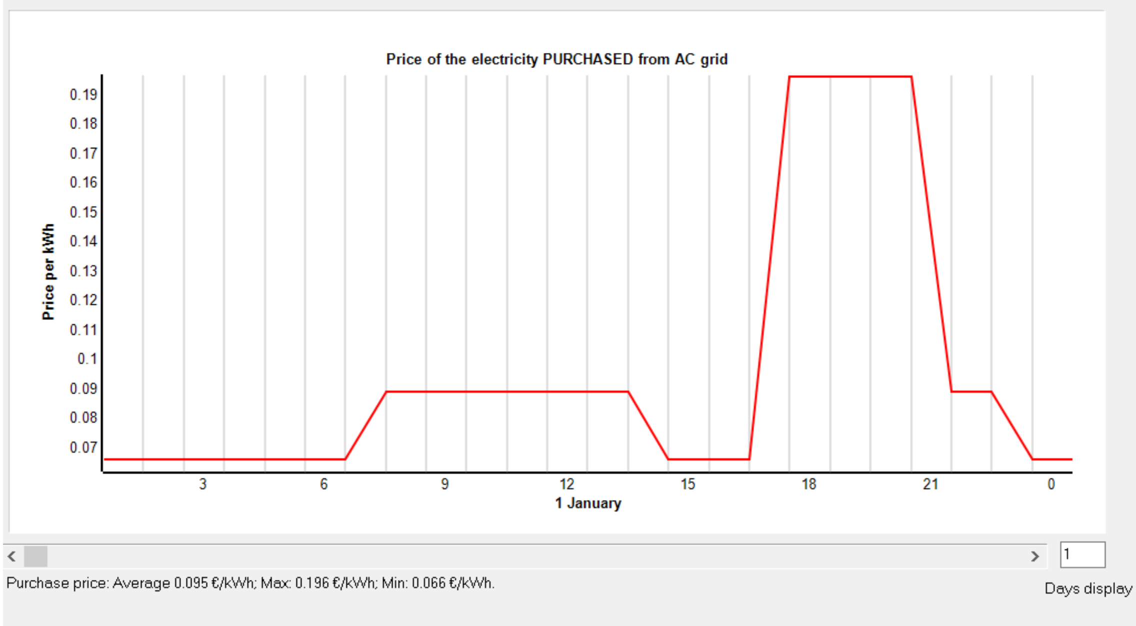
Click on purchase "**Hourly price**":



And in the next window select "**Hourly periods**" and indicate there are 3 periods, with the prices shown below and the default hourly periods:



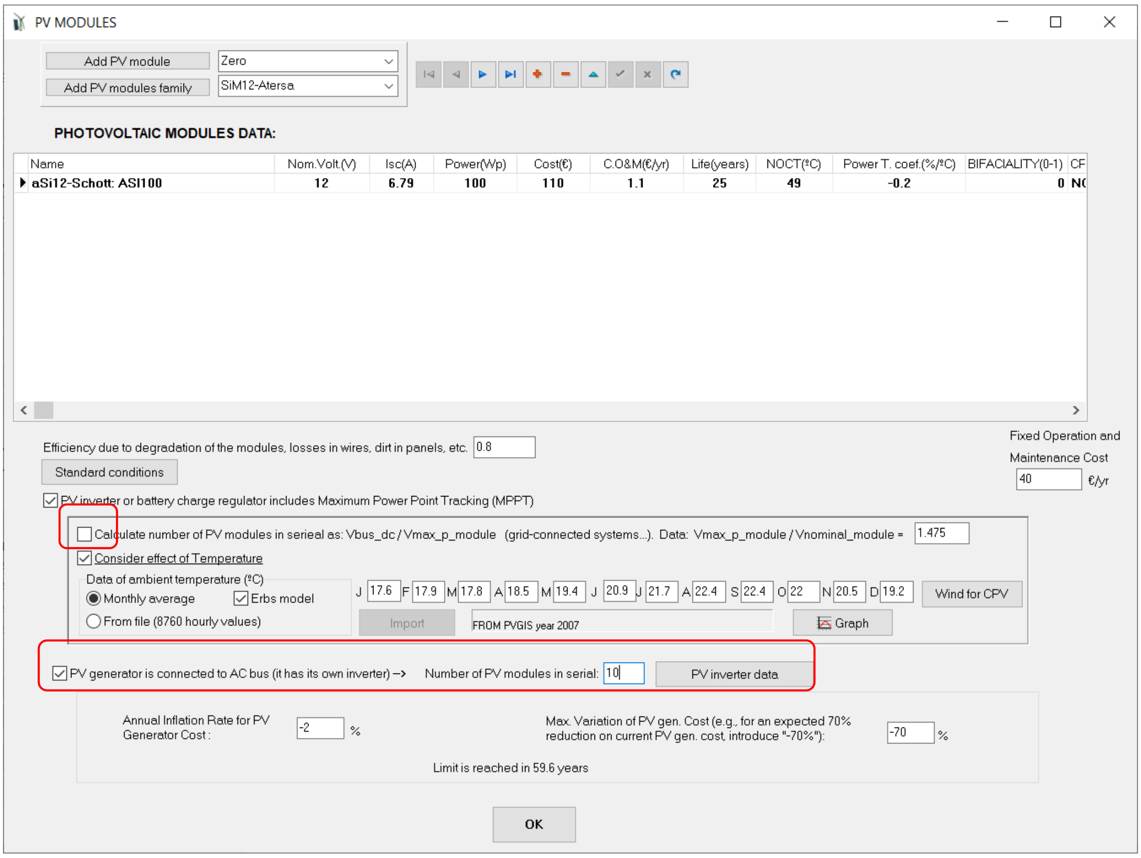
By clicking on "**Draw**" you can see the hourly purchase price:



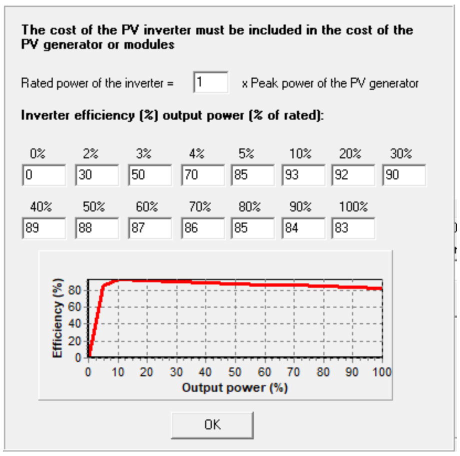
We return to the main screen accepting.

The photovoltaic modules will be connected to the AC grid through their own inverter that will be defined in the PV modules screen, while there will be an inverter-charger for the batteries.

In the **PV MODULES** screen, uncheck "**Calculate number of PV modules ...**" and check "**PV generator is connected to AC bus ...**", entering 10 in the number of PV modules in serial.



By clicking on "**PV inverter data**" we see the data of the inverter:



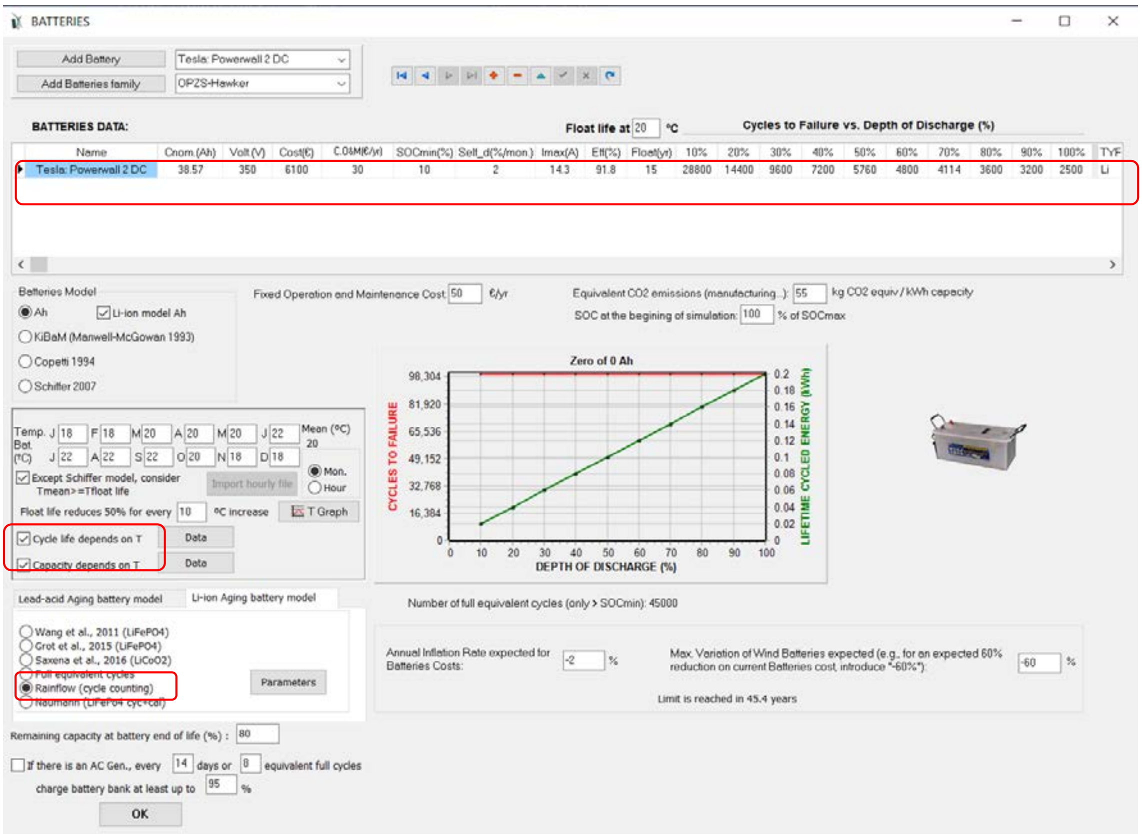
Let's use the default values.

We change the name of the PV modules since we must add in its cost the proportional cost of the photovoltaic inverter. We change the name for example by adding "-2", and we change the price to 150 €.

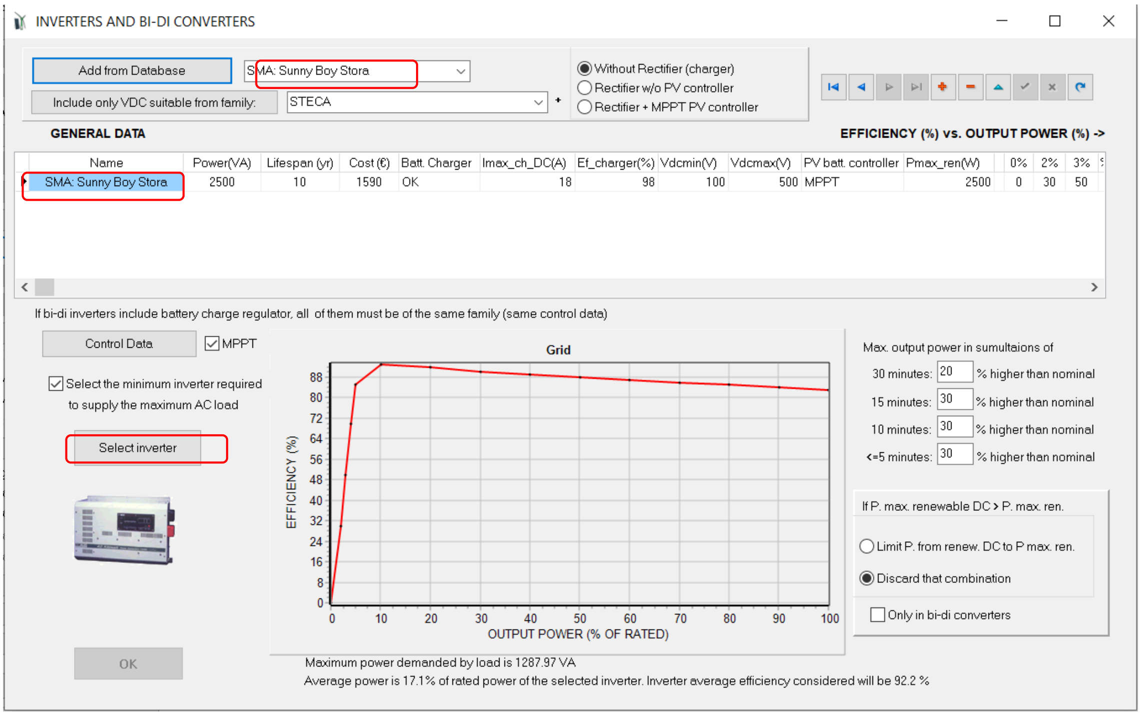
PHOTOVOLTAIC MODULES DATA:

Name	Nom.Volt.(V)	Isc(A)	Power(Wp)	Cost(€)
aSi12-Schott: ASI100-2	12	6.79	100	150

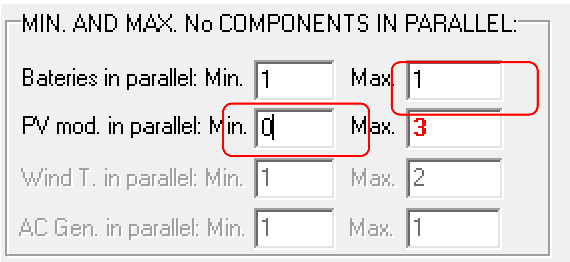
In the battery screen, remove them all and add the Tesla Powerwall 2 DC from the database, keeping as the life model of lithium batteries the **Rainflow** model, and selecting the options of the cycle life dependence on temperature and capacity dependence on temperature.



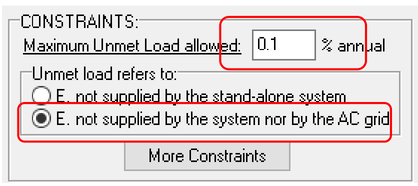
In the **INVERTERS** screen, delete the current one and add the SMA Sunny Boy Storage, which is an inverter-charger suitable for Tesla batteries. Leave the rest of the options as default. Click in "**Select Inverter**" and then "**OK**".



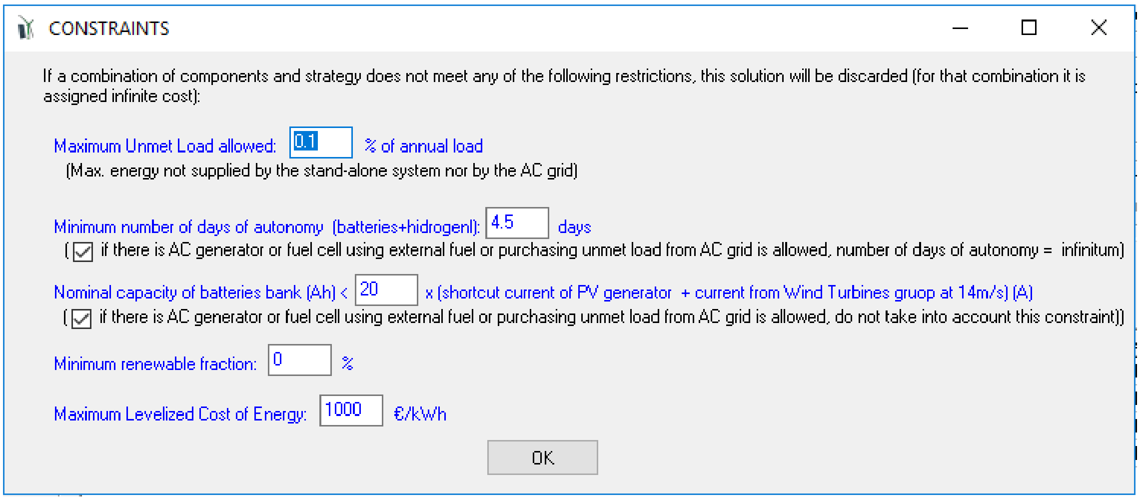
Click on **PRE-SIZING** and then leave minimum and maximum number of parallel components as follows (1 max. batteries in parallel, 0 min. PV in parallel):



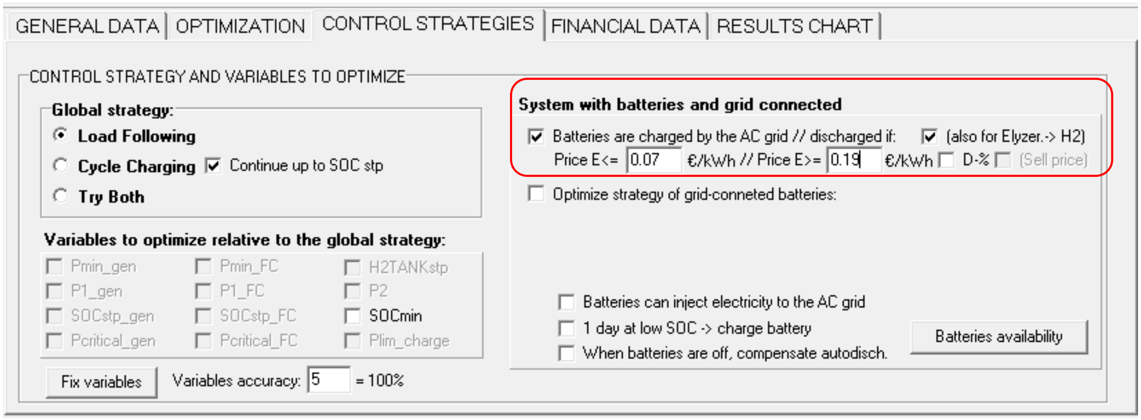
The constraint of the maximum unmet load allowed is left at 0.1% (leaving it at 0% is not convenient, since sometimes decimal rounds imply that the software counts small values of unmet load, so if we put 0% it is possible that solutions that are correct are discarded). We define unmet load as energy not supplied neither by the autonomous system nor by the AC grid.



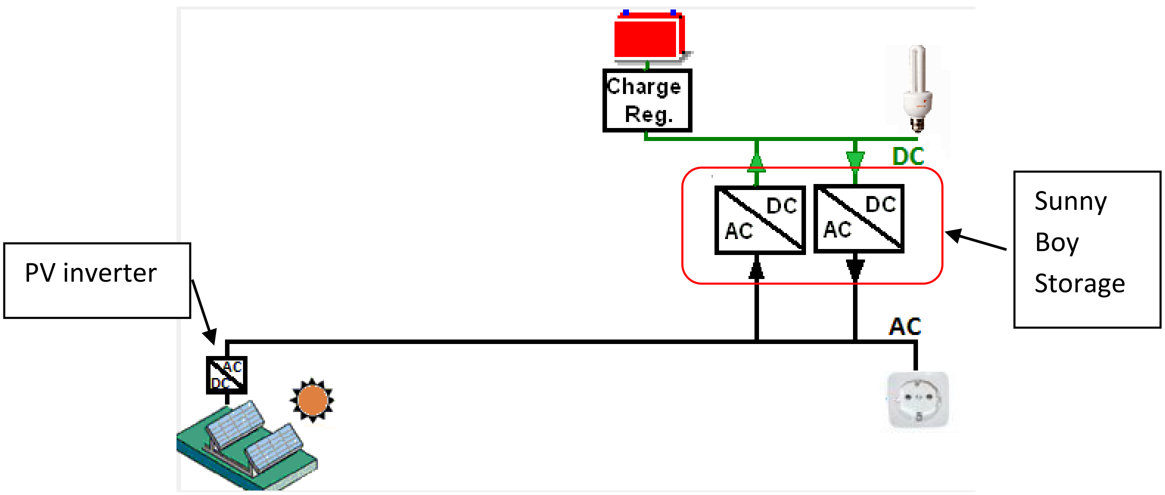
In "**More Constraints**" we indicate that the minimum renewable fraction must be 0% (that is, we eliminate this restriction):



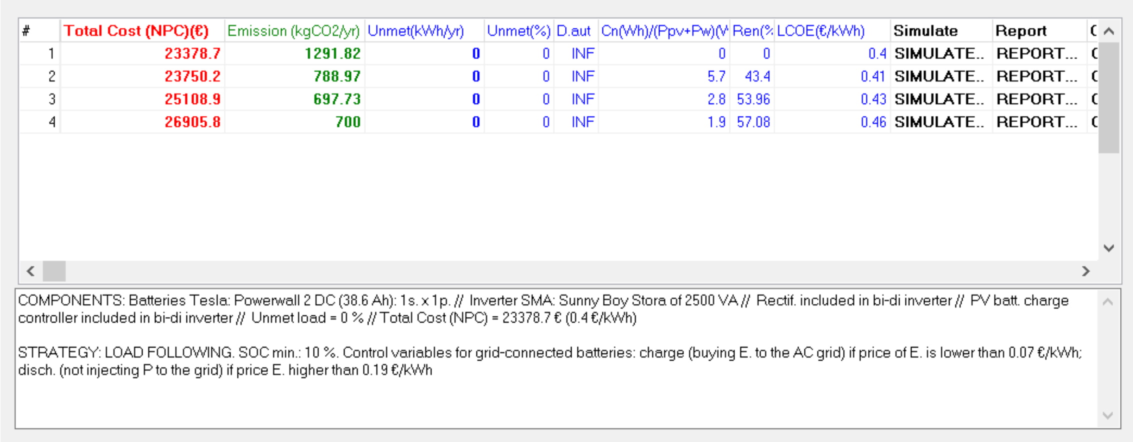
In the main screen, "**CONTROL STRATEGIES**" tab, check "**Batteries are charged by the AC grid // discharged if**" and indicate as maximum and minimum prices for the default charge / discharge values slightly higher and lower respectively of the minimum and maximum of electricity price: 0.07 and 0.19 €/kWh. In this way batteries will be charged during the valley hours and they will be discharged supplying the energy of the consumption during the peak hours.



Now the scheme of the system is:



Click on "**CALCULATE**" button and we obtain the following:



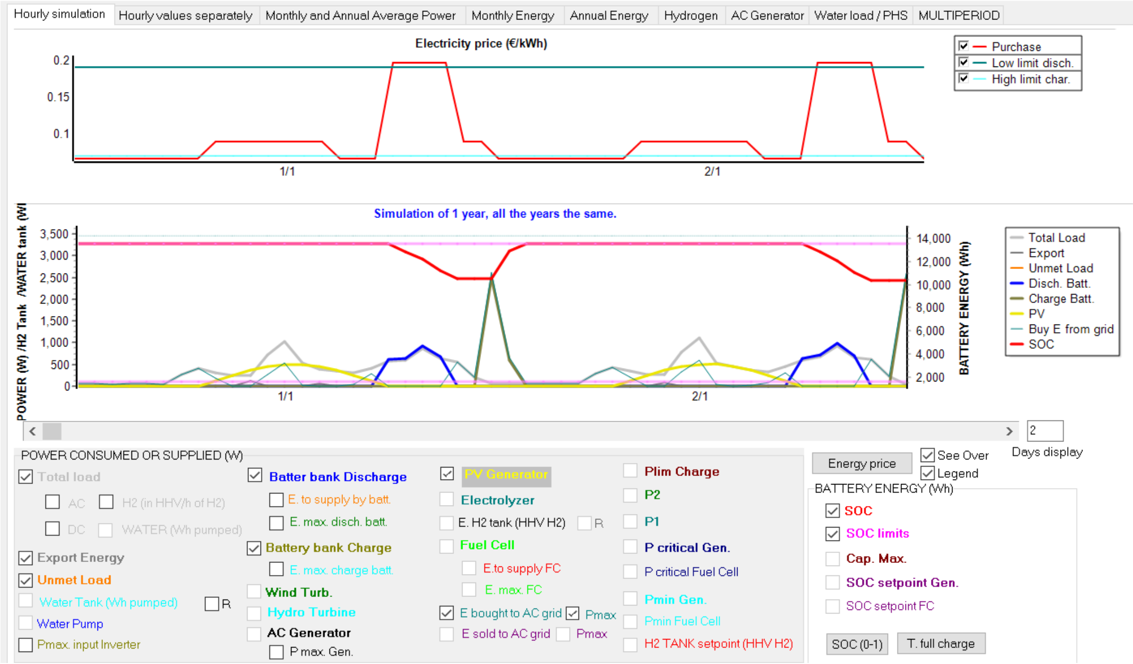
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report
1	23378.7	1291.82	0	0	INF	0	0	0.4	SIMULATE..	REPORT...
2	23750.2	788.97	0	0	INF	5.7	43.4	0.41	SIMULATE..	REPORT...
3	25108.9	697.73	0	0	INF	2.8	53.96	0.43	SIMULATE..	REPORT...
4	26905.8	700	0	0	INF	1.9	57.08	0.46	SIMULATE..	REPORT...

COMPONENTS: Batteries Tesla: Powerwall 2 DC (38.6 Ah): 1s. x 1p. // Inverter SMA: Sunny Boy Stora of 2500 VA // Rectif. included in bi-di inverter // PV batt. charge controller included in bi-di inverter // Unmet load = 0 % // Total Cost (NPC) = 23378.7 € (0.4 €/kWh)

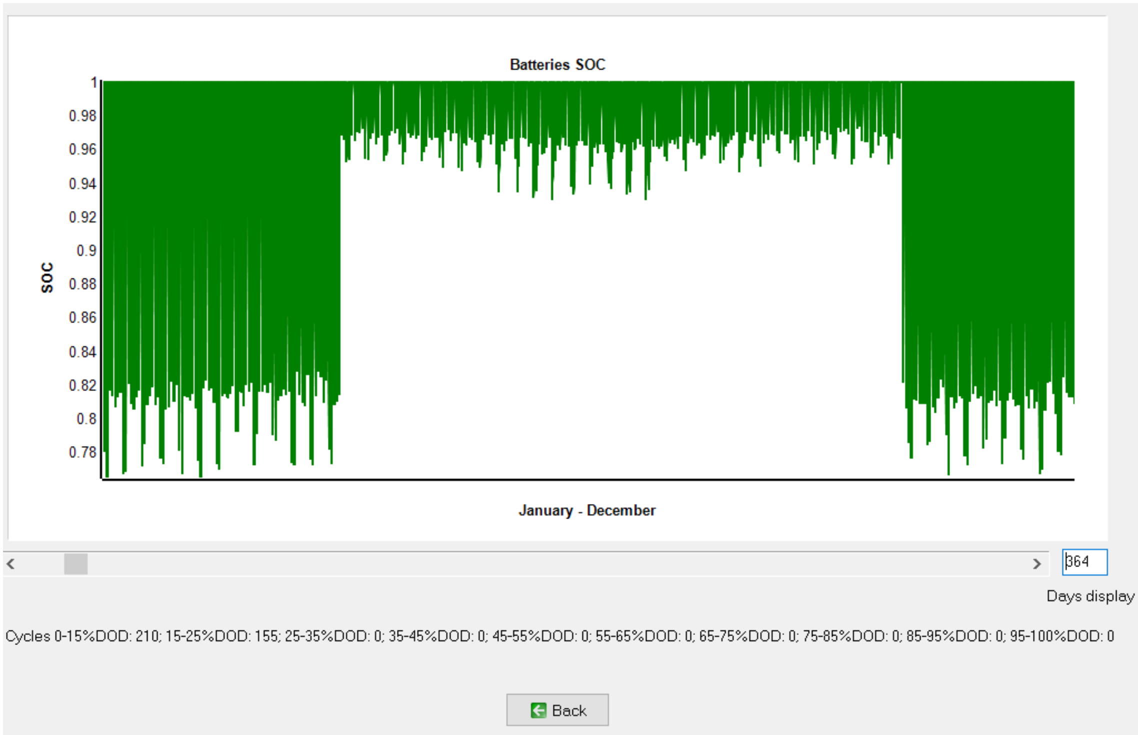
STRATEGY: LOAD FOLLOWING. SOC min.: 10 %. Control variables for grid-connected batteries: charge (buying E. to the AC grid) if price of E. is lower than 0.07 €/kWh; disch. (not injecting P to the grid) if price E. higher than 0.19 €/kWh

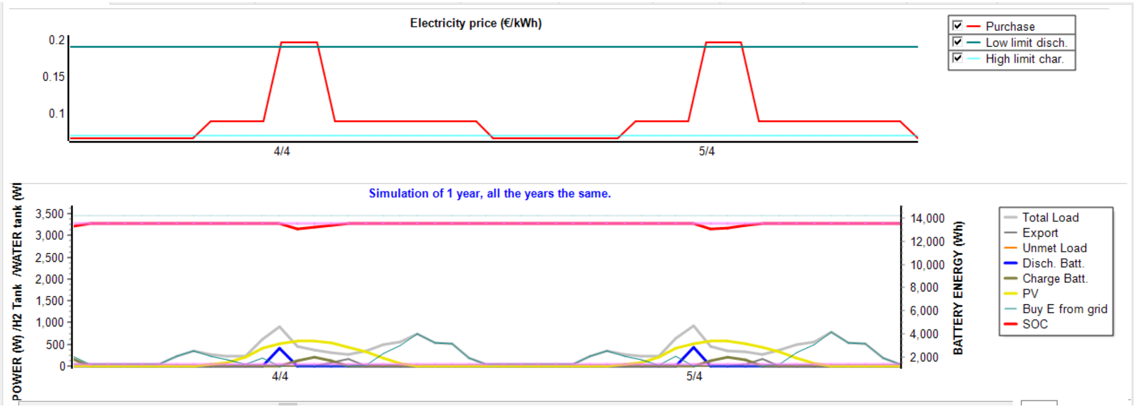
The optimal system (among the 4 possible systems: 0 to 3 parallel branches of PV modules) does not include PV. Batteries are charged during valley hours and discharged during peak hours. In the simulation of the optimal solution, if we select “See Over” (the energy price) and “Legend”, we see the energy price over the simulation, and we can see the control strategy.

The second best option has a similar NPC and LCOE (a bit higher), but it includes PV (next figure). We see that battery bank is charged during the valley hours until reaching the 100% of the SOC, and in the peak hours it is discharging supplying the energy of the load consumption. In the hours of the flat period (not valley, not peak) the batteries are nor charged or discharged, the power is obtained from the PV and, if needed, acquired directly from the grid.



By clicking in the button "**SOC (0-1)**" we see the daily DOD is around 20% during winter but much lower during the central months of the year, as during those months the peak periods are during the day, where there is PV generation, therefore batteries cannot supply much energy (see next figure for two days of april, 4th and 5th).

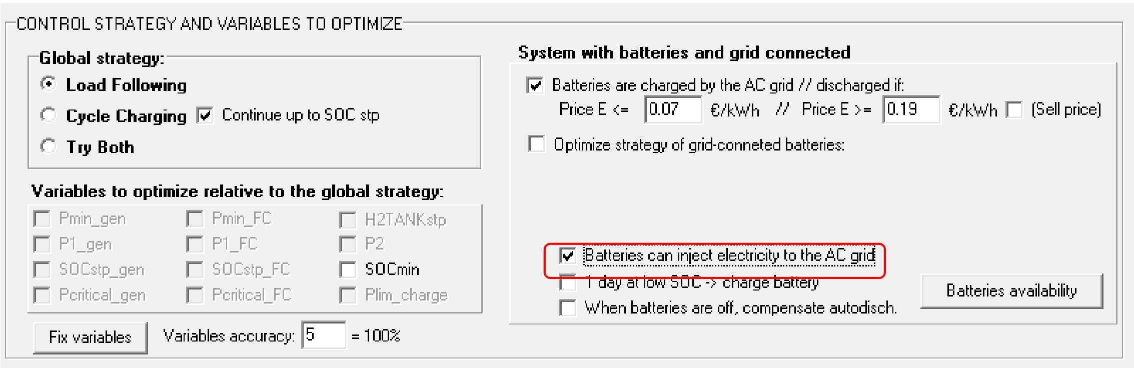




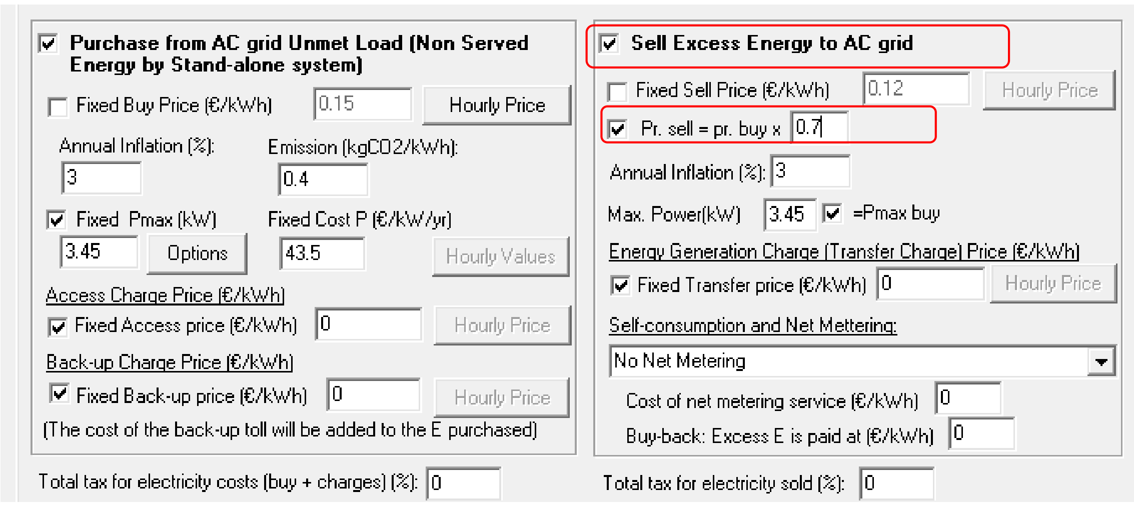
Variant: batteries can inject power into the AC grid.

Save the project. Then save as with the name "**BatGrid2.hoga**"

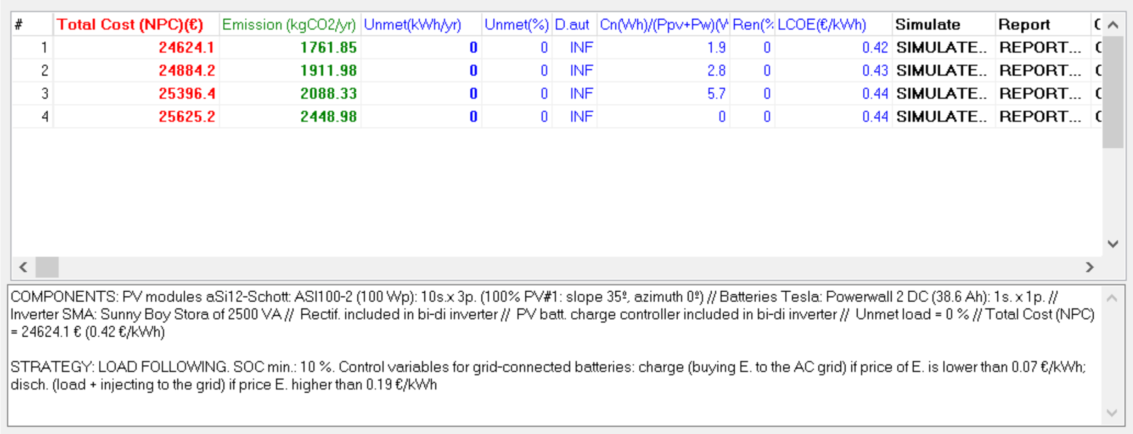
Assume that the batteries could inject energy in the AC grid (at peak times), at a price 70% of the purchase (probably too optimistic, if allowed to sell to the AC grid). On the main screen, CONTROL STRATEGIES tab, check "**Batteries can inject electricity to the AC grid**".



In the **LOAD / AC GRID** screen, tab **PURCHASE / SELL E**, indicate that energy can be sold to the AC grid and the sale price as the purchase price x 0.7:



We accept, save the project and calculate.



#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	24624.1	1761.85	0	0	INF	1.9	0	0.42	SIMULATE..	REPORT...
2	24884.2	1911.98	0	0	INF	2.8	0	0.43	SIMULATE..	REPORT...
3	25396.4	2088.33	0	0	INF	5.7	0	0.44	SIMULATE..	REPORT...
4	25625.2	2448.98	0	0	INF	0	0	0.44	SIMULATE..	REPORT...

COMPONENTS: PV modules aSi12-Schott: ASI100-2 (100 Wp): 10s.x 3p. (100% PV#1: slope 35º, azimuth 0º) // Batteries Tesla: Powerwall 2 DC (38.6 Ah): 1s. x 1p. // Inverter SMA: Sunny Boy Stora of 2500 VA // Rectif. included in bi-di inverter // PV batt. charge controller included in bi-di inverter // Unmet load = 0 % // Total Cost (NPC) = 24624.1 € (0.42 €/kWh)

STRATEGY: LOAD FOLLOWING. SOC min.: 10 %. Control variables for grid-connected batteries: charge (buying E. to the AC grid) if price of E. is lower than 0.07 €/kWh; disch. (load + injecting to the grid) if price E. higher than 0.19 €/kWh

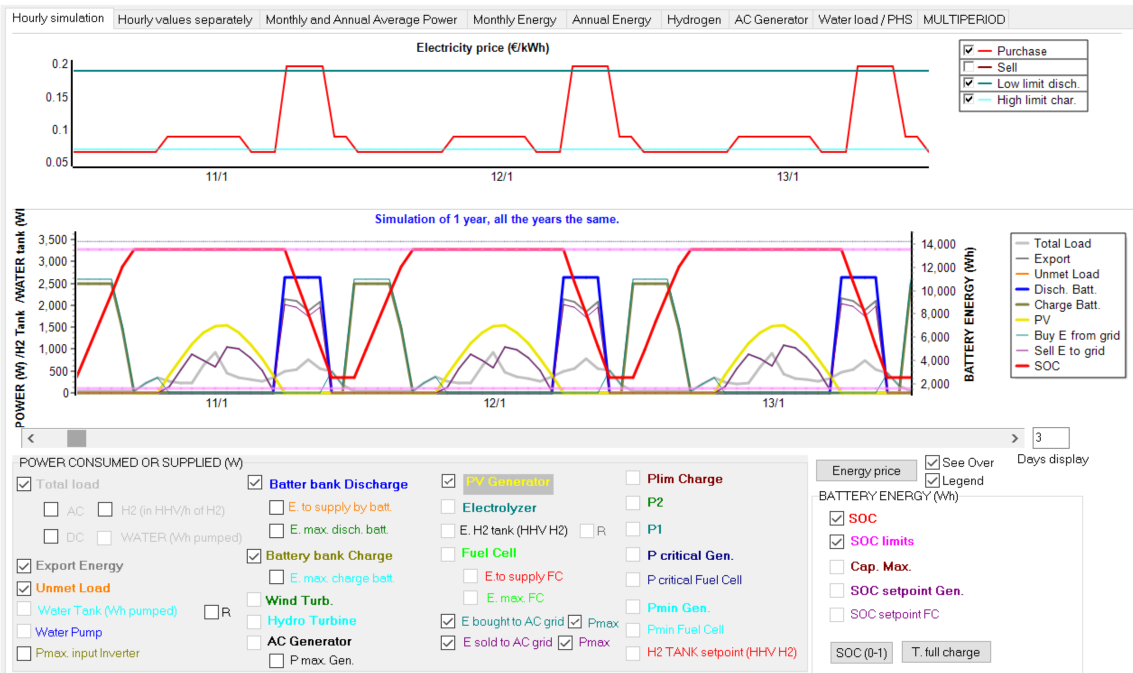
The optimum obtained is different, since to be able to sell to the AC grid at a reasonable price the photovoltaic modules are convenient. The price of kWh consumed is now 0.42 € / kWh, price higher than the optimal of the previous project.

COMPONENTS: PV modules aSi12-Schott: ASI100-2 (100 Wp): 10s.x 3p. (100% PV#1: slope 35º, azimuth 0º) // Batteries Tesla: Powerwall 2 DC (38.6 Ah): 1s. x 1p. // Inverter SMA: Sunny Boy Stora of 2500 VA // Rectif. included in bi-di inverter // PV batt. charge controller included in bi-di inverter // Unmet load = 0 % // Total Cost (NPC) = 24624.1 € (0.42 €/kWh)

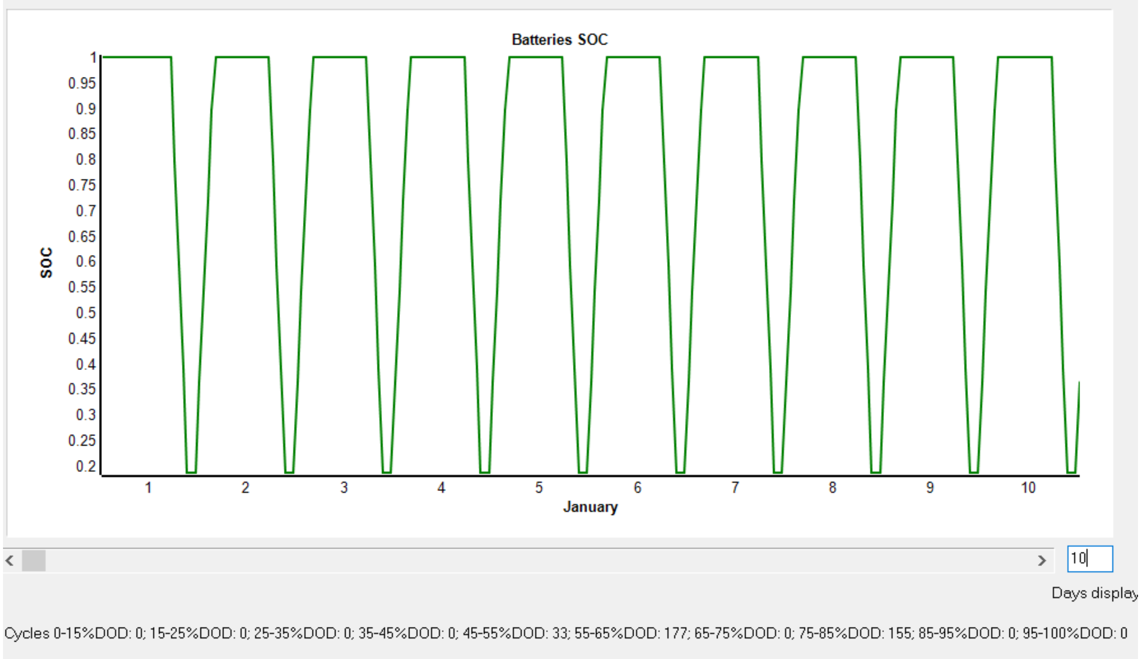
STRATEGY: LOAD FOLLOWING. SOC min.: 10 %. Control variables for grid-connected batteries: charge (buying E. to the AC grid) if price of E. is lower than 0.07 €/kWh; disch. (load + injecting to the grid) if price E. higher than 0.19 €/kWh

In the table or in the report we can see that the battery lifetime is 7.12 years (half than in the previous project, as in this case cycle degradation is higher due to the energy injection to the AC grid, 1 full cycle is performed each day).

In the simulation of the optimum solution (3 consecutive days), it is seen that at peak times the batteries are discharged to the maximum power, supplying the whole load and the rest of the power is injected into the grid.



By clicking in the button “**SOC (0-1)**” we see the daily DOD is around 80% for winter:



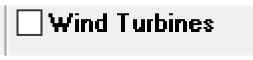
Finally, we save the project.

38. Diesel generators in parallel.

Next we are going to create a project with great load consumption where we will have several AC generators in parallel.

Open the project "Pr1" and save it with the name "**DieselPar.hoga**".

In the main screen eliminate the possibility of wind turbines.



In the load consumption screen, multiply by 10 the AC load, using the scale factors:

And “**Generate**” hourly load, obtaining 40.9 kWh/day.

In the PV modules screen, delete the type SiP12-TAB: PV-135-mod.

Change the name to the remaining one, adding "x10", obtaining "aSi12-Schott: ASI100 x10", which would be a PV panel equivalent to 10 of the originals. Doing this we reduce the search space, since having great consumption if we kept the original panel the maximum number in parallel could be very large. Multiply by 10 the short-circuit current, nominal power, acquisition cost, unit O&M cost and weight:

Name	Nom.Volt.(V)	Isc(A)	Power(Wp)	Cost(€)	C.O&M(€/yr)	Life(years)	NOCT(ºC)	Power T. coef.(%/ºC)	BIFACIALITY(0-1)	CF
aSi12-Schott: ASI100x10	12	67.9	1000	1100	11	25	49	-0.2	0	NC

In the battery screen, remove all of them and add the OPZS-Hawker: TZS-24, which is the highest capacity of that type.

BATTERIES DATA: Float life at 20 ºC — Cycles to Failure vs. Depth of Discharge (%)

Name	Cnom.(A·h)	Volt.(V)	Cost(€)	C.O&M(€/yr)	SOCmin(%)	Self_d(%/mon.)	Imax(A)	Eff(%)	Float(yr)	10%	20%	30%	40%	50%	60%	70%	80%	90%	TYPE	Weig
OPZS-Hawker:TZS-24	3360	2	1010	10.1	20	3	672	85	18	12000	6500	4250	3100	2500	2050	1800	1600	1500	LA	

In the inverters screen, delete the inverter and add the type Generic: 8000 CH, then "Select inverter" and accept with OK.

GENERAL DATA — EFFICIENCY (%) vs. OUTPUT POWER (%) ->

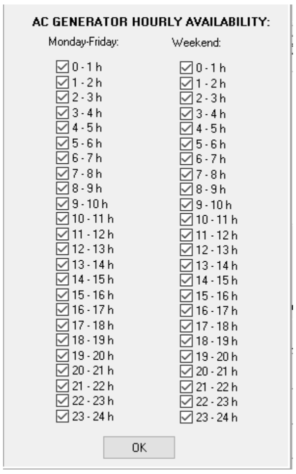
Name	Power (VA)	Lifespan (yr)	Acq. cost (€)	Batt. Charger	Imax_ch.DC (A)	Ef_charger(%)	VDCmin(V)	VDCmax(V)	PV batt. controller	Pmax_ren(W)	0%	2%
Generic: 8000 CH	8000	10	3840	OK	60	98	48	48	NO	1E15	0	30

In the AC Generators screen, leave only the 1.9 kVA one:

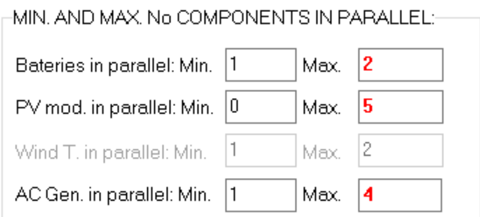
GENERATORS DATA:

Name	Power(kVA)	Cost(€)	C.O&M(€/h)	Life(h)	Pmin (%Pn)	FUEL: Fuel type	F.Unit	F.Cost(€/ud.)	F. inflat.(%)	Emis.(kg CO2/unit)	A(unit/kW·h)	B(unit/kW·h)	(kg)
Diesel 1.9kVA	1.9	800	0.14	10000	30	Diesel	litre	1.3	5	3.5	0.246	0.08145	110

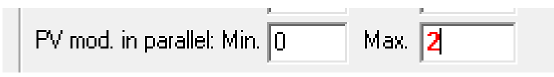
And allow availability throughout the whole day:



In the main screen, click on "**PRE-SIZING**" button and then the number of min. and max. components in parallel will be set as follows:

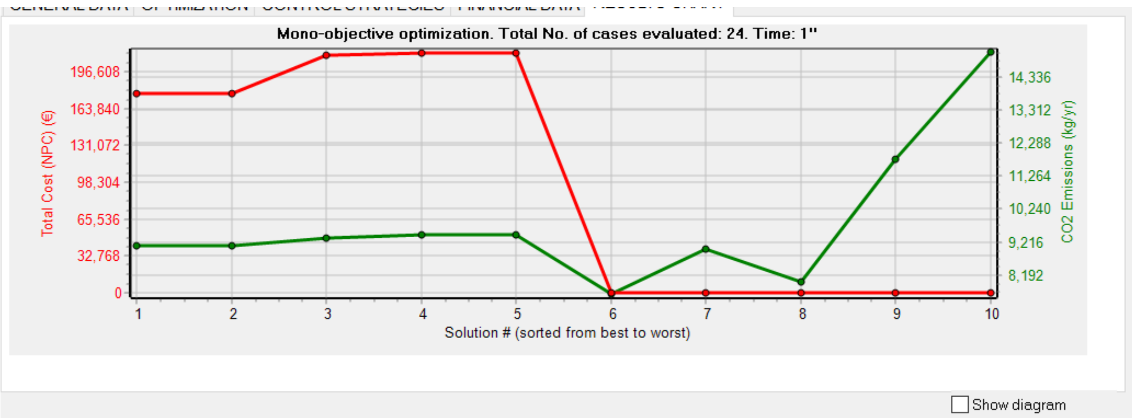


Next we change the maximum allowed of PV modules in parallel to 2:



In this way we will force several diesel generators in parallel and we will see its operation (note that it is purposely done to force several diesel and see its operation in the simulation, since with more modules in parallel the system would be cheaper).

Save and click on the CALCULATE button. We get:



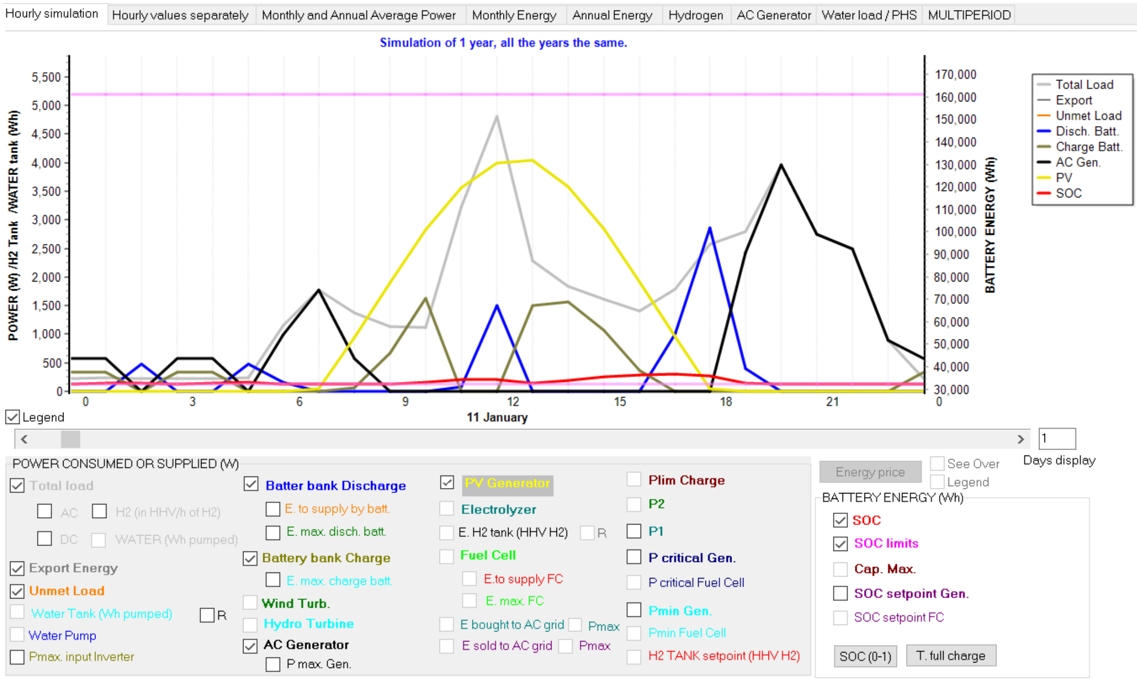
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	177506.5	9093.97	0	0	INF	24.7	60.91	0.61	SIMULATE..	REPORT...	C
2	177757.9	9093.97	0	0	INF	24.7	60.91	0.61	SIMULATE..	REPORT...	C
3	211804.4	9354.9	44.7	0.3	INF	49.5	61.6	0.72	SIMULATE..	REPORT...	C
4	213062.2	9441.9	0	0	INF	49.5	61.6	0.73	SIMULATE..	REPORT...	C
5	213310.9	9441.9	0	0	INF	49.5	61.6	0.73	SIMULATE..	REPORT...	C
6	INF	7606.66	955.3	6.39	INF	24.7	60.91	INF	SIMULATE..	REPORT...	C
7	INF	9003.75	45.9	0.31	INF	24.7	60.91	INF	SIMULATE..	REPORT...	C
8	INF	7991.61	930.8	6.23	INF	49.5	61.6	INF	SIMULATE..	REPORT...	C
9	INF	11780.15	2144.2	14.35	INF	49.5	30.89	INF	SIMULATE..	REPORT...	C

COMPONENTS: PV modules aSi12-Schott: ASI100x10 (1000 Wp): 4s.x 2p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TZS-24 (3360 Ah): 24s. x 1p. // 3 x AC Gen. Diesel 1.9kVA 1.9 kVA // Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // PV batt. charge controller Generic of 177 A // Unmet load = 0 % // Total Cost (NPC) = 177506.5 € (0.61 €/kWh)

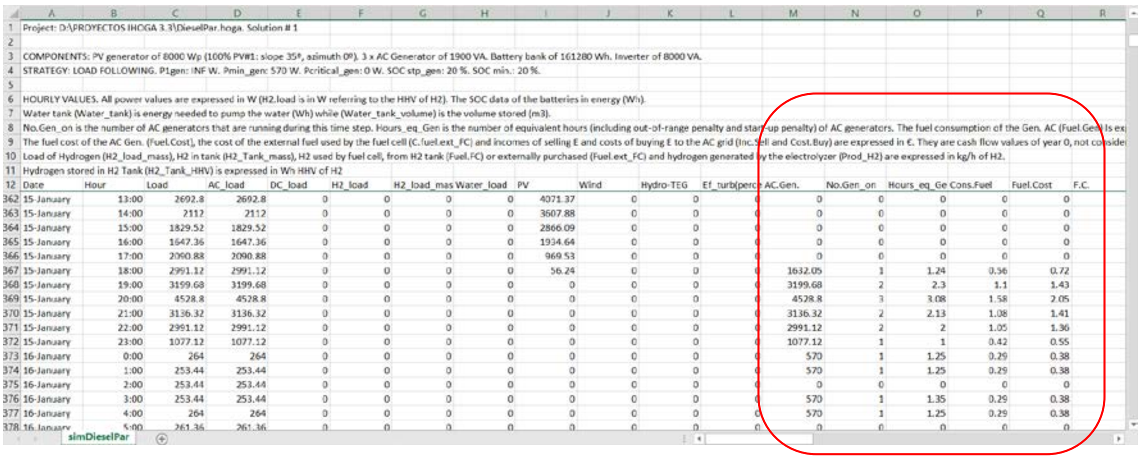
STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.

The best combination includes three 1.9 kVA diesel generators. We see that the expected life of the batteries is 18 years (the maximum allowed).

In the simulation it can be seen that 1, 2 or 3 diesel generators run, depending on whether they have to give less than 1.9 kVA, less than 1.9x2 or more power. It is also observed that the batteries are long time at the minimum charge state, which in real conditions can suppose that their lifetime was much lower than expected.



If we save the simulation data and open the Excel file, we can see how from January 6 at 10 pm the diesel generator runs during certain hours, and we can see that 1 or 2 generators run in parallel, in addition to the equivalent operating hours consumed in that hour (if there is one, 1 hour plus the penalty for the start, if any, plus the penalty for operating outside the optimal zone, if applicable; if there are two, 2 hours more penalties, if any) .



Project: D:\PROYECTOS IHOGA 3.3\DieselPar.hoga. Solution # 1

COMPONENTS: PV generator of 8000 Wp (100% PV#1: slope 35º, azimuth 0º). 3 x AC Generator of 1900 VA. Battery bank of 161280 Wh. Inverter of 8000 VA.

STRATEGY: LOAD FOLLOWING. P1gen: INF W. Pmin_gen: 570 W. Pcritical_gen: 0 W. SOC stp_gen: 20 %. SOC min.: 20 %.

HOURLY VALUES. All power values are expressed in W (H2.load is in W referring to the HHV of H2). The SOC data of the batteries in energy (Wh).

Water tank (Water_tank) is energy needed to pump the water (Wh) while (Water_tank_volume) is the volume stored (m3).

No.Gen_on is the number of AC generators that are running during this time step. Hours_eq_Gen is the number of equivalent hours (including out-of-range penalty and start-up penalty) of AC generators. The fuel consumption of the Gen. AC (Fuel.Gen) Is ex

The fuel cost of the AC Gen. (Fuel.Cost), the cost of the external fuel used by the fuel cell (C.fuel.ext_FC) and incomes of selling E and costs of buying E to the AC grid (Inc.Sell and Cost.Buy) are expressed in €. They are cash flow values of year 0, not conside

Load of Hydrogen (H2_load_mass), H2 in tank (H2_Tank_mass), H2 used by fuel cell, from H2 tank (Fuel.FC) or externally purchased (Fuel.ext_FC) and hydrogen generated by the electrolyzer (Prod_H2) are expressed in kg/h of H2.

Hydrogen stored in H2 Tank (H2_Tank_HHV) is expressed in Wh HHV of H2

Date	Hour	Load	AC_load	DC_load	H2_load	H2_load_mas	Water_load	PV	Wind	Hydro-TEG	Ef_turb(perc	AC.Gen.	No.Gen_on	Hours_eq_Ge	Cons.Fuel	Fuel.Cost	F.C.
15-January	13:00	2692.8	2692.8	0	0	0	0	4071.37	0	0	0	0	0	0	0	0	
15-January	14:00	2112	2112	0	0	0	0	3607.88	0	0	0	0	0	0	0	0	
15-January	15:00	1829.52	1829.52	0	0	0	0	2866.09	0	0	0	0	0	0	0	0	
15-January	16:00	1647.36	1647.36	0	0	0	0	1934.64	0	0	0	0	0	0	0	0	
15-January	17:00	2090.88	2090.88	0	0	0	0	969.53	0	0	0	0	0	0	0	0	
15-January	18:00	2991.12	2991.12	0	0	0	0	56.24	0	0	0	1632.05	1	1.24	0.56	0.72	
15-January	19:00	3199.68	3199.68	0	0	0	0	0	0	0	0	3199.68	2	2.3	1.1	1.43	
15-January	20:00	4528.8	4528.8	0	0	0	0	0	0	0	0	4528.8	3	3.08	1.58	2.05	
15-January	21:00	3136.32	3136.32	0	0	0	0	0	0	0	0	3136.32	2	2.13	1.08	1.41	
15-January	22:00	2991.12	2991.12	0	0	0	0	0	0	0	0	2991.12	2	2	1.05	1.36	
15-January	23:00	1077.12	1077.12	0	0	0	0	0	0	0	0	1077.12	1	1	0.42	0.55	
16-January	0:00	264	264	0	0	0	0	0	0	0	0	570	1	1.25	0.29	0.38	
16-January	1:00	253.44	253.44	0	0	0	0	0	0	0	0	570	1	1.25	0.29	0.38	
16-January	2:00	253.44	253.44	0	0	0	0	0	0	0	0	0	0	0	0	0	
16-January	3:00	253.44	253.44	0	0	0	0	0	0	0	0	570	1	1.35	0.29	0.38	
16-January	4:00	264	264	0	0	0	0	0	0	0	0	570	1	1.25	0.29	0.38	
16-January	5:00	261.36	261.36	0	0	0	0	0	0	0	0	0	0	0	0	0	

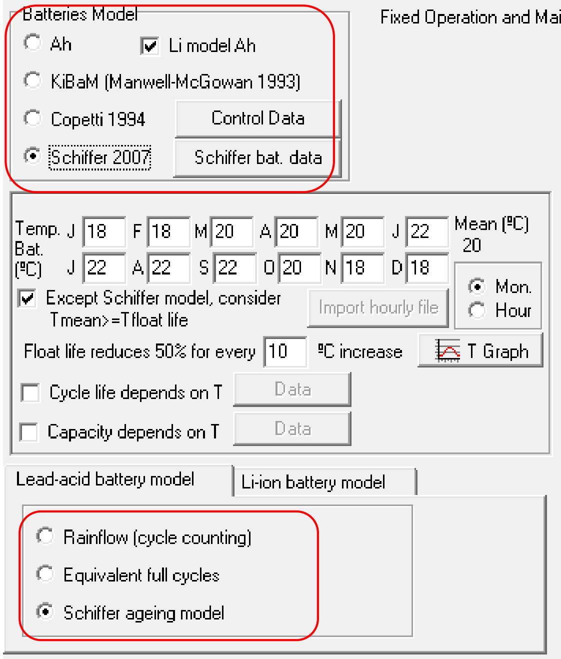
simDieselPar

Finally, we save the project.

39. Optimization of the control strategy.

Next we will save the previous project with the name "**DieselParControl.hoga**" to see the effect of the optimization of the strategy and control variables.

We will use the Schiffer model for the batteries, much more precise model and that take into account the real operating conditions of the batteries. We select the "Schiffer" model on the batteries screen, leaving everything else unchanged:



If we click on the first row of the results table, we see how it drastically increases the cost, since the first row is updated to the results considering the Schiffer model of Batteries.

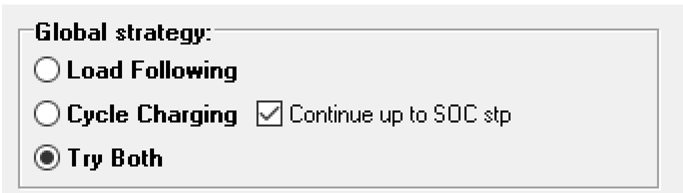
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	569817.6	19568.21	0	0	INF	24.7	64.59	1.94	SIMULATE..	REPORT...	C

This large difference in costs compared to the classical model of batteries is due to the estimated life of the Schiffer model is 0.77 years, compared to 18 years that was estimated with the classic model. That implies that every less than a year you have to change the batteries, which means a great total NPC. The reality will be closer to the estimation by the Schiffer model, since batteries in low state of charge for a long time deteriorate rapidly.

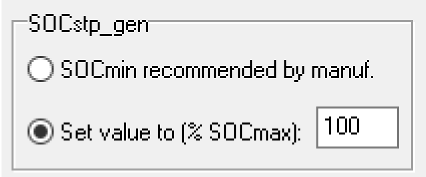
E ch. bat(kWh)	E disch. bat (kWh)	E elyzer. (kWh)	E gen (kWh)	E FC (kWh)	Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. E
3634.3	3813.5	0	5292.1	0	5756.29	0.77	4032	24

Therefore, it may be better to use another control strategy.

In the main screen of the program, "**CONTROL STRATEGIES**" tab, select "**Continue up to SOC stp**" (so that in the "Cycle charging" strategy the AC generator will continue to charge the batteries up to the SOC setpoint value") and select "**Try Both**" (both strategies will be tested, Load Following and Cycle Charging).



Below, in the control variables, click on the button “**Fix Variables**”. A window appears where you can set values for control strategies. We leave everything by default, making sure that the SOCstp_gen (SOC setpoint of the batteries when charged by the generator) is 100%. When testing the "Load following" strategy, the SOCstp_gen is set to SOCmin, whereas when testing the "Cycle charging" strategy, the SOCstp_gen is set to the value that is marked here (default is 100%).



Save the project and CALCULATE.

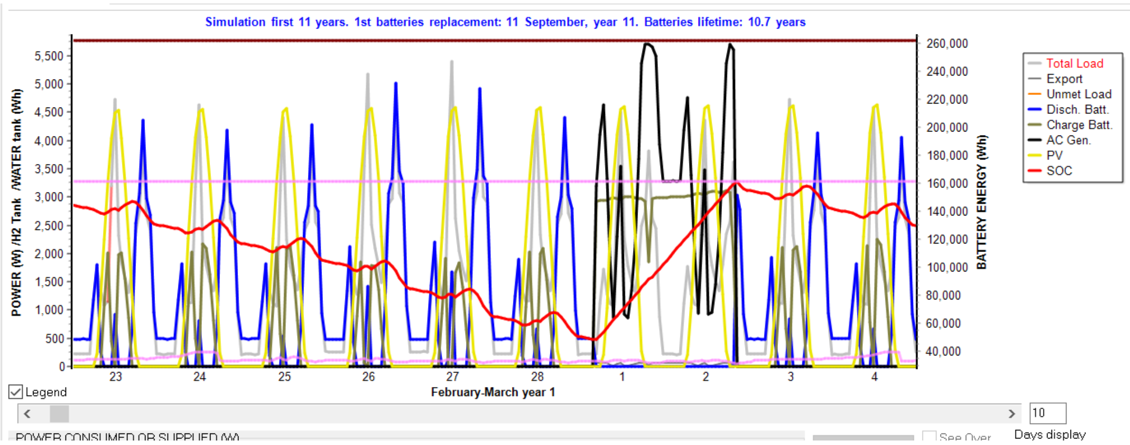
Now the cost of the optimum is 181624.2 € (0.62 €/kWh), and the battery life is estimated to be 10.68 years. The optimal strategy is *Cycle charging*, *continue to SOCstp.*

Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	Costs
181624.2	9268.27	0	0	INF	24.7	55.86	0.62	SIMULATE..	REPORT...	COSTS
182388.3	9344.41	0	0	INF	24.7	55.75	0.62	SIMULATE..	REPORT...	COSTS
203940.4	9567.6	3.8	0.03	INF	24.7	58.11	0.7	SIMULATE..	REPORT...	COSTS
229212.6	9941.85	0	0	INF	49.5	57.17	0.78	SIMULATE..	REPORT...	COSTS
229856.6	9977.49	0	0	INF	49.5	57.16	0.78	SIMULATE..	REPORT...	COSTS
326448.4	12232.15	8.6	0.06	INF	49.5	59.33	1.11	SIMULATE..	REPORT...	COSTS
INF	15487.34	0	0	INF	49.5	20.67	INF	SIMULATE..	REPORT...	COSTS
INF	15632.97	0	0	INF	49.5	21.09	INF	SIMULATE..	REPORT...	COSTS
INF	15268.62	16.4	0.11	INF	49.5	23.35	INF	SIMULATE..	REPORT...	COSTS

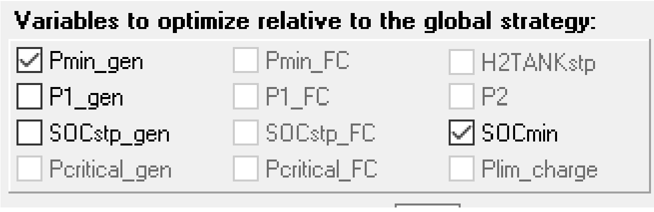
COMPONENTS: PV modules aSi12-Schott: ASI100x10 (1000 Wp): 4s.x 2p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TZS-24 (3360 Ah): 24s. x 1p. // 3 x AC Gen. Diesel 1.9kVA 1.9 kVA // Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // PV batt. charge controller Generic of 177 A // Unmet load = 0 % // Total Cost (NPC) = 181624.2 € (0.62 €/kWh)

STRATEGY: CYCLE CHARGING, continue up to SOCstp. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: INF. SOC setpoint_gen: 100 %. SOC min.: 20 %.

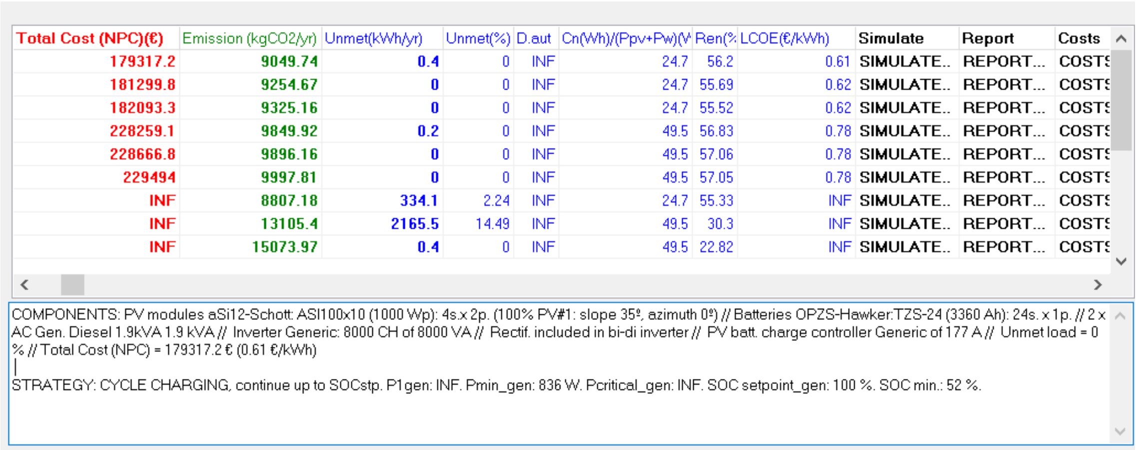
In the simulation, it should be noted that when the diesel generator set (3x1900 W) must run, it operates at maximum power (without loss of power) to charge the batteries to the maximum possible current (limited in this case by the Inverter-charger, which limits the DC current to 60 A, i.e. at 60A*48V=2880 W the battery charging power). The generator continues to charge the batteries until it reaches the SOCstp_gen (100% SOC, i.e. full charge), unless the strategy indicates that the batteries must supply the load, at that point the generator would stop charging.



It is possible that the control variables have different optimal values than those preset by default. We could optimize up to 4 variables in this case, however, to avoid excessive computation time, we will optimize only *Pmin_gen* (minimum power of the diesel generator set) and *SOC_min* (minimum SOC for the batteries). For this we mark these variables to optimize:



Then save the project, click on "CALCULATE" and after a few minutes we obtain the results table, where the optimum is slightly different from the one obtained previously (2 diesel generators instead of 3, *Pmin_gen* is 836 W and *SOC_min* 52%) and whose cost is slightly lower.

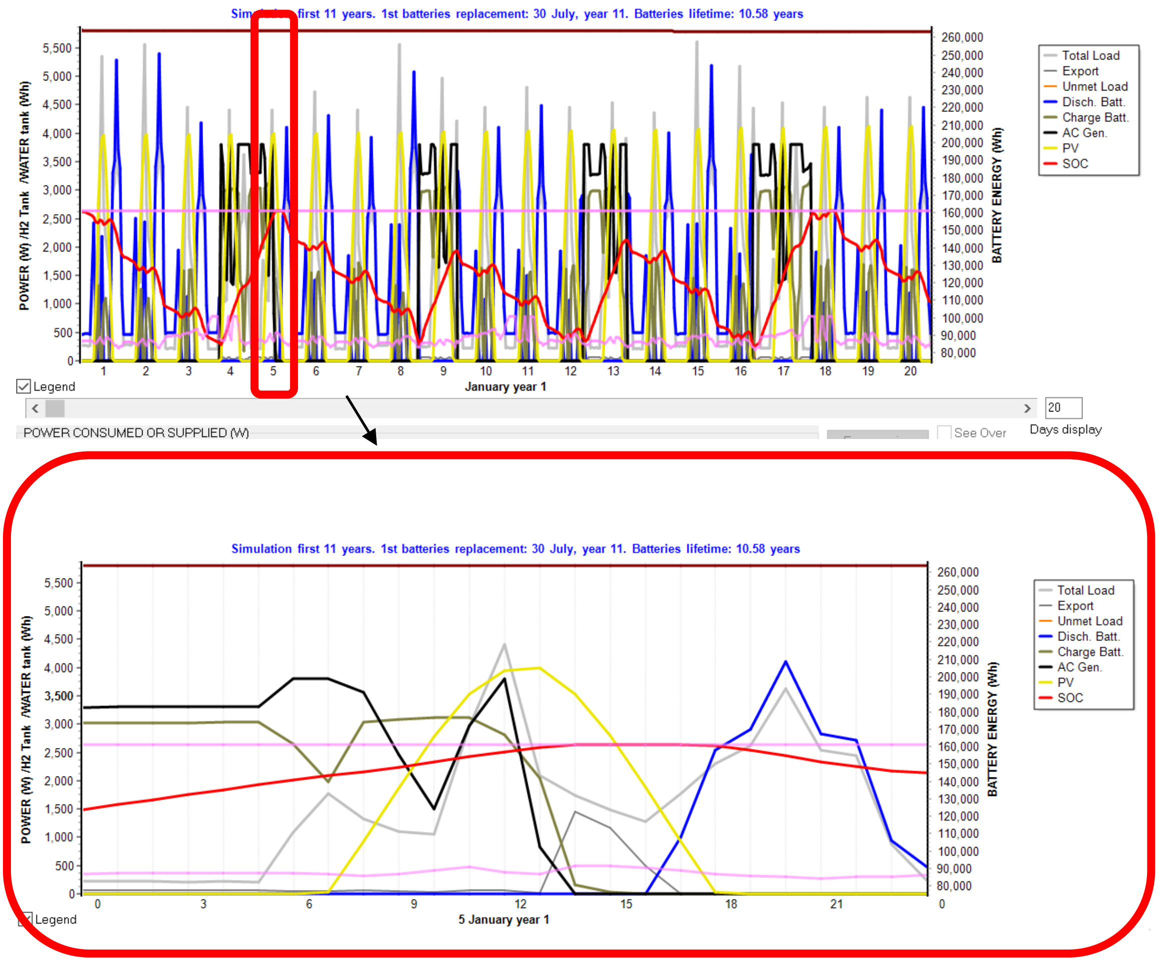


Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	Costs
179317.2	9049.74	0.4	0	INF	24.7	56.2	0.61	SIMULATE..	REPORT...	COSTS
181299.8	9254.67	0	0	INF	24.7	55.69	0.62	SIMULATE..	REPORT...	COSTS
182093.3	9325.16	0	0	INF	24.7	55.52	0.62	SIMULATE..	REPORT...	COSTS
228259.1	9849.92	0.2	0	INF	49.5	56.83	0.78	SIMULATE..	REPORT...	COSTS
228666.8	9896.16	0	0	INF	49.5	57.06	0.78	SIMULATE..	REPORT...	COSTS
229494	9997.81	0	0	INF	49.5	57.05	0.78	SIMULATE..	REPORT...	COSTS
INF	8807.18	334.1	2.24	INF	24.7	55.33	INF	SIMULATE..	REPORT...	COSTS
INF	13105.4	2165.5	14.49	INF	49.5	30.3	INF	SIMULATE..	REPORT...	COSTS
INF	15073.97	0.4	0	INF	49.5	22.82	INF	SIMULATE..	REPORT...	COSTS

COMPONENTS: PV modules aSi12-Schott: ASI100x10 (1000 Wp): 4s.x 2p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TZS-24 (3360 Ah): 24s. x 1p. // 2 x AC Gen. Diesel 1.9kVA 1.9 kVA // Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // PV batt. charge controller Generic of 177 A // Unmet load = 0 % // Total Cost (NPC) = 179317.2 € (0.61 €/kWh)

STRATEGY: CYCLE CHARGING, continue up to SOCstp. P1gen: INF. Pmin_gen: 836 W. Pcritical_gen: INF. SOC setpoint_gen: 100 %. SOC min.: 52 %.

In the simulation we can see the performance of the optimal solution, for example the first 20 days of January.



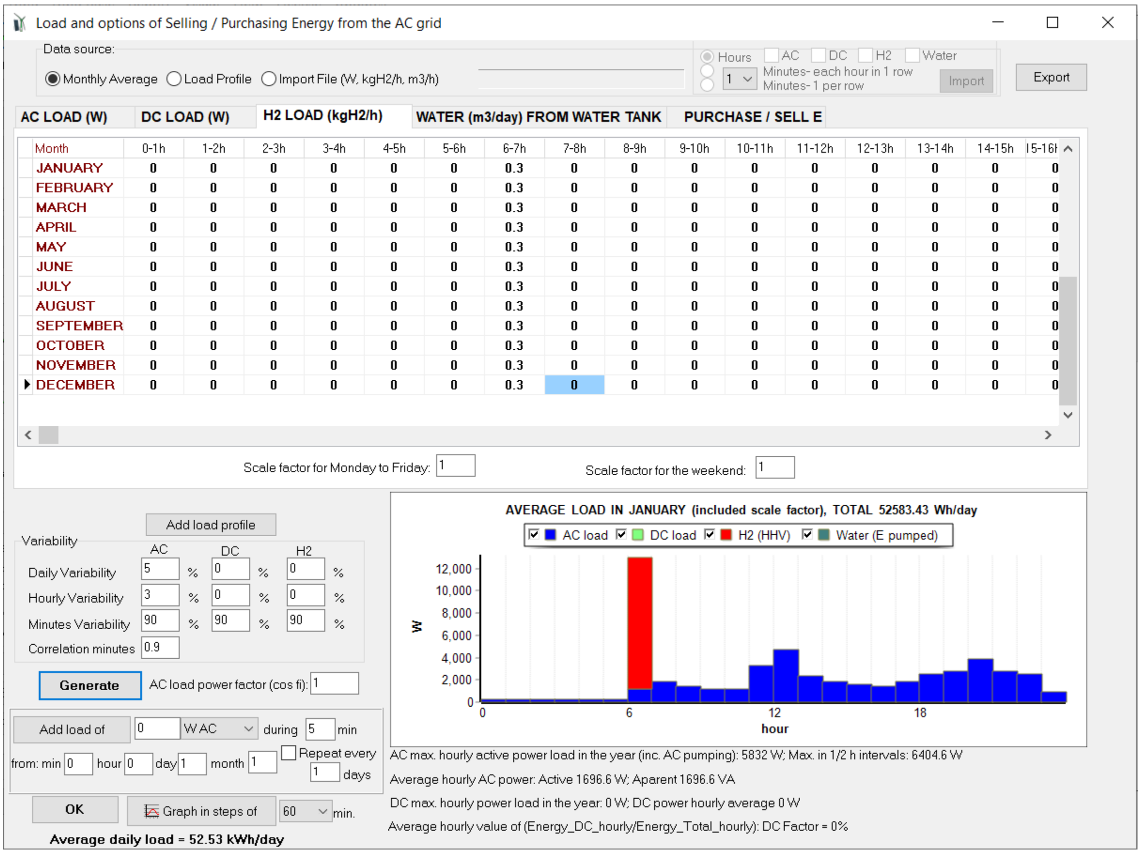
Finally, we save the project.

40. Add hydrogen components.

Next we will add hydrogen to the DieselPar.hoga project. We open that project and save it as "**DieselParH2.hoga**".

Suppose we need to feed a hydrogen vehicle, so that every day at 6 o'clock in the morning we supply 0.3 kg of H2 in the vehicle (for about 30 km of autonomy). Therefore, we will add a hydrogen charge in the "**LOAD / AC GRID**" screen:

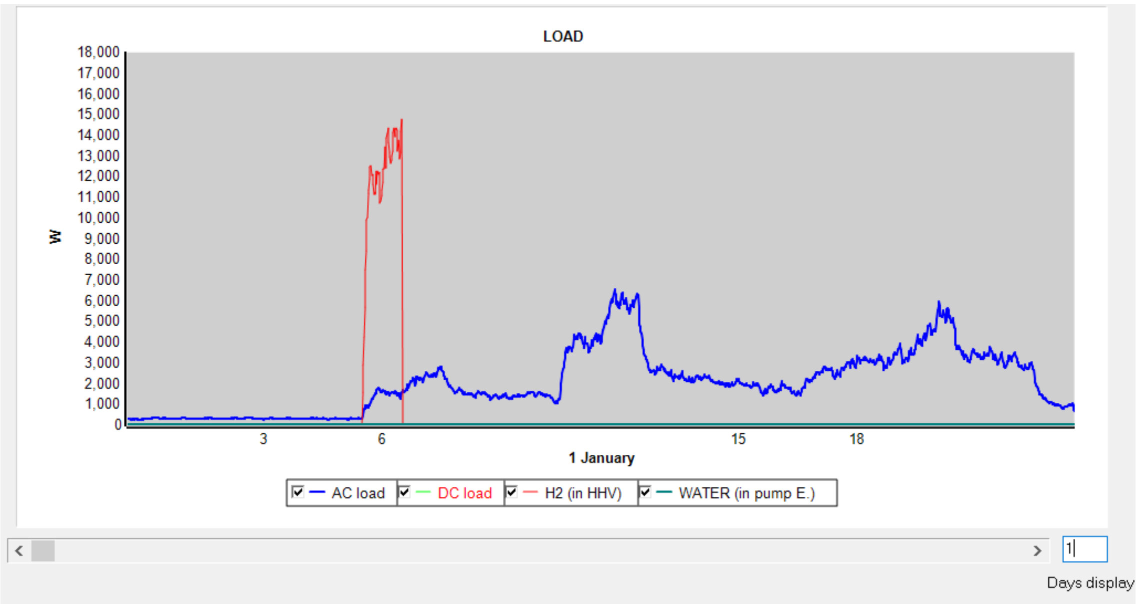
Click in the tab "**H2 LOAD (kgH2/h)**" and write 0.3 in the cell of 6-7 h of JANUARY. Then click on an adjacent cell (left or right) and appears for every month the consumption of 0.3 kg of H2 from 6 to 7 a.m.



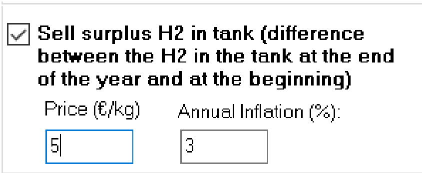
Next click on “**Generate**” button:

As 0.3 kg of H2 have a higher heating value HHV of 0.3kg·39.4kWh/kg = 11.82 kWh, it is shown in the graph as a load of 11.82 kW during the hour from 6 to 7 a.m. in red (added to the previously defined AC load in blue).

By clicking on "**Graph in steps of**", selecting 1 minute, we obtain something like this (the 1-minute step H2 consumption has been obtained considering a variability of 90% and a correlation of 0.9):

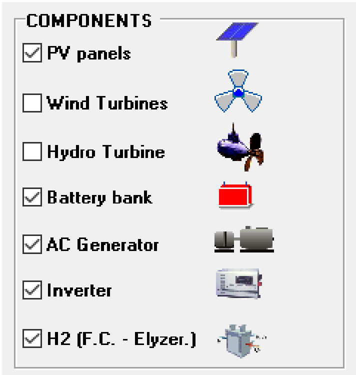


We return to the **LOAD / AC GRID** screen and in the tab "**PURCHASE / SELL E**" we check "**Sell surplus H2 in tank (...)**" so that if at the end of the year there is in the hydrogen tank more hydrogen than at the beginning of the year, we will sell the difference, in this case at 5 € / kg.



We return to the main screen by pressing the OK button.

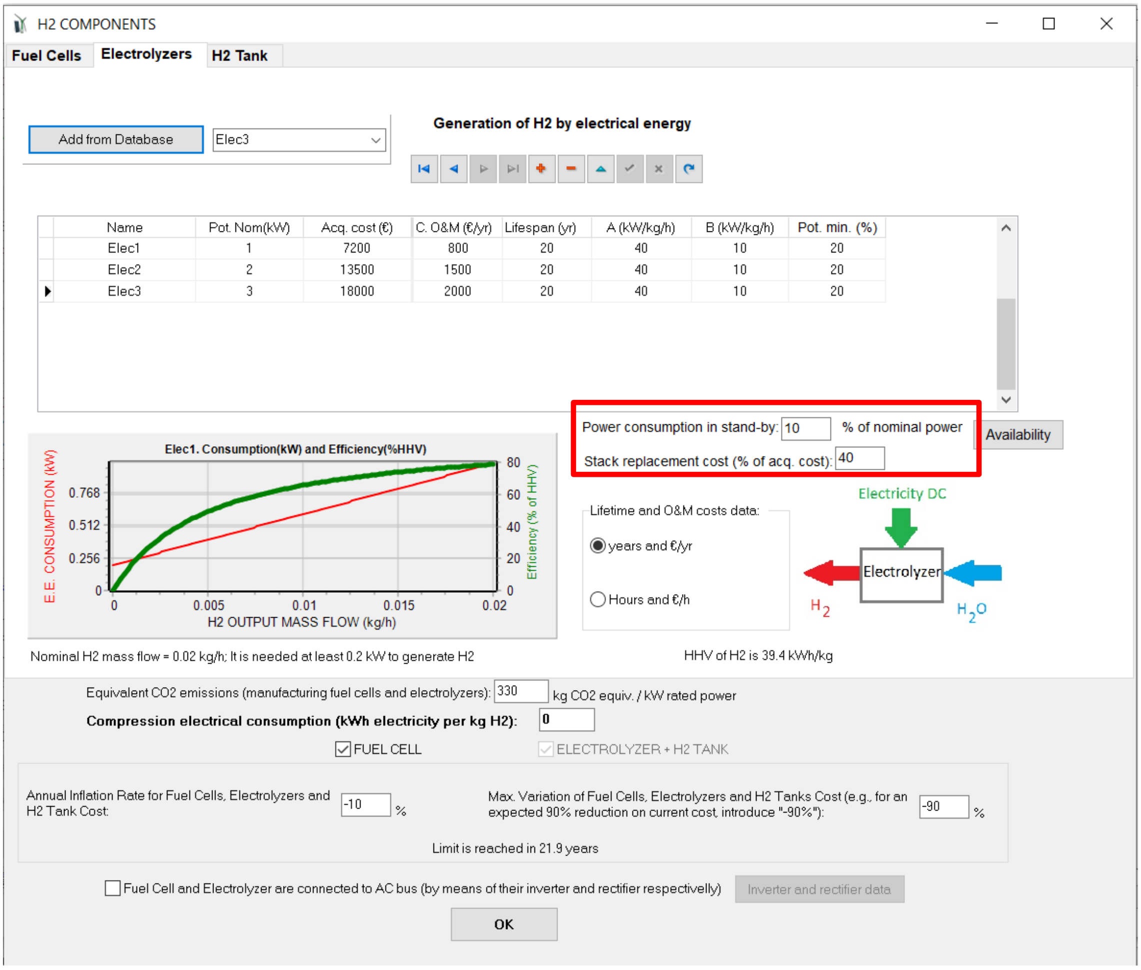
In the main screen, we check "**H2 (F.C. - Elyzer.)**" Since we will need at an electrolyzer to generate H2.



Then we click on 

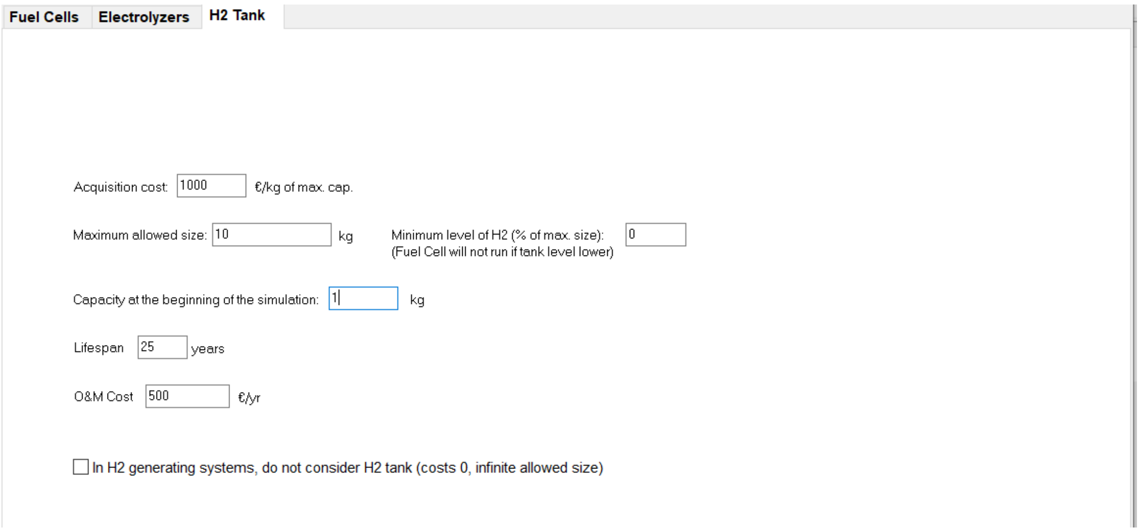
and the hydrogen components screen appears.

In the tab "**Electrolyzers**", we add from the database the electrolyzers Elec2 of 2 kW, and Elec 3 of 3 kW, and delete the "Zero" one.

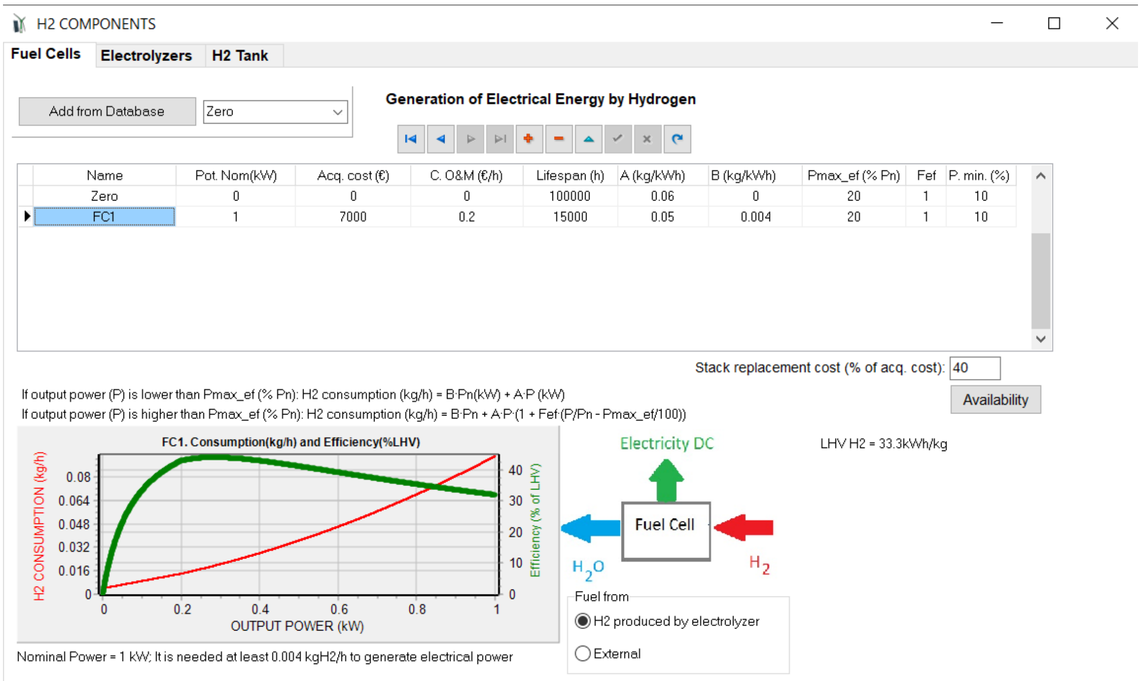


Note that, by default, the electrolyzers power consumption in stand-by (when it is not producing hydrogen) is 10% of its nominal power, and the stack replacement cost is 40% of acquisition cost.

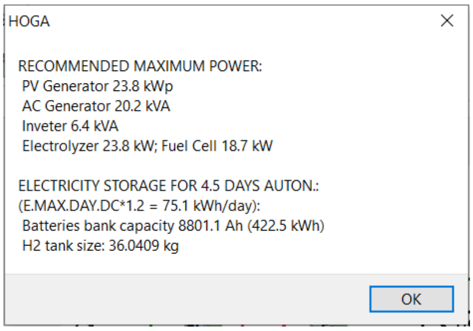
In the "**H2 tank**" tab we leave everything by default except the amount of H2 at the beginning of the simulation, which we leave in 1 kg.



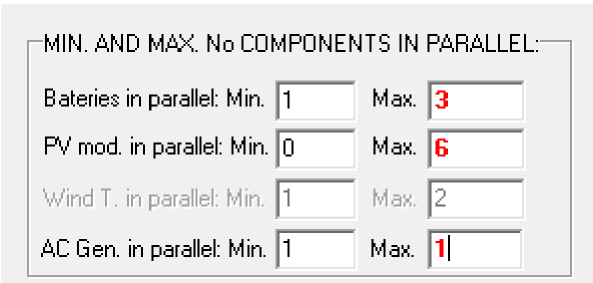
In the tab "**Fuel Cells**" we leave everything by default (possibility of no fuel cell, i.e. Zero, or fuel cell of a 1 kW).



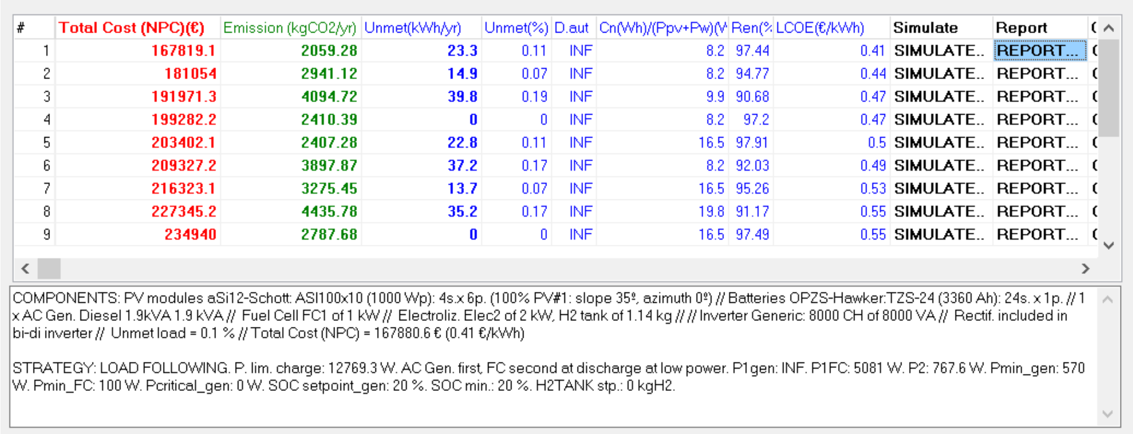
We leave this screen with "OK" and in the main screen we click **"PRE-SIZING**", obtaining:



The recommended AC generator of 20.2 kVA (11 diesel generators in parallel) would be to supply the maximum total power (the total consumption at 6 a.m.), however it does not make sense since the consumption of H2 is generated in the electrolyzer during the previous day, so in this case it does not make sense the 11 generators in parallel that iHOGA recommends. Therefore, we change this value, and set 1 for the max. number in parallel:

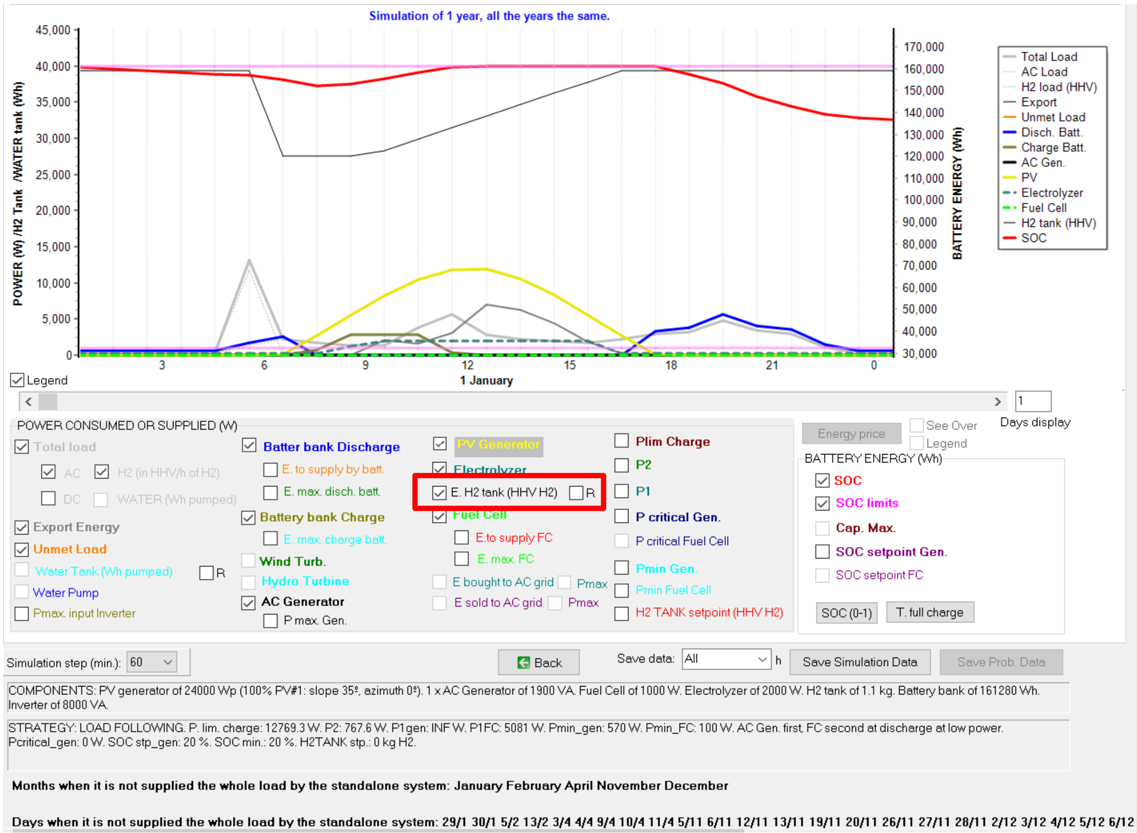


Save the project and then click on "**CALCULATE**", obtaining the following results:



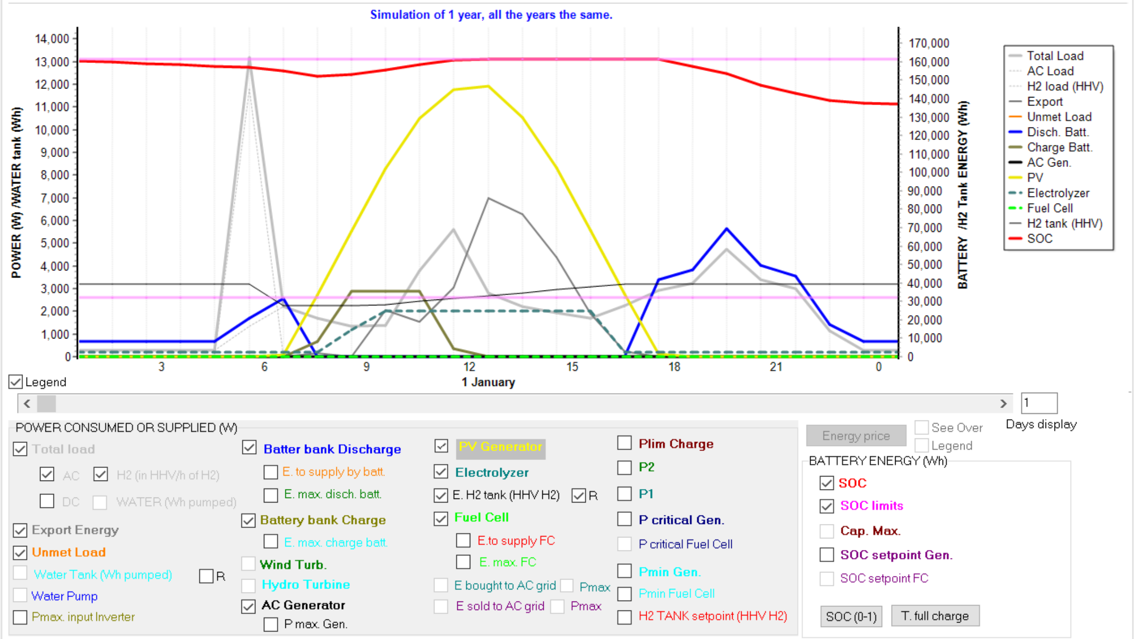
The optimal solution (first row) includes 24 modules (4s x 6p) of 100 Wp, diesel generator (to have infinite autonomy, cheaper than having a large bank of batteries), fuel cell of 1 kW, electrolyzer of 2 kW and H2 tank of 1.14 kg.

Click on "SIMULATE" of the first row:



The black thin line is the energy in the H2 tank (in HHV of hydrogen). In the simulation we can see the load peak at 6 a.m., with the high H2 load to supply the car, which is taken from the H2 tank (we can see the H2 tank energy is reduced in 11.82 kWh, corresponding to 0.3 kg of H2). Later, when the electrolyzer generates H2, the H2 tank energy increases as it stores the H2 generated.

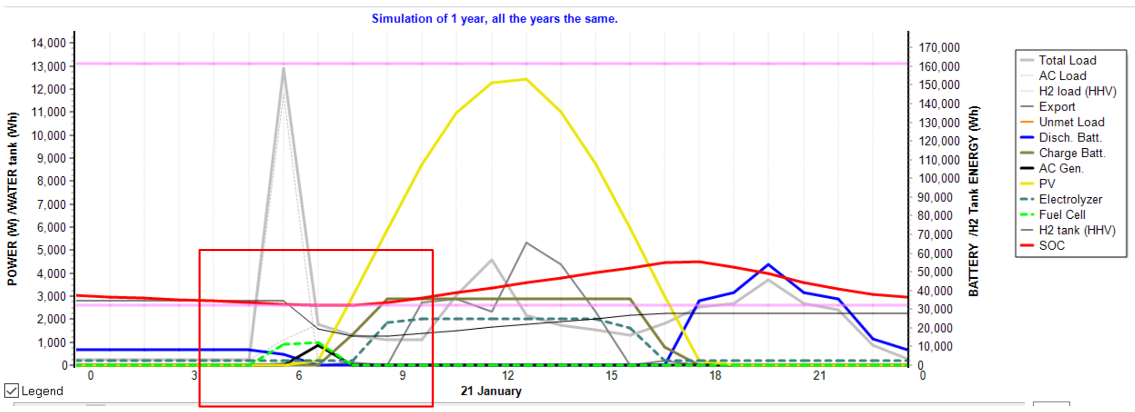
We check the "R" checkbox at the right of the E. H2 tank (HHV H2) so that the energy of the H2 tank will be shown in the right axis (together with the battery energy):



We can see that when there is excess energy (at 8 a.m and later), first it is used to charge the batteries (as P.lim.charge is 12769.3 W, therefore during each hour, if the excess energy is lower than this value, the priority is to charge the batteries), and, if the batteries are being charged at their maximum current, if there is still excess energy, the electrolyzer runs to produce H2).

We can also see that when the electrolyzer is in stand-by, it consumes 10% of its nominal power, and it is supplied by the renewable sources or by the batteries, as the rest of the load.

In January 21st we can see that from 6 to 8 a.m. the battery cannot supply the AC load no longer as it is at the minimum SOC, so it must be supplied by the backup generator or by the fuel cell. The control strategy P2 is 767.6 W (it is a value calculated by iHOGA, but maybe it is not the optimal, this control variable could be optimized), that means that if the load that must be met is lower thant that value, the AC backup generator will run, and if it is higher it will be supplied by the fuel cell. As the AC load (including the stand-by consumption of the electrolyzer) during these hours is higher than P2, the fuel cell (nominal output power 1 kW) tries to supply the load (throught the inverter, considering its losses). However, as the AC load is higher than the load that can supply the fuel cell, the backup AC diesel generator runs at its minimum output power to fully supply the load.



The meaning of the values of the control strategies are explained in the report. You can close the simulation window and, in the main screen, first row of the table, click "REPORT":

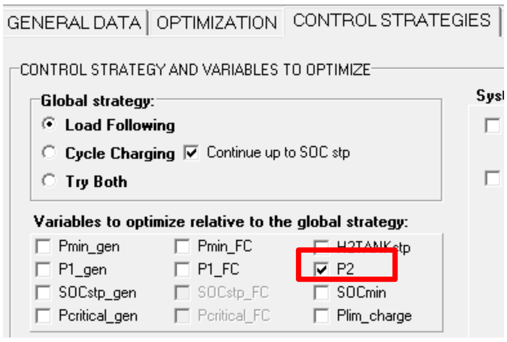
CONTROL STRATEGY:

IF THE POWER PRODUCED BY THE RENEWABLE SOURCES IS HIGHER THAN LOAD: CHARGE
If the spare power from renewable is lower than Plim_charge = 12769.3 W the Batteries are charged. Otherwise the Electrolyzer generates H2

IF THE POWER PRODUCED BY THE RENEWABLE SOURCES IS LESS THAN LOAD: DISCHARGE
If the power not supplied to meet the load is lower than P1FC = 5081 W, it will be supplied by the Batteries. If the Batteries cannot supply the whole and the rest is lower than P2 = 767.6 W, the rest will be supplied by the AC Generator, otherwise the rest will be supplied by the Fuel Cell.
If the power not supplied to meet the load is higher than P1FC = 5081 W, it will be supplied by the Fuel Cell. If the Fuel Cell cannot supply the whole and the rest is lower than P1gen = INF W, the rest will be supplied by the Batteries, otherwise the rest will be supplied by the AC Generator.
(In this case P1>P2)

AC Generator Minimum Power : 570 W
When power to be supplied by AC Gen. is < Pcritical_gen = 0 W, AC gen. runs at full power (without excess), charging the Batt. (this hour and the next hours) until 20 % SOC is reached and generating H2 in Elyzer until H2 Tank= 0 kg
Fuel Cell Minimum Power : 100 W
When power to be supplied by FC is < Pcritical_FC = 0 W, the FC runs at full power (without excess), charging the Batteries (this hour and the next hours) until 20 % of SOC is reached
LOAD FOLLOWING. SOC min. batteries = 20 %

As it has been said, it is possible that the value of P2 is not optimal. We could optimize it, in the main screen, CONTROL STRATEGIES tab, click in P2 (we could optimize more control variables, but in this case we will only optimize P2):



We optimize again ("CALCULATE" button) and we obtain:

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	167785.4	2055.38	29.3	0.14	INF	8.2	97.42	0.41	SIMULATE..	REPORT...
2	180707.9	2910.07	15	0.07	INF	8.2	94.91	0.44	SIMULATE..	REPORT...
3	191503	4050.3	39.9	0.19	INF	9.9	90.9	0.47	SIMULATE..	REPORT...
4	198695.1	2364.28	0.4	0	INF	8.2	97.32	0.46	SIMULATE..	REPORT...
5	203258.3	2396.15	28.8	0.14	INF	16.5	97.9	0.5	SIMULATE..	REPORT...
6	209145.8	3880.54	37.2	0.17	INF	8.2	92.11	0.49	SIMULATE..	REPORT...
7	216054.5	3251.05	13.8	0.07	INF	16.5	95.37	0.53	SIMULATE..	REPORT...
8	226915.7	4395.78	35.2	0.17	INF	19.8	91.36	0.55	SIMULATE..	REPORT...
9	232116.5	2613.08	55.4	0.25	INF	16.5	97.59	0.54	SIMULATE..	REPORT...

COMPONENTS: PV modules aSi12-Schott: ASI100x10 (1000 Wp): 4s.x 6p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TZS-24 (3360 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 kVA // Fuel Cell FC1 of 1 kW // Electroliz. Elec2 of 2 kW, H2 tank of 1.14 kg // // Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // Unmet load = 0.1 % // Total Cost (NPC) = 167785.4 € (0.41 €/kWh)

STRATEGY: LOAD FOLLOWING. P. lim. charge: 12769.3 W. AC Gen. first, FC second at discharge at low power. P1gen: INF. P1FC: 5081 W. P2: 614.1 W. Pmin_gen: 570 W. Pmin_FC: 100 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %. H2TANK stp.: 0 kgH2.

The optimal system is the same, but P2 now is 614.1 W, near the default value used for P2, therefore the difference is very low. In other cases, the optimization of this control variable (and/or other control variables) can lead to big reductions in NPC.

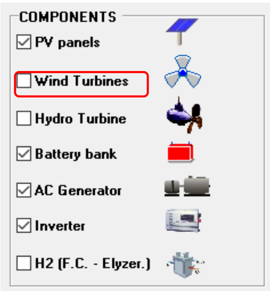
41. Optimization of a temporary PV-diesel-batteries system.

Next we will perform the optimization of a temporary PV-diesel-battery installation. This type of facility is transported, assembled, operated for a few days or months and then dismantled and transported back to its storage place. For example, field hospitals for emergencies, etc.

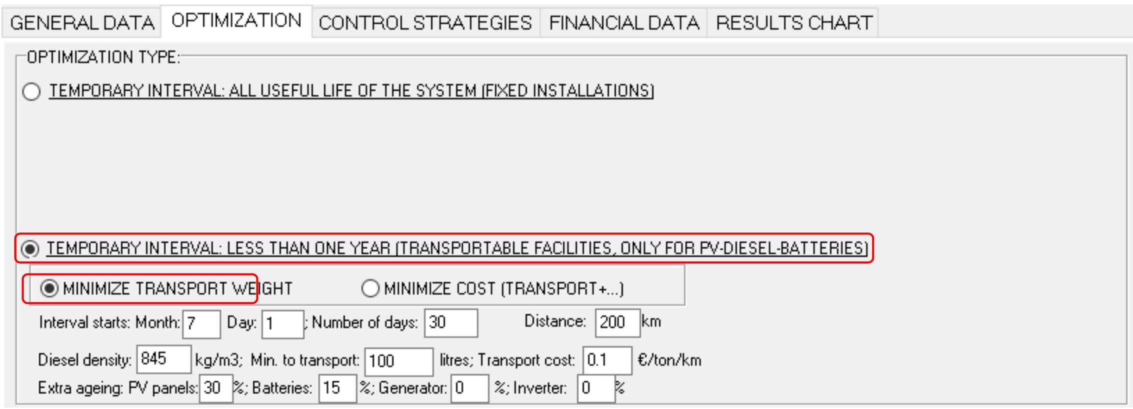
The total weight of the transport (round trip) or the total cost, which includes transport costs, operation and maintenance costs, as well as the degradation cost of the components, can be minimized. We will carry out the minimization of transport weight, assuming that it is the most critical variable since it is an installation that must be transported by helicopter or into conflicting areas.

We open the "Pr1.hoga" project and save it as "**Pr1-Temp.hoga**".

Eliminate the possibility of wind turbines, since this type of optimization only consider weight and cost of PV-Diesel-battery systems.

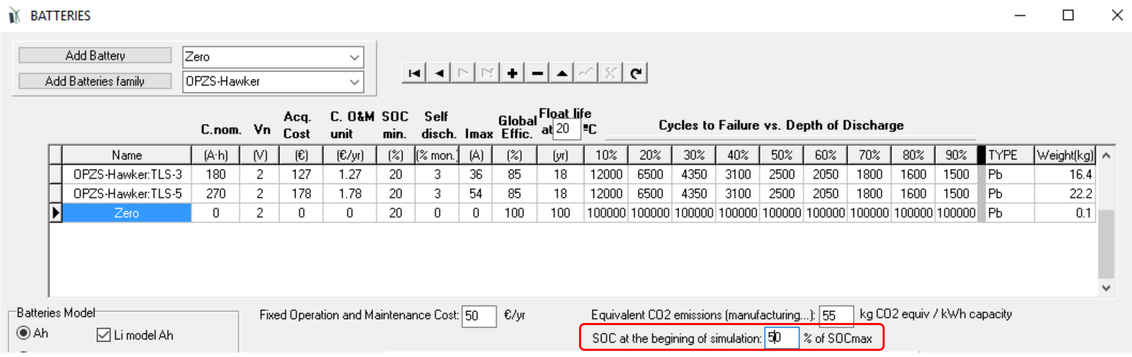


Then, in the main screen, tab "OPTIMIZATION", mark "TEMPORARY INTERVAL: LESS THAN ONE YEAR ..." and leave marked "MINIMIZE TRANSPORT WEIGHT ".

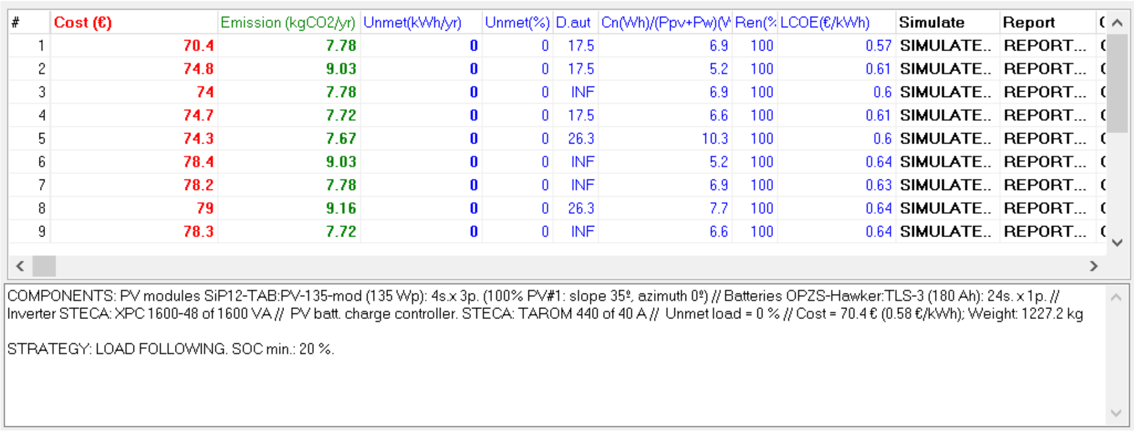


We leave the default data (period of 30 days beginning July 1, distance, transport cost, etc.).

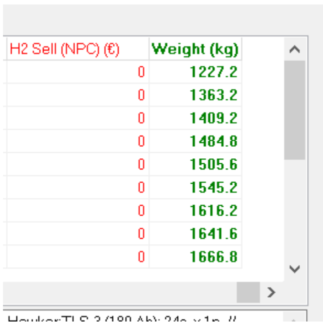
In the batteries screen, we will indicate the SOC at the beginning of the simulation (in this case on July 1 at 0h), we will assume that the batteries are at 50%:



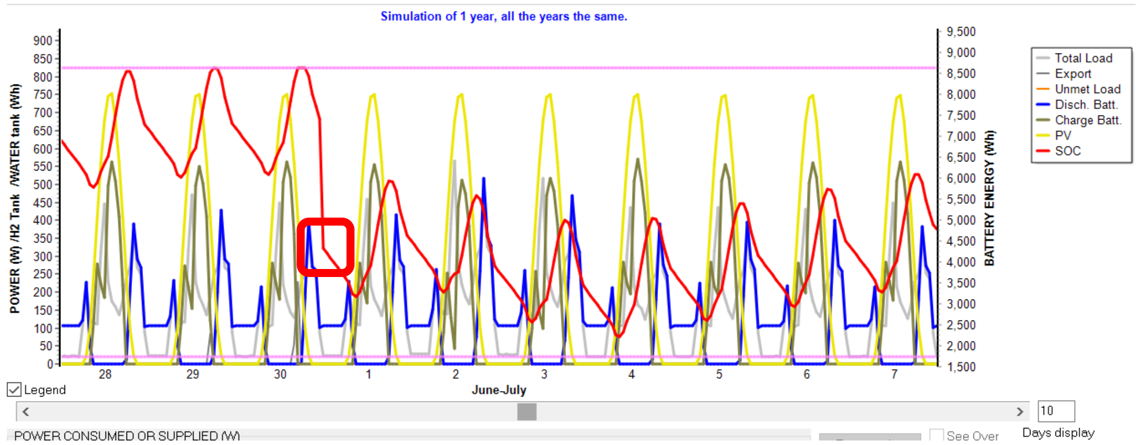
Return to the main screen and click on "CALCULATE". We obtain the following results, graphically representing cost (transport + operation + degradation) in red and weight to be transported (round trip) in green. The solutions are ordered from less to greater weight.



In the last column of the table we can see the transport weight:



If we click on "SIMULATE" in the first row, we see the simulation of the whole year of the optimal solution, however the optimization is the corresponding to the 30 days beginning July 1. You can see how on July 1 at 0h the SOC of the batteries goes to 50% (to start the simulation of the period of interest).



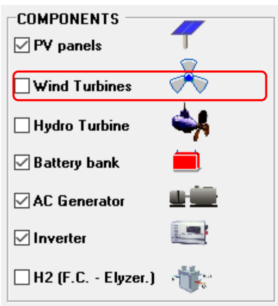
42. Optimization of a system with AC grid connection in which the AC grid is unavailable at certain times.

Next we will perform the optimization of a PV-diesel-battery installation with connection to the AC grid, taking into account that the AC grid can fail during certain hours. Such systems are common in certain areas in developing countries, where AC power is weak and frequently fails.

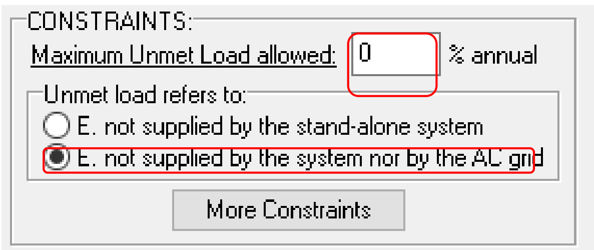
Open the project “Pr1.hoga” and save it as “**Pr1-Grid.hoga**”.

Let's assume that we want to cover absolutely the entire demand, that is, we want a maximum unmet load of 0%, and we define it as energy not served either by the autonomous system (photovoltaic modules, batteries, generator) or AC grid.

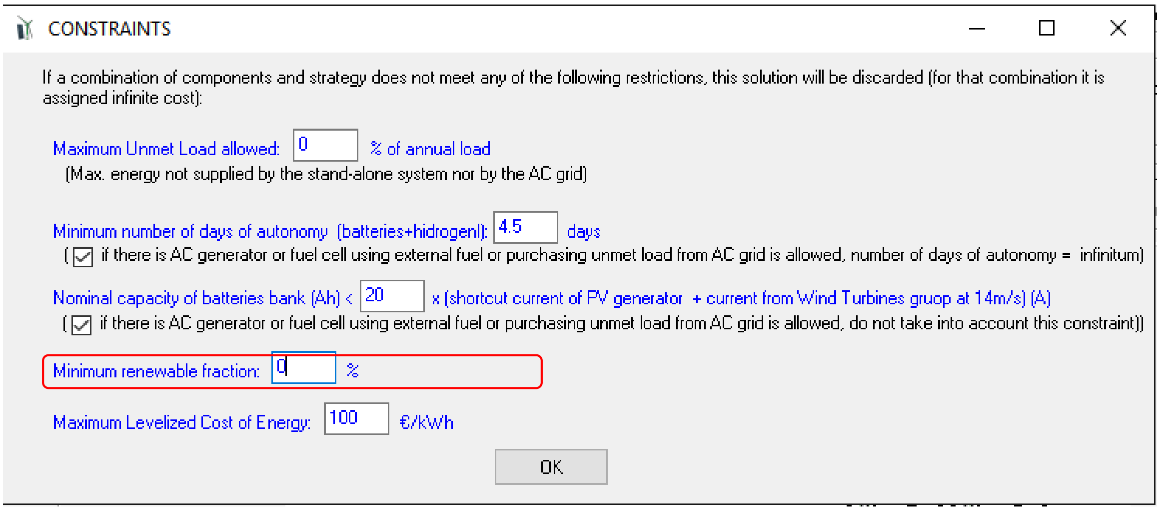
In the main screen, in the "**GENERAL DATA**" tab, "**COMPONENTS**", we disable the tab "Wind Turbines", because we only want to consider PV modules, batteries and AC generator (besides inverter necessary for batteries to supply AC voltage):



In the same tab, under "**CONSTRAINTS**" change the Maximum Unmet Load Allowed to 0%, and also change the definition of the unmet load to “E. not supplied by the system nor by the AC grid”.

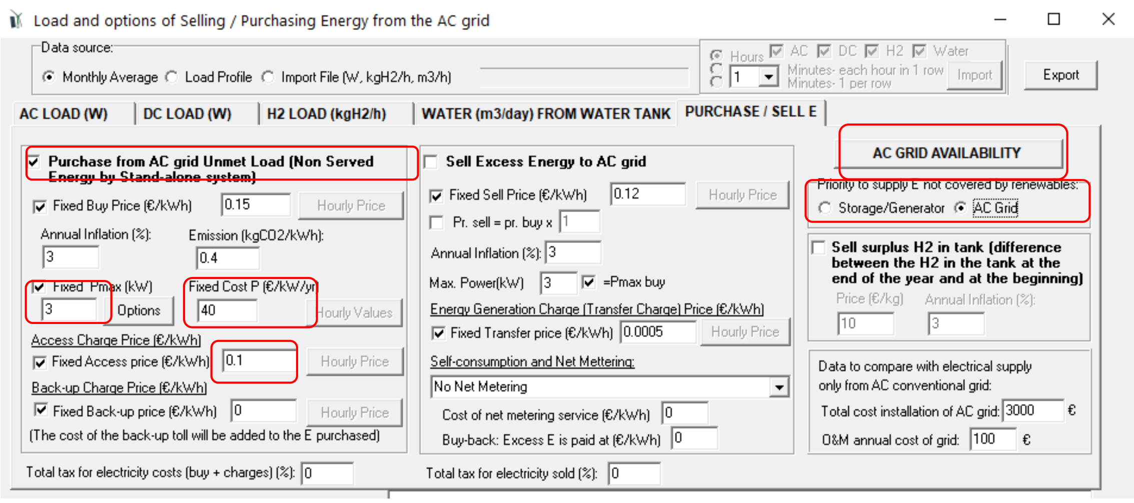


We want the possibility of not existing renewable generation to be taken into account. To do this, click on the "**More Constraints**" button, and we eliminate the restriction of the minimum renewable fraction, leaving it at 0%:



In the "**LOAD / AC GRID**" screen, "**PURCHASE / SELL E**" tab, check the box "**Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system)**". In this way we will buy to the AC grid the necessary energy to supply all the load. Let us suppose that the purchase price of the electricity purchased from the AC grid is the default value of 0.15 €/kWh (plus 0.1 €/kWh of default access charge, that is, the total cost of electricity is 0.25 €/kWh). Also suppose that the maximum power from the grid (contract power) is 3 kW at a cost of 40 €/kW/year. The rest of the data by default.

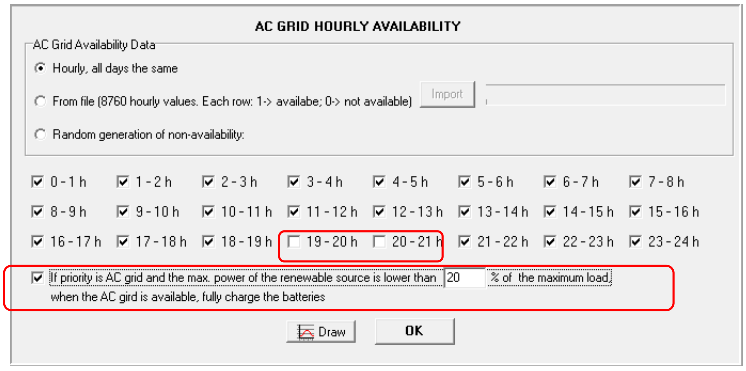
In "**Priority to supply E not covered by renewables**" we will mark "**AC grid**", indicating that at each temporary step, when renewable sources (photovoltaic in this case) cannot cover all the demand, then the energy not served will be tried to be covered as a priority through the AC network; if the AC network fails the batteries or the AC generator (depending on the control strategy) will try to cover the unmet load. This is what commercial drivers usually do.



Suppose that the AC grid usually fails every day, from 19 to 21 h. To indicate this data, click the button 

, the following window appears, in which we maintain the default option "**Horuly, all days the same**" and we will disable the boxes "19-20 h" and "20-21 h".

We will also check the box "**If priority is AC grid and the max. power of renewable source ...**", indicating that the controller, when the AC grid becomes available, will charge the batteries (only in cases where the maximum power of the renewable sources is less than 20% of the maximum consumption power). This is interesting for systems with little renewable power, since if this box were not checked, batteries could not be correctly charged with renewable sources.

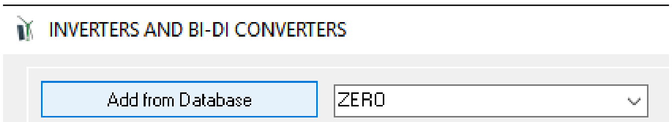


We click "OK" to accept the changes and leave that window.

Then click "OK" on the “LOAD / AC GRID” screen to return to the main screen.

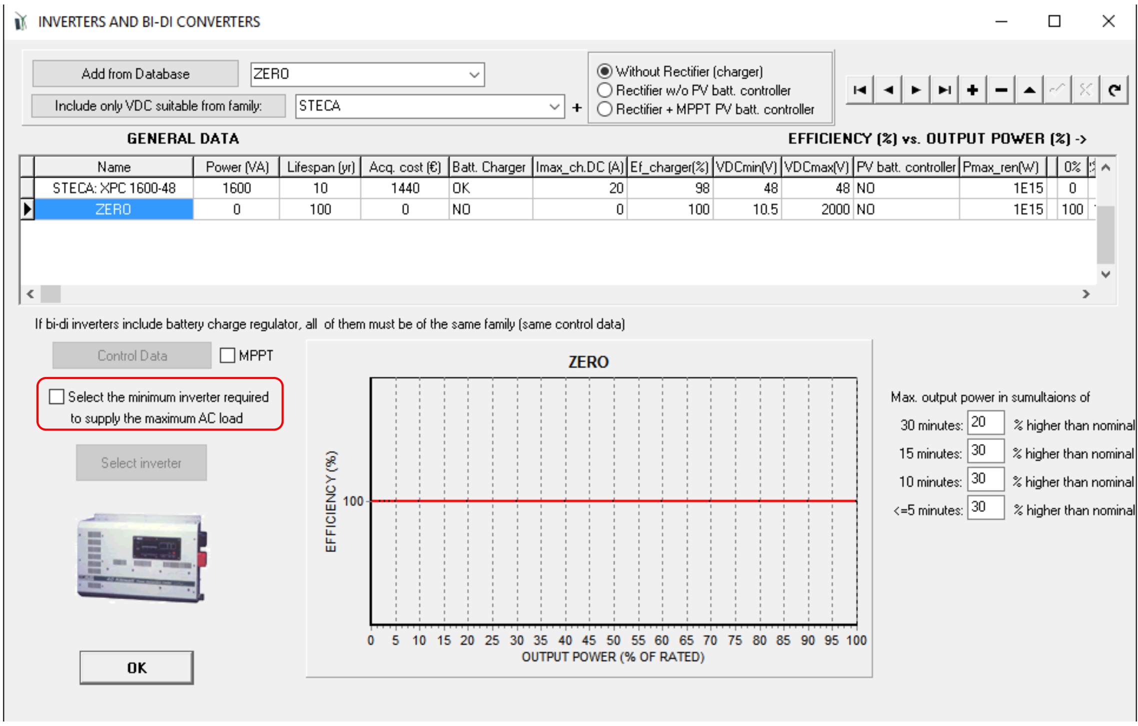
In the main screen, click the "INVERTERS" button.

With the inverter "ZERO" selected in the drop down above, click on "Add from database":



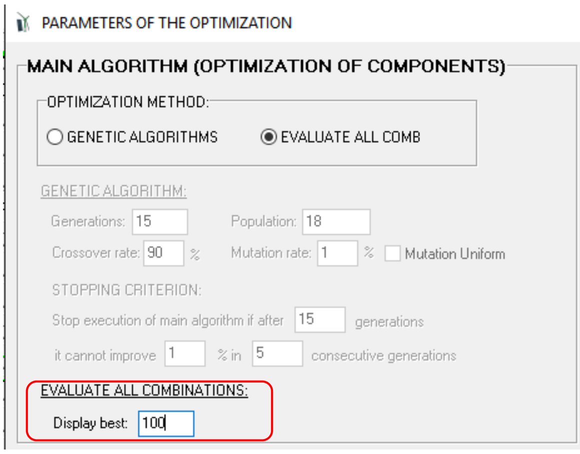
In this way we have added an inverter of 0 VA and cost 0, in case it is not considered a PV generator nor batteries it will be the best option.

And finally we uncheck the box "Select the minimum inverter required to supply the maximum AC load", this way it will be considered the two inverters that we have selected in the table and not only the minimum that covers the demand.



We click "OK" to return to the main screen of the program.

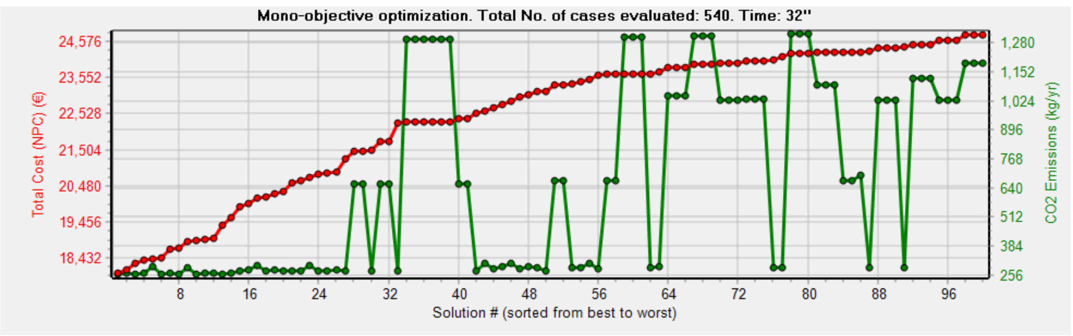
In the main screen, tab " OPTIMIZATION", click on "Parameters" button and in the screen that appears change in EVALUATE ALL COMBINATIONS, display best: 100. In this way we will see the 100 best results ordered when the optimization is done.



We accept and return to the main screen.

Save the project. In the main screen, click on "CALCULATE".

After a few seconds, the results are as follows:



Show diagram

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	17996.2	259.24	0	0	INF	8.8	67.62	0.61	SIMULATE..	REPORT...	C
2	18073.8	264.9	0	0	INF	10.3	66.02	0.61	SIMULATE..	REPORT...	C
3	18282.8	259.24	0	0	INF	8.8	67.62	0.62	SIMULATE..	REPORT...	C
4	18360.4	264.9	0	0	INF	10.3	66.02	0.62	SIMULATE..	REPORT...	C
5	18403.4	294.65	0	0	INF	13.3	61.64	0.63	SIMULATE..	REPORT...	C
6	18435.9	261.1	0	0	INF	6.6	69.42	0.63	SIMULATE..	REPORT...	C
7	18665	262.78	0	0	INF	6.9	69.28	0.63	SIMULATE..	REPORT...	C
8	18722.4	261.1	0	0	INF	6.6	69.42	0.64	SIMULATE..	REPORT...	C
9	18898.6	288.35	0	0	INF	13.3	61.62	0.64	SIMULATE..	REPORT...	C

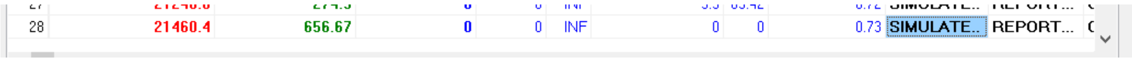
COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp): 4s.x 3p. (100% PV#1: slope 35º, azimuth 0º) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 17996.2 € (0.61 €/kWh)

STRATEGY: LOAD FOLLOWING. SOC min.: 20 %.

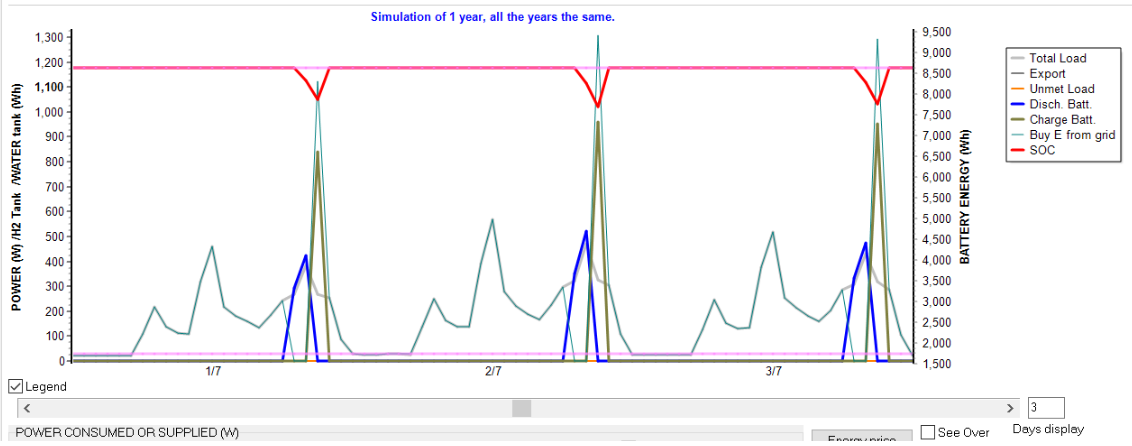
We can see that the optimum system includes photovoltaic generator and batteries. This is due to the fact that the price of the electric energy of the AC network is quite high (0.25 €/kWh, considering the cost of energy and the access charge); if that price was sufficiently low the optimum system might not include photovoltaic generator.

In the simulation of the optimum system (uncheck Pmax) we can see how the batteries supply the energy in the hours in which the network is not available. In this case the maximum photovoltaic power is greater than 20% of the maximum demand power, so the option of charging the batteries with the grid is not applied.

We can observe that the first solution that appears without photovoltaic generator is the number 28, with a configuration only with AC grid and batteries (plus inverter).



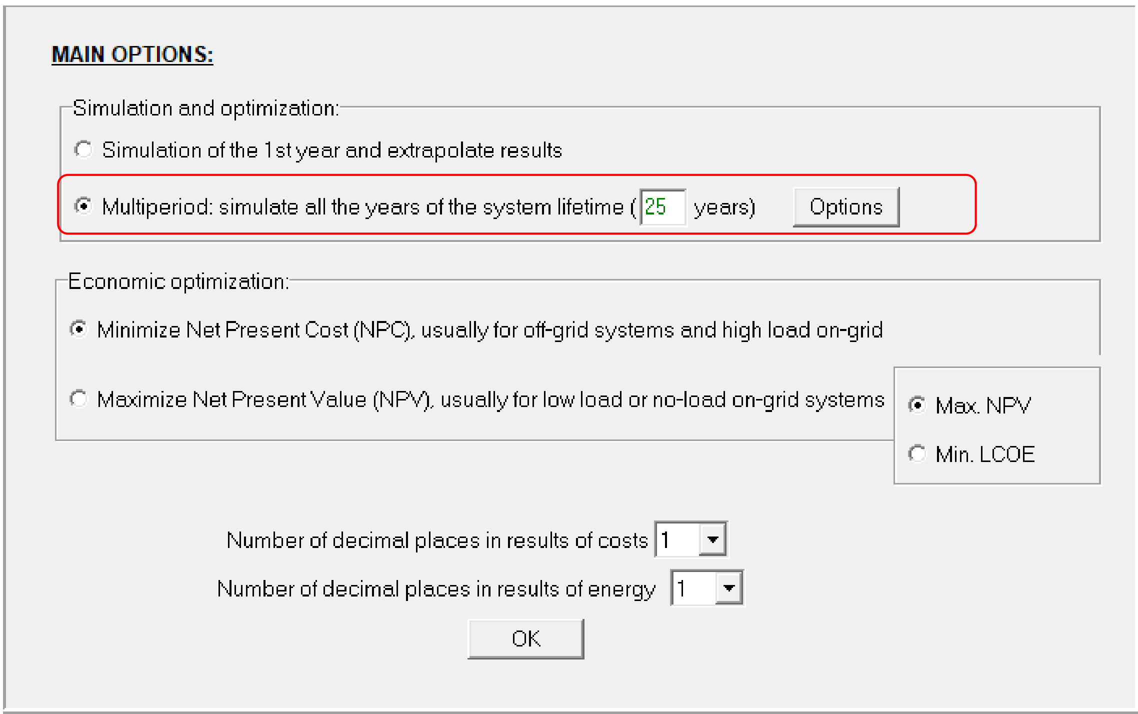
If we simulate this solution, we observe the following: the AC grid supplies all the electricity except the two hours a day in which the grid is not available, being supplied the electricity through the batteries; in the next hour the batteries are charged by the AC grid.



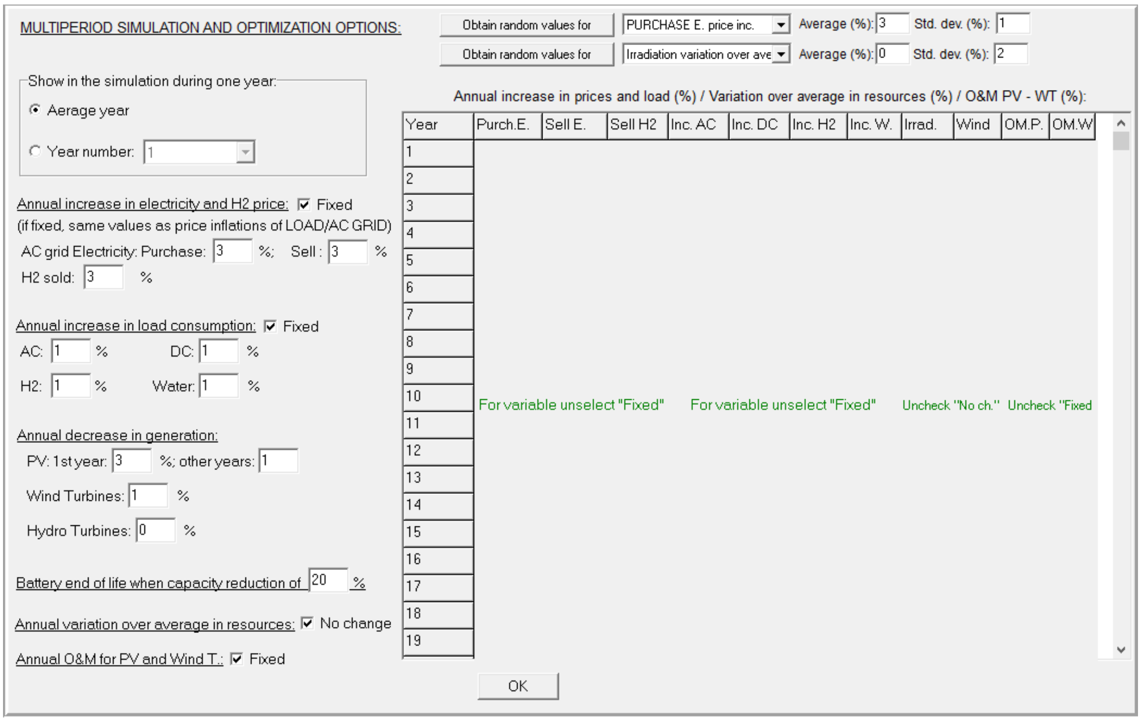
43. Multi-period optimization.

Open “Pr1” project and save it as “Pr1-Multiperiod”. In the upper menu, **Project->Options**.

Select “**Mutiperiod: simulate all the years of the system lifetime…**”



Then click in **Options** button.



By default, an annual increase of 3% in electricity and H2 price is considered (although in this case it will not be considered as there is no buy or sell of energy).

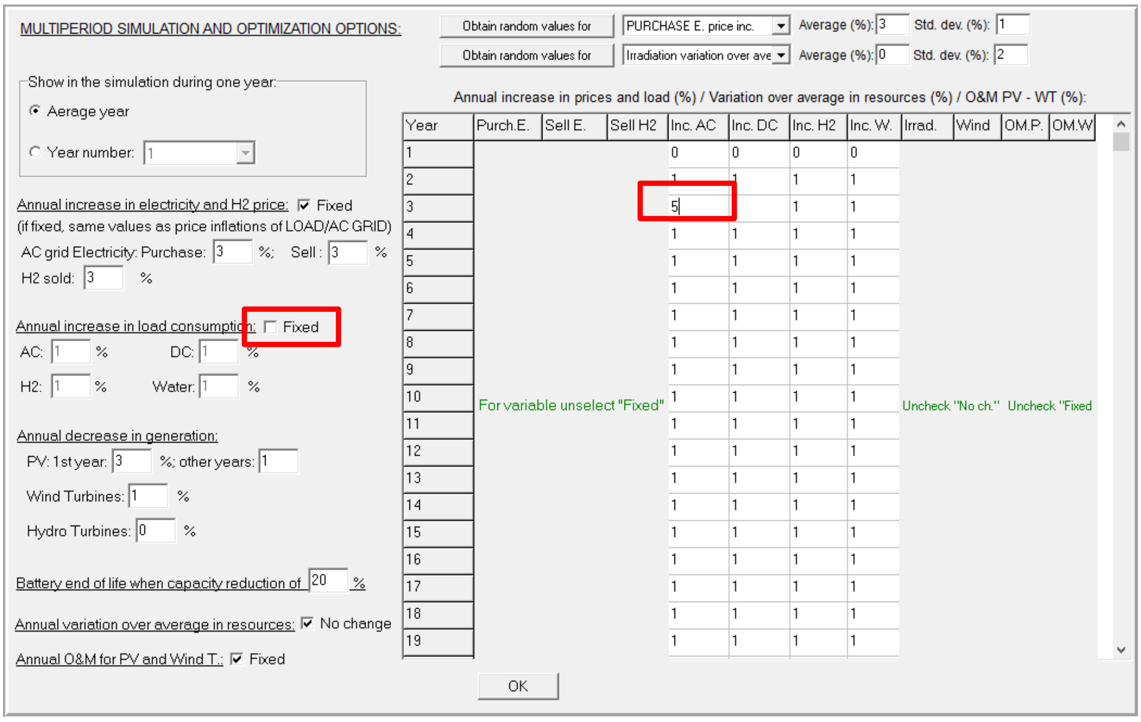
Also, an annual increase in the load consumption of 1% is considered (each year the load is 1% higher than the previous year).

It is also considered by default that the PV modules generation is decreased 3% after 1 year, and the rest of the years it is reduced 1%, wind turbines generation is reduced 1% per year, and battery bank capacity reduction is 20% at the end of its lifetime.

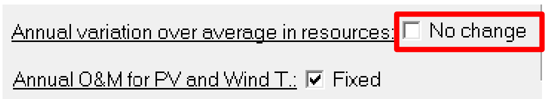
We can define annual values for these data, different for each year, unchecking the corresponding "Fixed" checkbox. Then in the table at the right appears the columns where you can change the values.

Also, you can define annual variation in resources, if you uncheck "No change", and annual O&M for PV or for wind turbines if you uncheck the checkbox "Fixed" at the bottom.

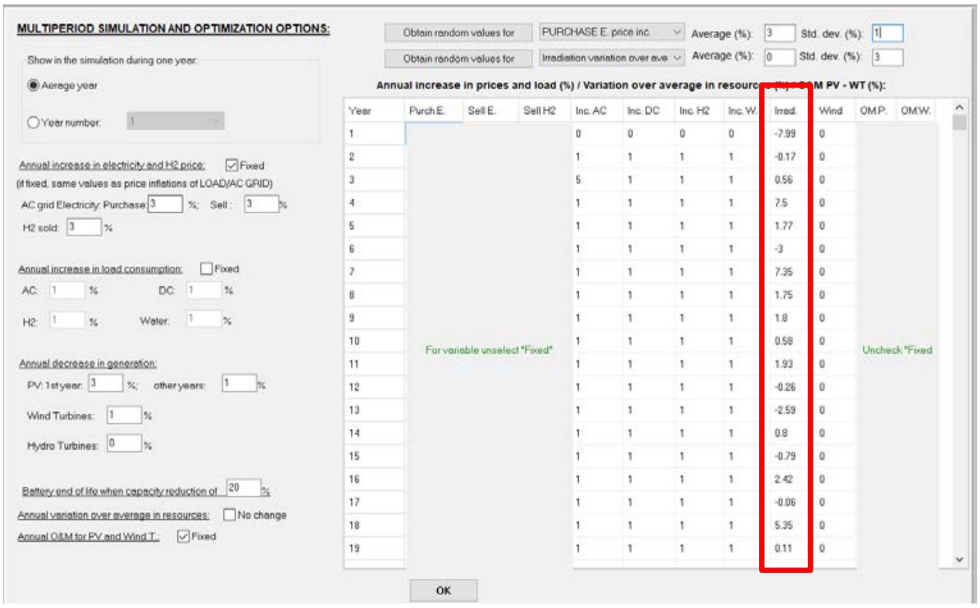
For example, let's suppose that the 3rd year the AC load will be increased in 5% (the rest of the years 1%): uncheck the corresponding "Fixed" checkbox and change in the table.



Also, let's suppose that we want the annual irradiation to change over the average with an standard deviation of 3%: uncheck "No change" and click in the button "**Obtain random values for**" Irradiation variation over average, Std. dev. 3%:



We obtain the following (the column Irrad. is the % over the annual average irradiation for each year, and it has been obtained randomly following a std. dev. of 3%, each case can be different):

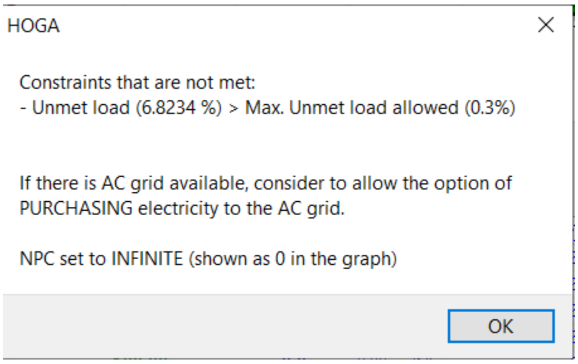


Note that the values obtained randomly of your project will be different from the ones of the figure, due to the randomness.

We leave the rest of the default values. Click OK, then OK.

Now, in the main screen, click in the first row of the results table. The optimal solution is simulated considering the multi-period, and all the columns are updated to the results of the multiperiod, with the average values of the 25 years of its lifetime.

A window appears showing that the unmet load is 6.8234%, higher than the maximum allowed of 0,3%, therefore the NPC is assigned the value INF (shown in the graph with 0 as NPC).

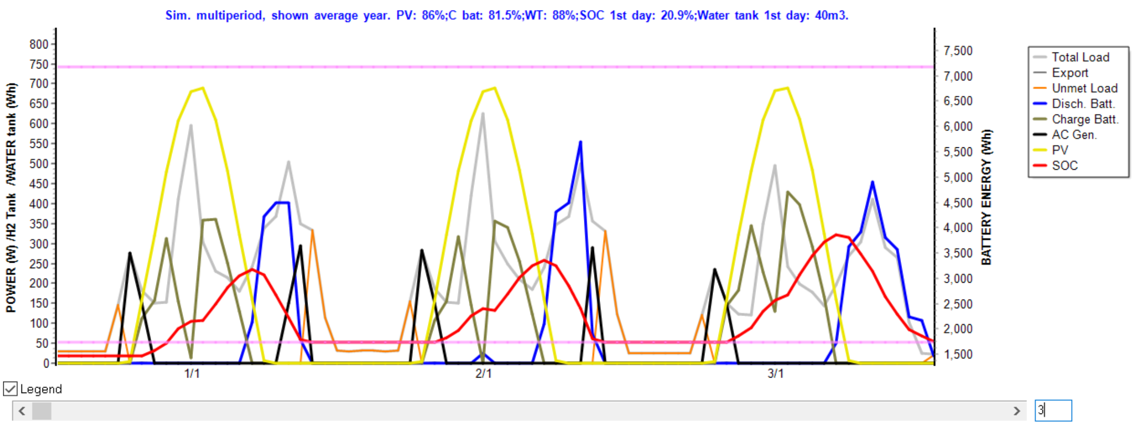


Gen	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	INF	516.18	119.9	6.82	INF	6.6	84.73	INF	SIMULATE..	REPORT...	C

Considering the increase of 1% annual in load (5% the third year) and the reduction in PV and in the battery capacity, and also the variation of irradiation during the years, the average annual unmet load during the 25 years is 6.8234%.

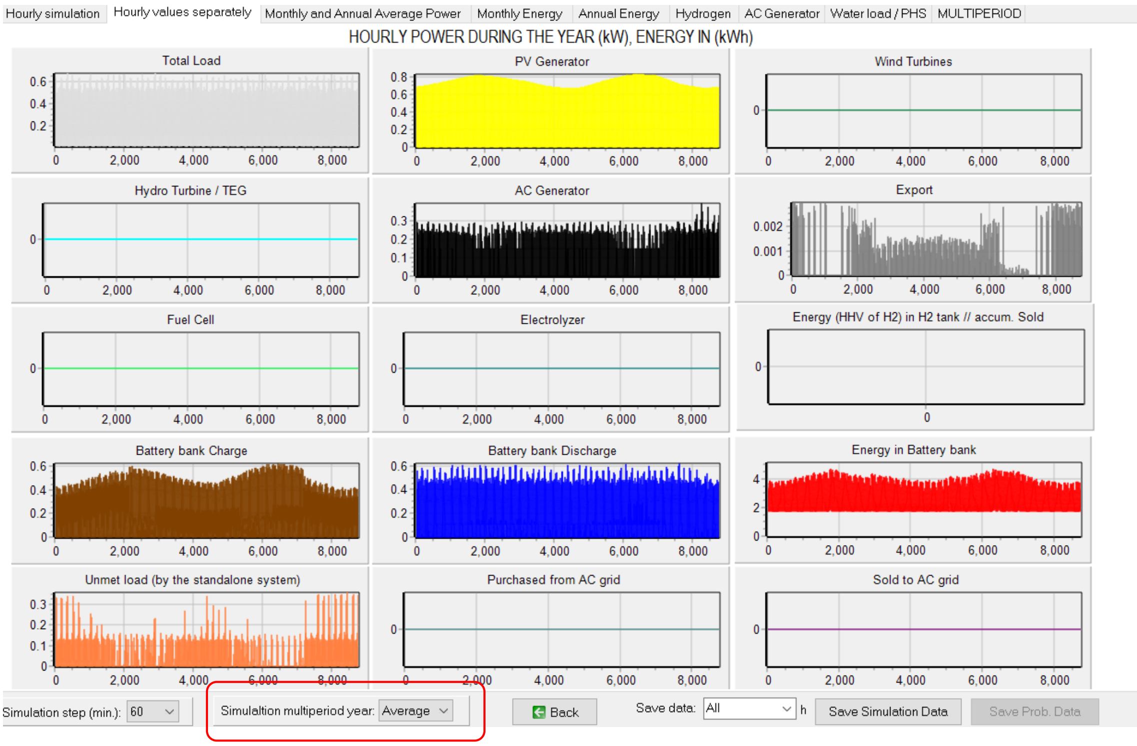
Except for the data of the NPC, all the data of the table are referred to the average values of the years of the system lifetime, that is, annual average values.

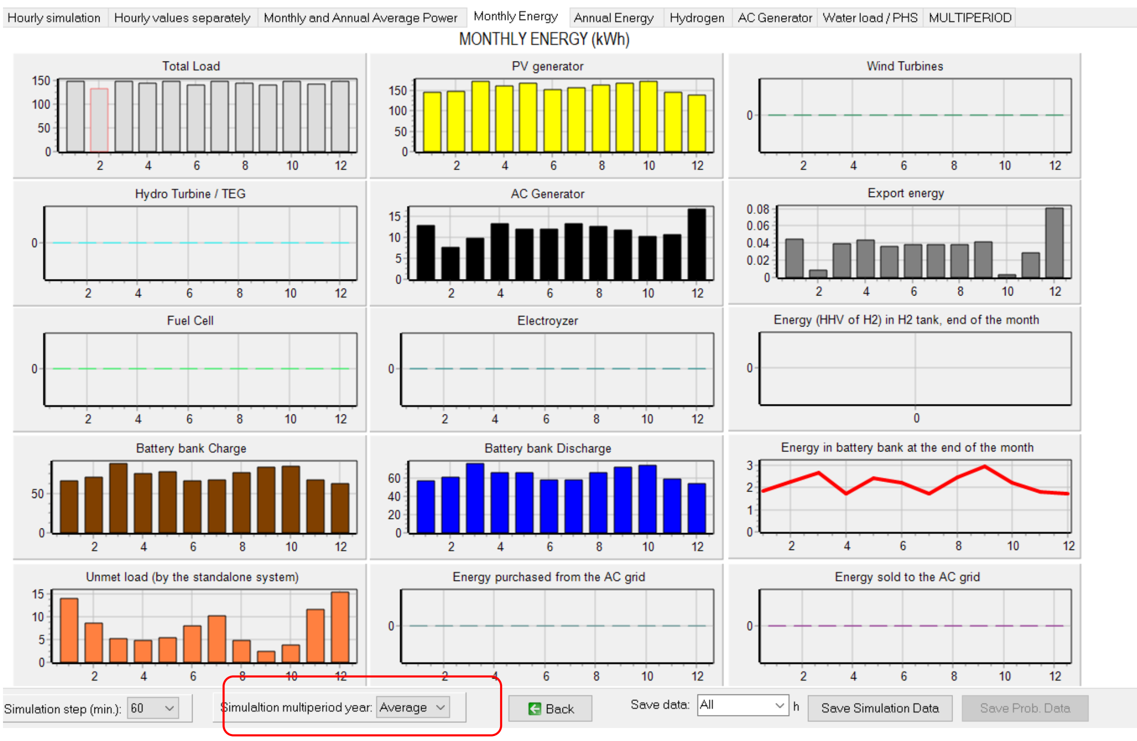
If we see the simulation, we see the average year:



We can see a lot of unmet load (in orange).

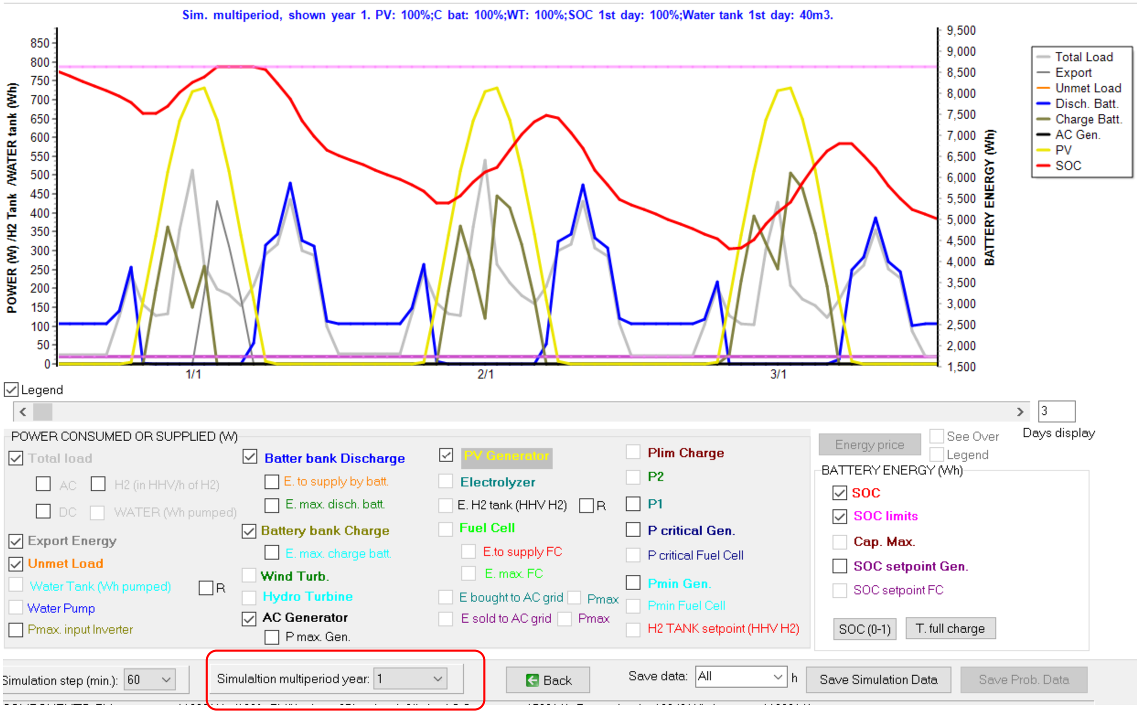
In the other tabs:

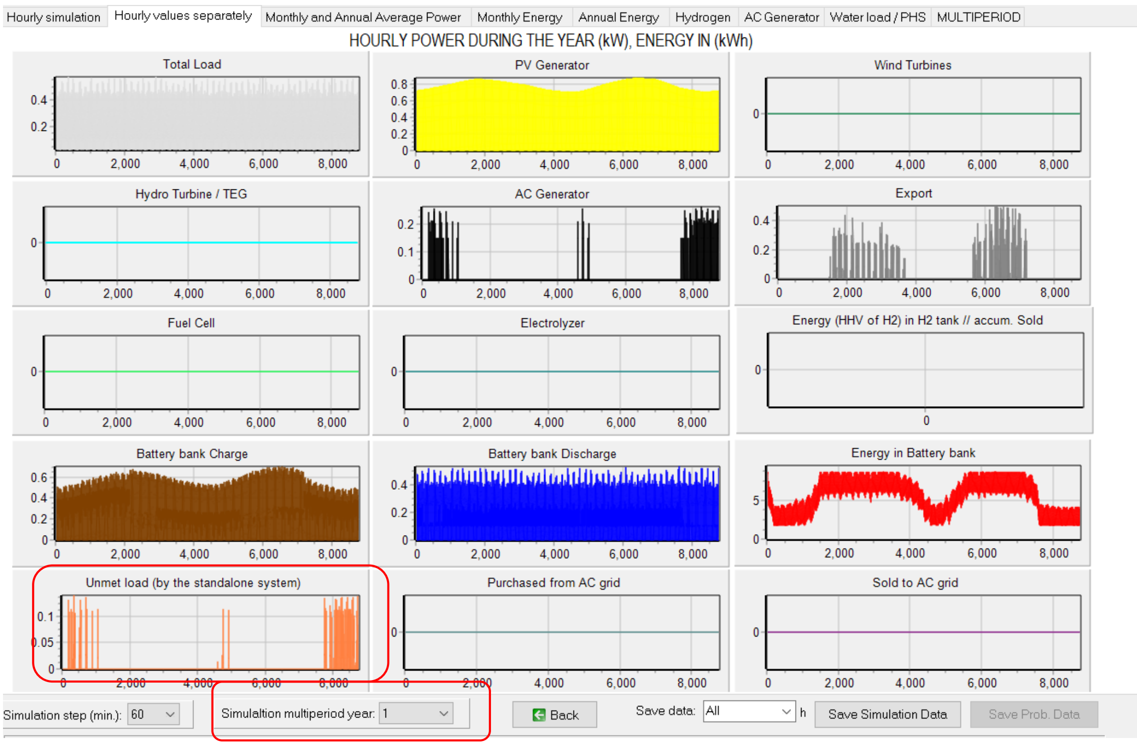




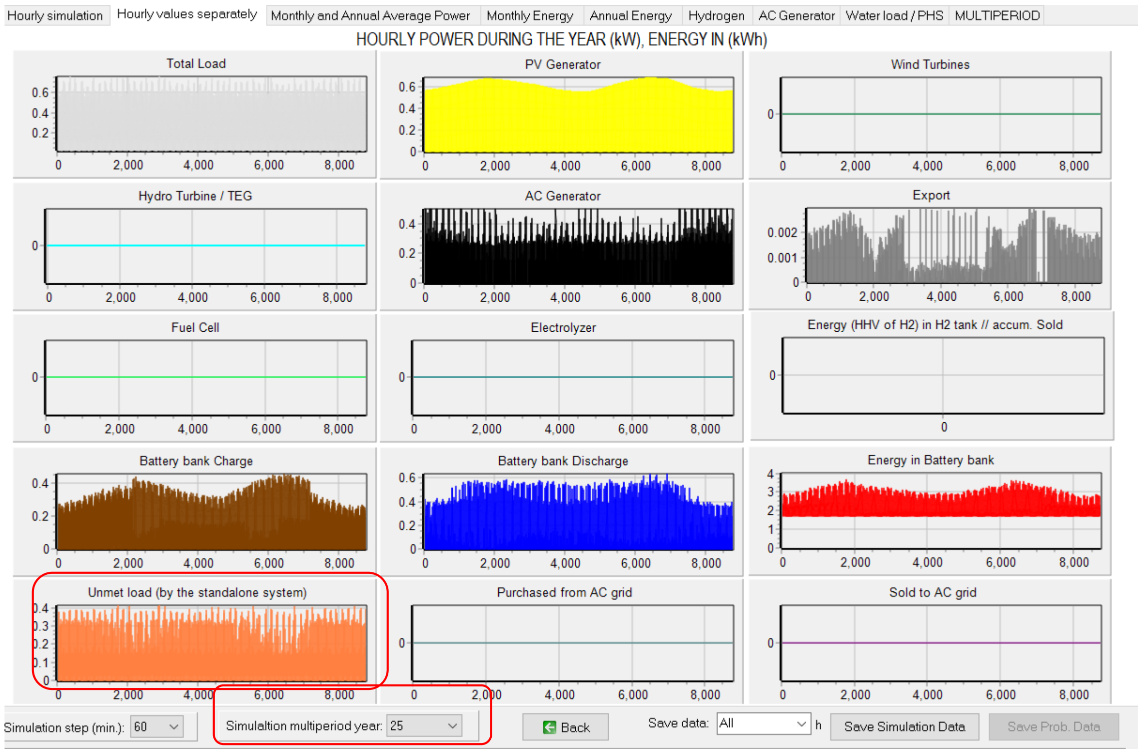
We can change the year shown:

Year 1: low unmet load

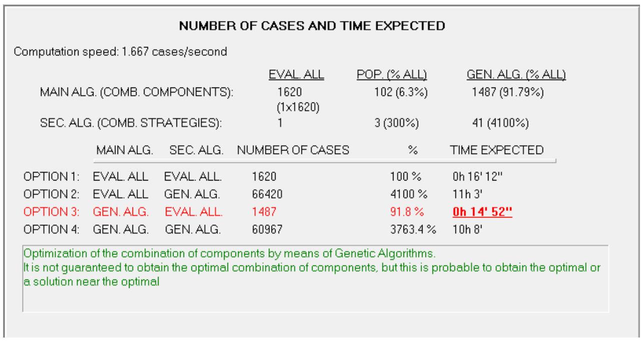




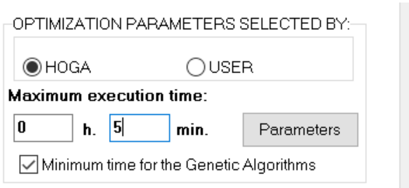
Year 25: high unmet load



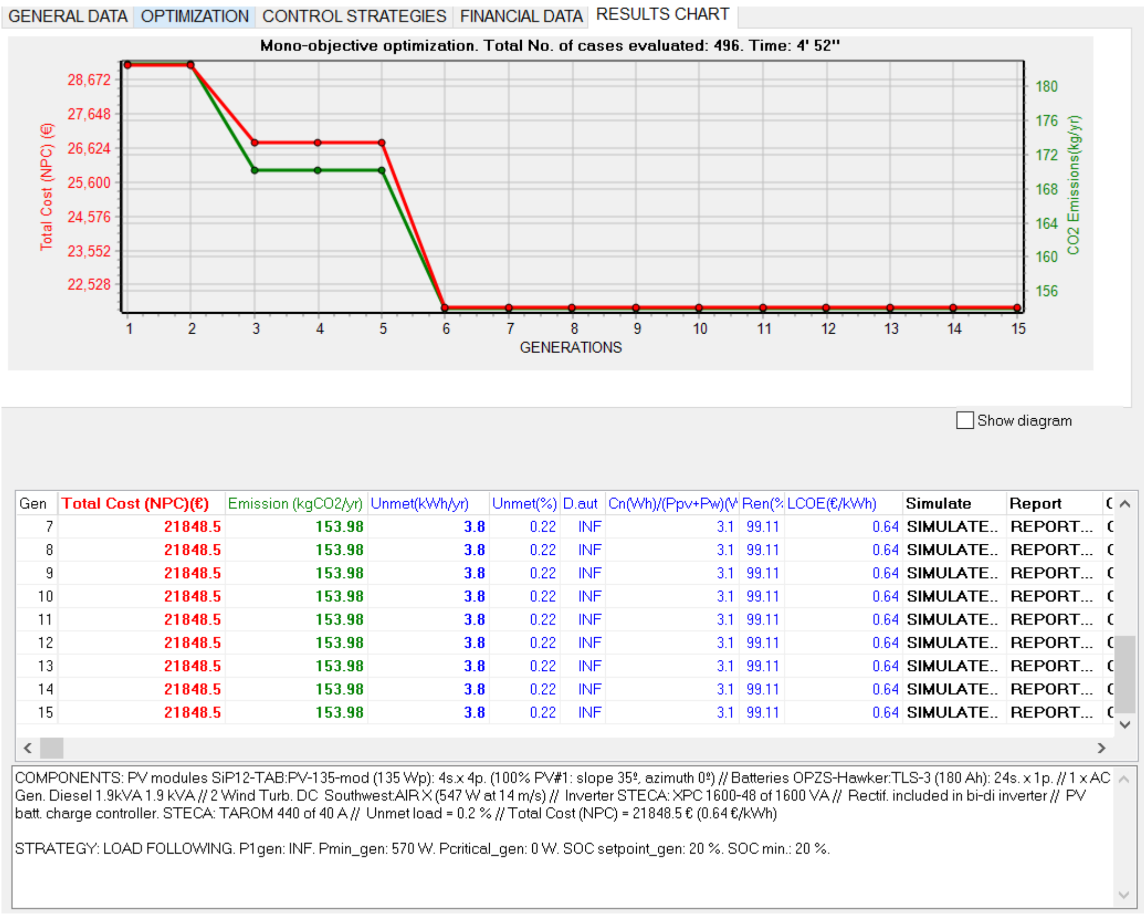
We can optimize considering the multiperiod. If we pass the mouse over the main screen, min. and max. number of components in parallel, we see the execution time. Evaluating all the combinations would need, in this computer, 16 minutes.



We change the maximum execution time to 5 minutes, therefore it will use genetic algorithms.



In the main screen, **CALCULATE**. Each combination will be simulated during the 25 years of the lifetime, considering the increase in load and the decrease in generation. After several minutes, the best solution found is the one of the last generation (already obtained in the 6th generation). It is possible that it is not the optimal solution, as genetic algorithms do not evaluate all the combinations, but it is likely that it is the optimal, or at least a solution very near to the optimal one.

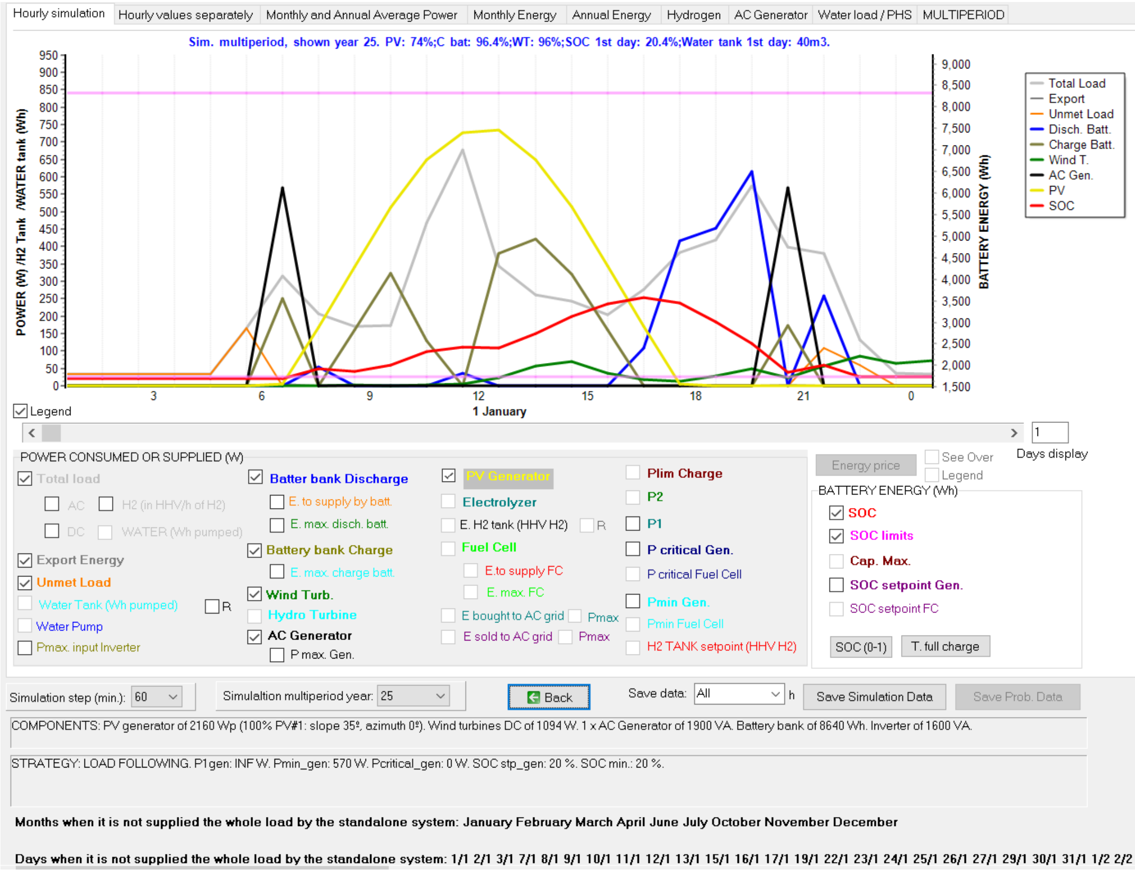


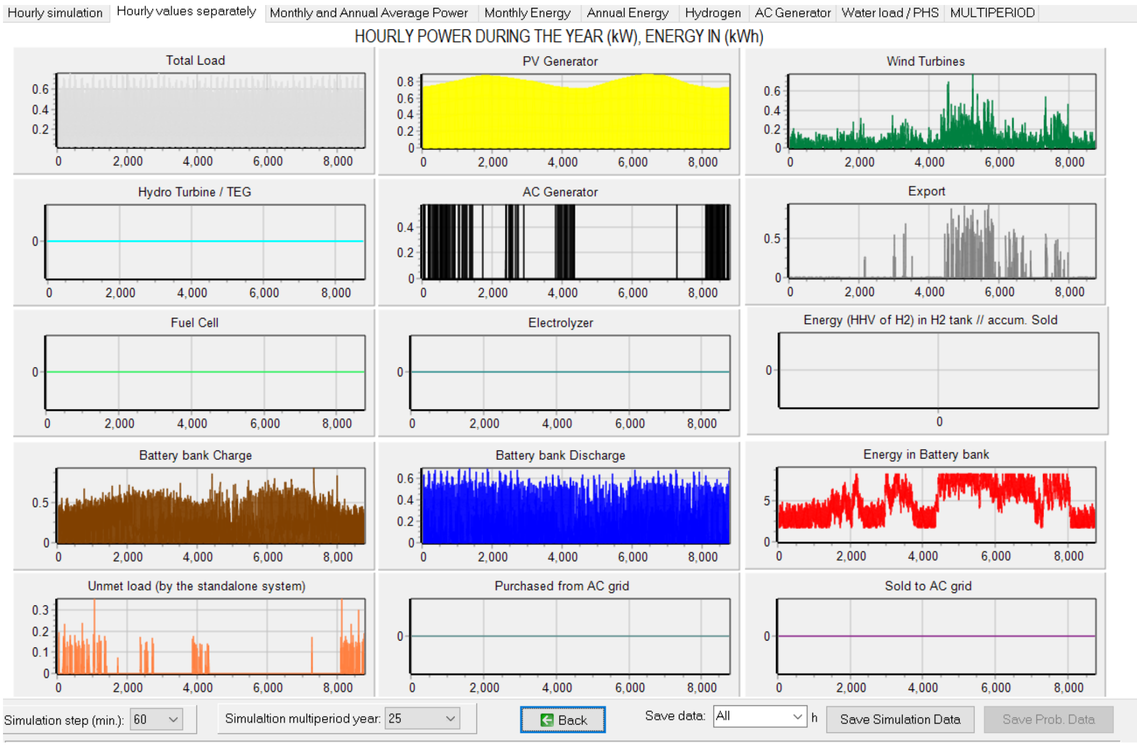
The cost of the optimal system is higher than in Pr1 project without multiperiod. The results with multiperiod are more realistic, including increase in load and variation in resources. It includes wind turbines, maybe if the maximum PV modules in parallel allowed was higher (5 or 6) there would not include wind turbine in the optimal solution.

Except for the data of the NPC, all the data of the table are referred to the average values of the years of the system lifetime, that is, annual average values.

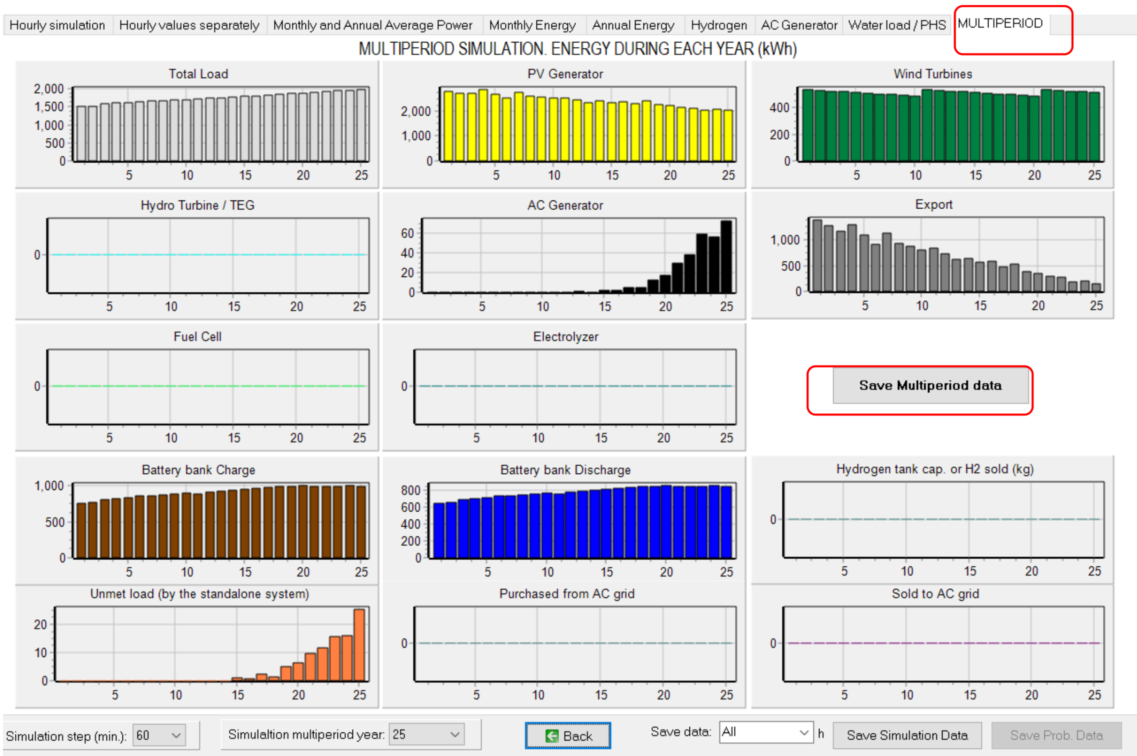
In the simulation of the optimal solution (last row of the table, SIMULATE):

We can see the simulation of the different years, for example the last year (year 25):





In the last tab (MULTIPERIOD) the annual values during the system lifetime (from year 1 to 25) are show:



We can see the increase in load during the years, the variation in the PV generation (considering the variation of irradiation and the reduction in the output power of the PV generator), the reduction of the wind turbines generation from year 1 to year 10 (the lifetime of the Air X wind turbines considered is 10 years) and its replacement in the year 11, the increase in the AC generator electricity production (first years no generation, from year 15 the generation is increasing to compensate the increase in load and the reduction in renewable sources), the reduction in the export energy (excess energy that cannot be used in the system and that could be sold to the AC grid if it was available, not in this case), the increase in the battery use (charge and discharge) and the increase of unmet load from year 16 to 25 (the average unmet load during the system lifetime is 0.22%).

In the middle right of this tab the button “**Save Multiperiod data**” can be used to save in Excel format the annual data of the input variables and of the reults. Once saved, you can open the Excel file, where the economic data are cash flow of each year (not present value), that is, money that the owner of the system will have to spend or will receive that year.

The final column (total emissions) include emissions of the backup generator (diesel or any other fuel), the emissions due to the energy bought to the AC grid, etc.; 1st year includes life cycle emissions (manufacturing, recycling, etc.) of the different components.

Project: Pr1-Multioperiod.hoga. Generation # 15

RESULTS DURING THE YEARS OF THE SYSTEM LIFETIME, MULTIPERIOD SIMULATION.

Costs and incomes are cash flow of each year (not present value)

Year	Cum. Inf. Purch. E(%)	Cum. Inf. Sell E(%)	Cum. Inf. Sell H2(%)	AC load(%)	DC load(%)	H2 load(%)	Water load(%)	Irrad.(%)
1	103	103	103	100	100	100	100	-7.99
2	106.09	106.09	106.09	101	101	101	101	-0.17
3	109.27	109.27	109.27	106.05	102.01	102.01	102.01	0.56
4	112.55	112.55	112.55	107.11	103.03	103.03	103.03	7.5
5	115.93	115.93	115.93	108.18	104.06	104.06	104.06	1.77
6	119.41	119.41	119.41	109.26	105.1	105.1	105.1	-3
7	122.99	122.99	122.99	110.36	106.15	106.15	106.15	7.35
8	126.68	126.68	126.68	111.46	107.21	107.21	107.21	1.75
9	130.48	130.48	130.48	112.57	108.29	108.29	108.29	1.8
10	134.39	134.39	134.39	113.7	109.37	109.37	109.37	0.58
11	138.42	138.42	138.42	114.84	110.46	110.46	110.46	1.93
12	142.58	142.58	142.58	115.99	111.57	111.57	111.57	-0.26
13	146.85	146.85	146.85	117.15	112.68	112.68	112.68	-2.59
14	151.26	151.26	151.26	118.32	113.81	113.81	113.81	0.8
15	155.8	155.8	155.8	119.5	114.95	114.95	114.95	-0.79
16	160.47	160.47	160.47	120.69	116.1	116.1	116.1	2.42
17	165.28	165.28	165.28	121.9	117.26	117.26	117.26	-0.06
18	170.24	170.24	170.24	123.12	118.43	118.43	118.43	5.35
19	175.35	175.35	175.35	124.35	119.61	119.61	119.61	0.11
20	180.61	180.61	180.61	125.6	120.81	120.81	120.81	0.53
21	186.03	186.03	186.03	126.85	122.02	122.02	122.02	-2.36
22	191.61	191.61	191.61	128.12	123.24	123.24	123.24	-1.94

multip

In the bottom of the simulation screen we see the months and days when there is unmet load. In the case of the multiobjective simulation, it refers to the last year.

Months when it is not supplied the whole load by the standalone system: January February March April June July October November December

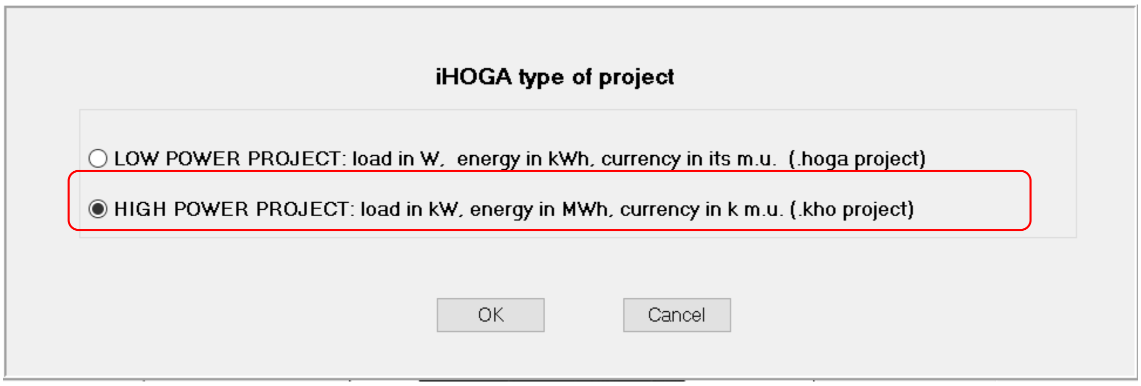
Days when it is not supplied the whole load by the standalone system: 1/1 2/1 3/1 7/1 8/1 9/1 10/1 11/1 12/1 13/1 15/1 16/1 17/1 19/1 22/1 23/1 24/1 25/1 26/1 27/1 29/1 30/1 31/1 1/2 2/2

44. High power project, maximization of NPV.

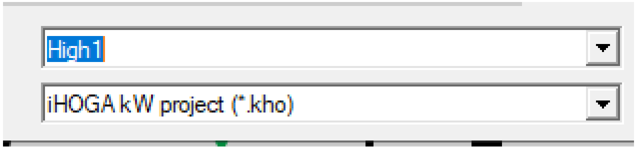
Now we will create a high power project where there will be a generator and we want to maximize the net present value (NPV).

As now we will create a high power project, we must close the software and open it again. **Project->New.**

Choose **HIGHER POWER PROJECT: load in KW….**

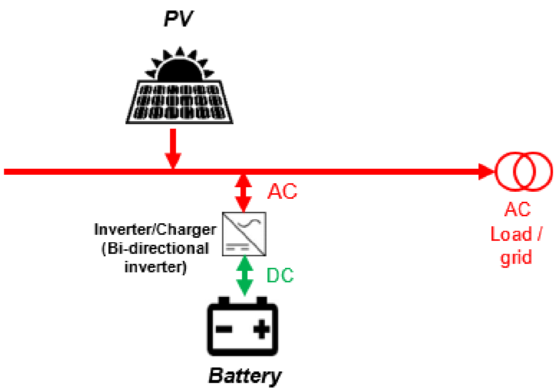


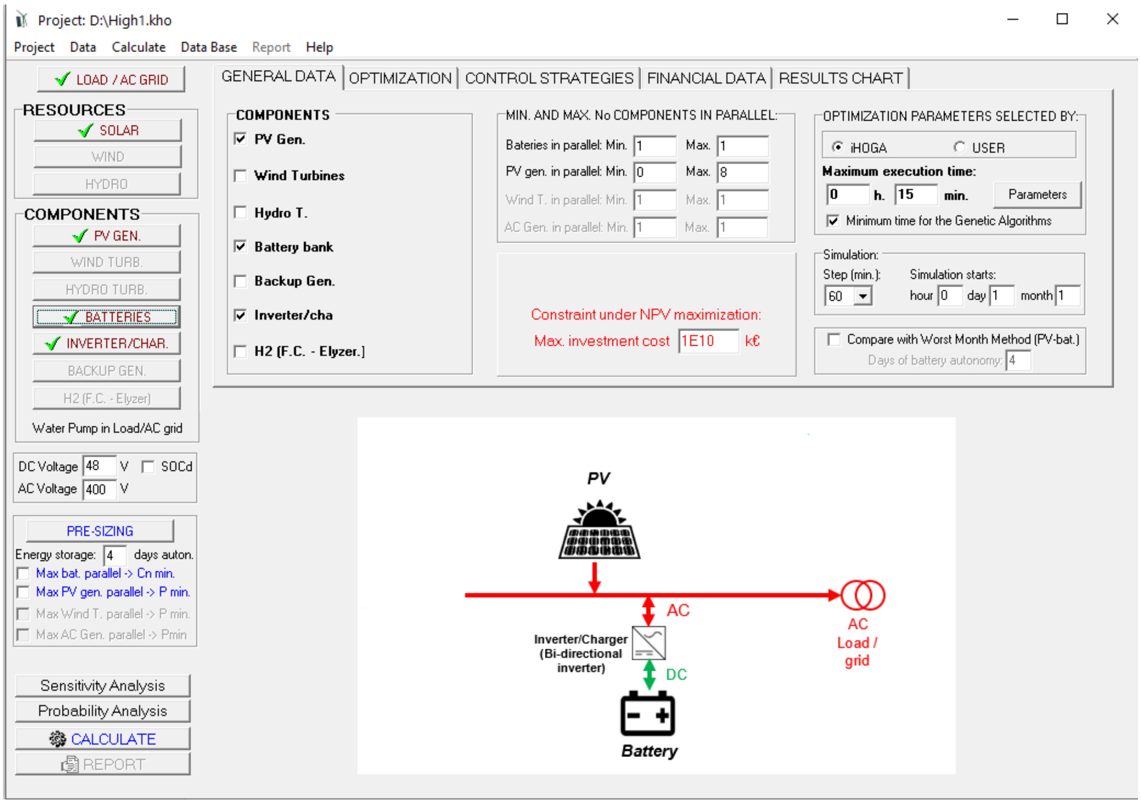
In the “creating new project” dialog, give the name High1, and the extension is .kho so the project will be **High1.kho**.



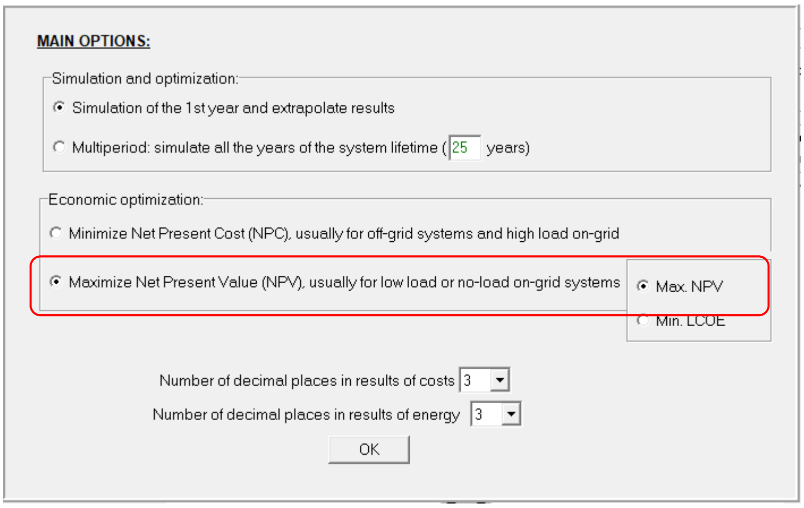
The file High1.kho will be created in the folder selected, and a folder with the same name (High1) will also be created. If, later, you want to move your project to another folder or share it with another person, you must move / share the .kho file and also the folder with the same name (in this case, you must move / share High1.kho file and High1 folder).

By default, a grid-connected PV-battery system is preset, without any load (zero load consumption).

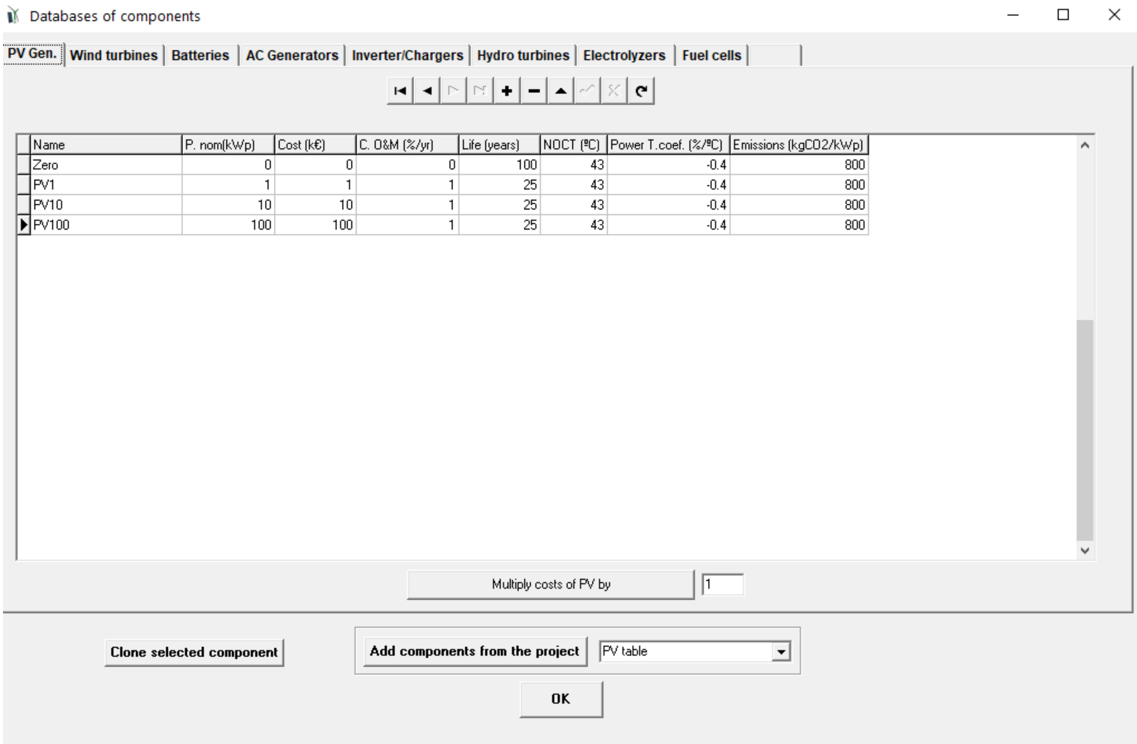




If we click the upper menu **Project->Options**, we see the type of project is to maximize net present value (no load, generator connected to the grid). We can choose between maximizing NPV or minimizing LCOE, we leave the default one (Max. NPV).



In the main screen, we can see the database (menu **Database**):

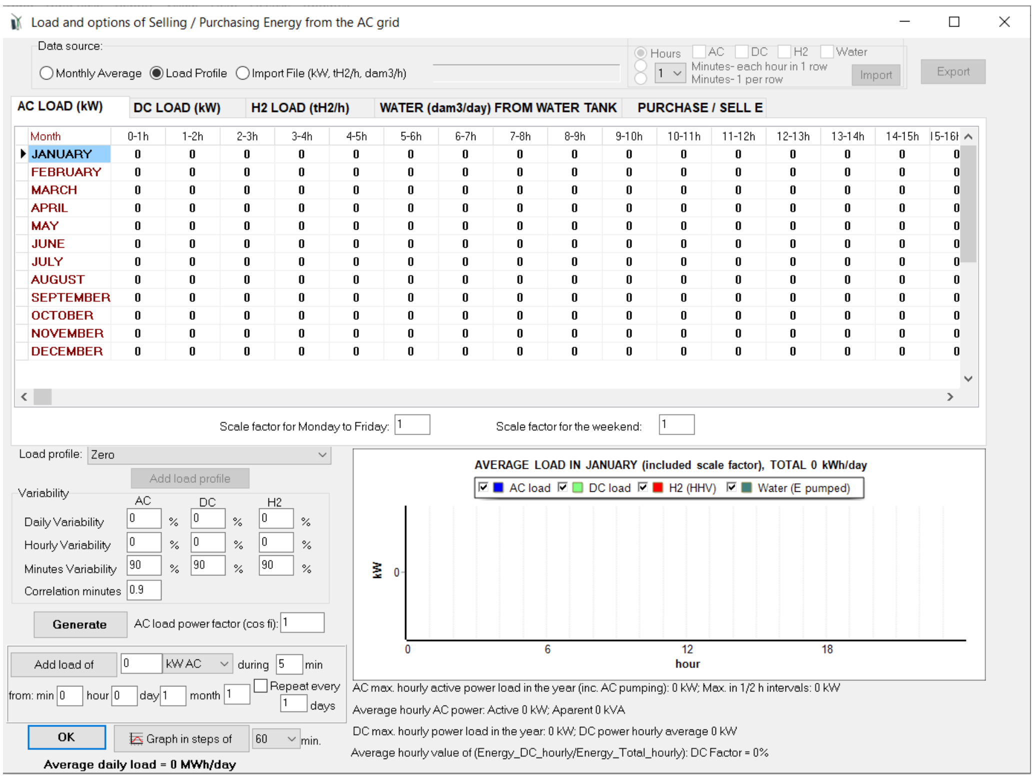


In high power projects, power is in kW and costs in k€. Some data are missing as they are not used in high power projects. Instead of PV modules, we use PV generators. O&M of PV generators, wind turbines, batteries, hydro turbines are in % of the cost. The battery charge controllers are missing, as they are included in the inverter-chargers.

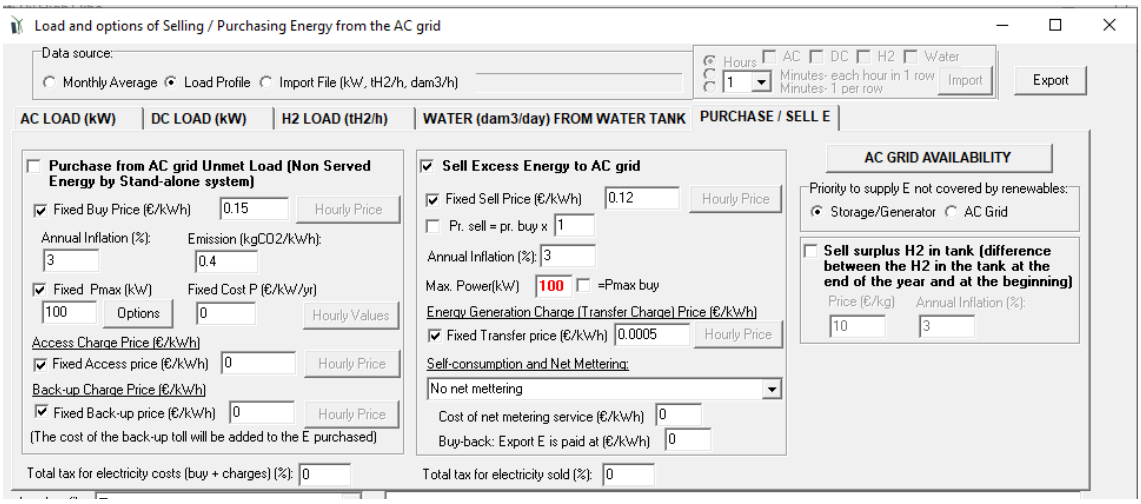
By default, everything is AC coupled.

We will use the default irradiation data.

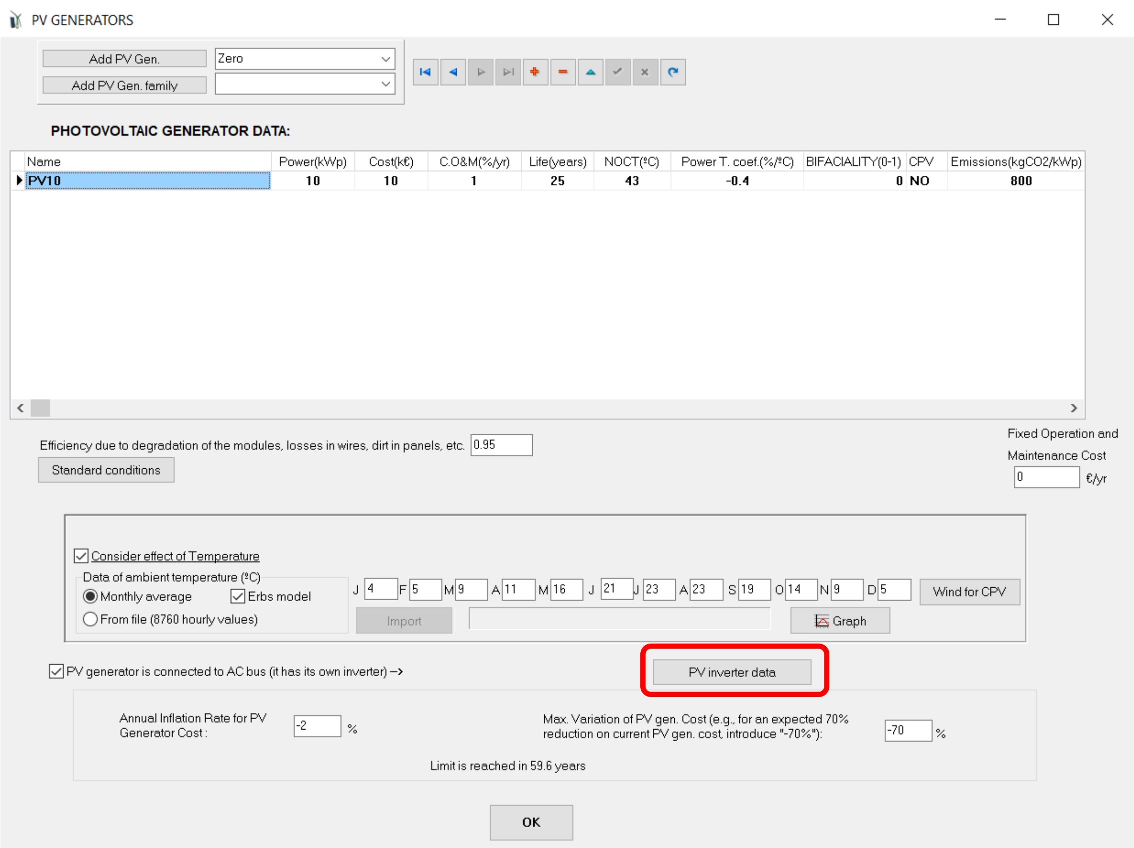
We can see the load is 0 (LOAD / AC GRID button):



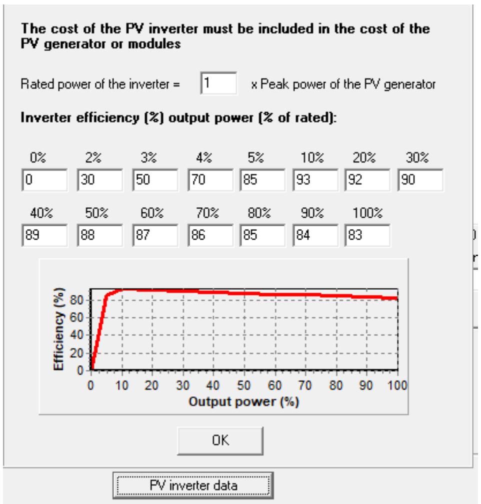
And, in the PURCHASE / SELL E tab, we see the electricity is bought at 0.15 €/kWh (but it is not used, as there is no load and it is not allowed to purchase from AC grid) and sold at 0.12 €/kWh, and the limit power from / to the grid is 100 kW. We don't change any data.



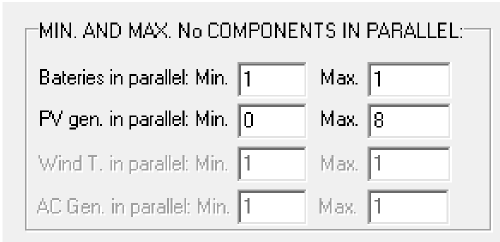
We can see the default PV generator is of 10 kW:



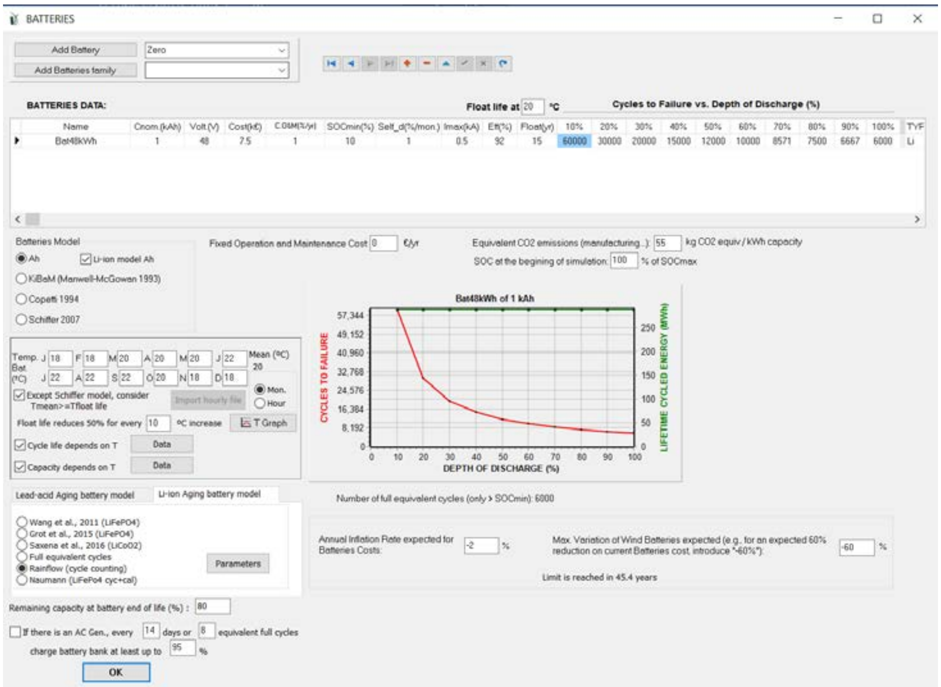
The PV generator is connected to the AC grid, and it has its own inverter, which cost is included in the cost of the PV generator. If we click in "**PV inverter data**" button:



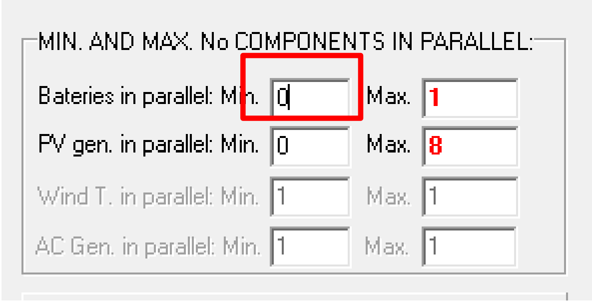
We accept and return to the main screen of the software. By default, there can be from 0 to 8 PV generators in parallel:



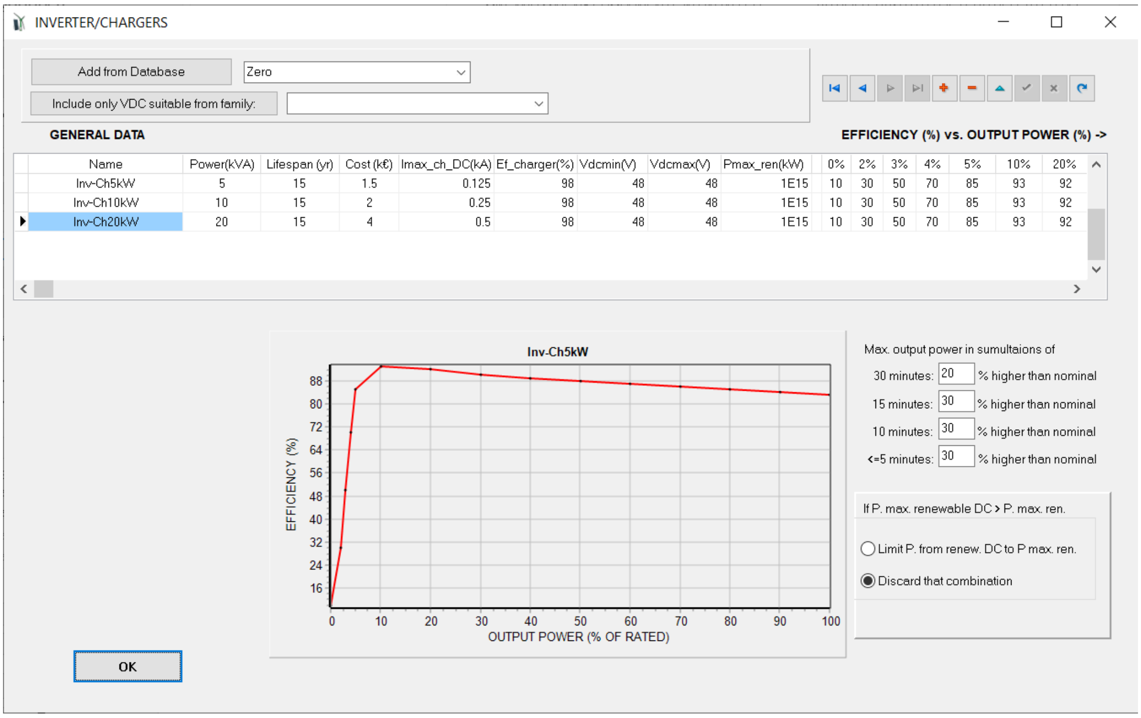
The default battery bank is of 48 kWh, li-ion:



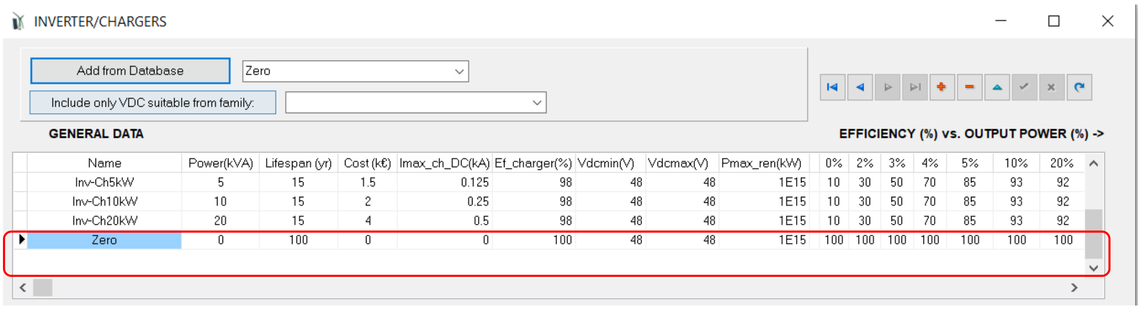
We want the possibility of not having battery in the system, changing its minimum to 0 in the main screen:



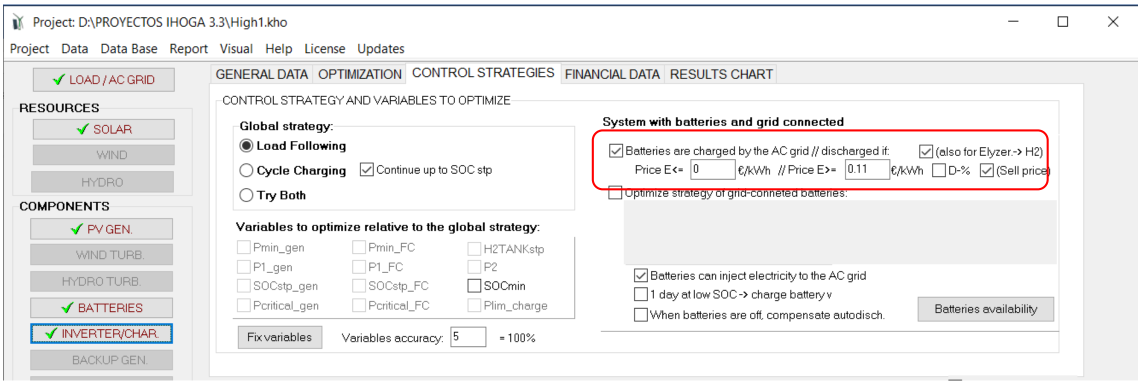
And the default inverter-chargers are of 5, 10 and 20 kW:



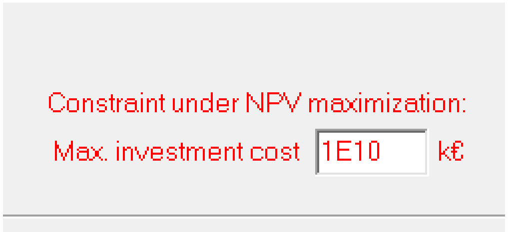
We add the inverter Zero to consider the possibility of not having inverter-charger:



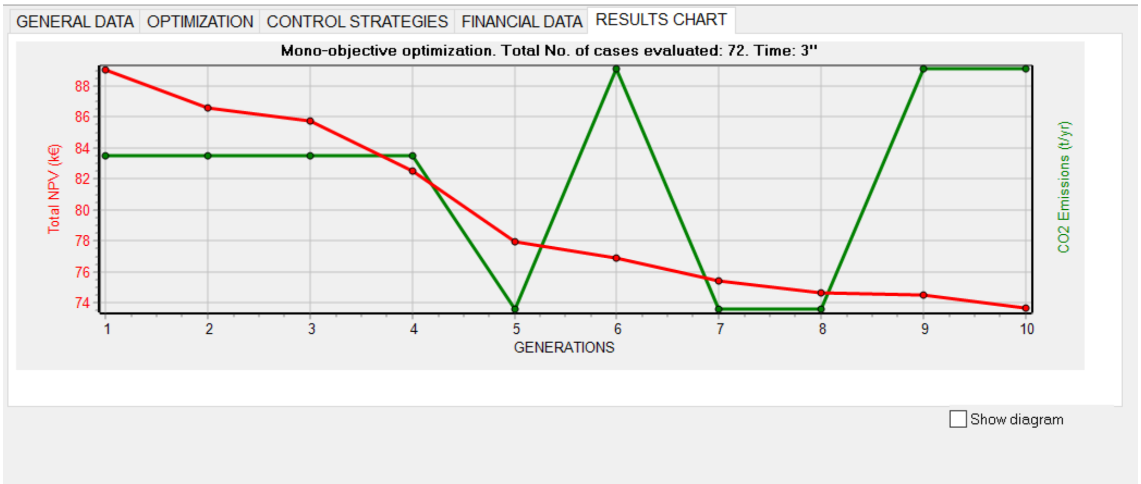
Also, by default, in the main screen, CONTROL STRATEGIES tab, we can see the grid-connected batteries never charge from the grid (price E < 0 €/kWh) and they discharge, injecting electricity to the grid, when the electricity price (of the energy sold to the AC grid, because “(Sell price)” is checked) is higher than 0.11 €/kWh, that is, always (sell electricity price was defined as a fixed value of 0.12 €/kWh). Therefore, the batteries will be charged with the power from the PV that cannot be injected to the grid, if it is higher than 100 kW (the maximum power allowed to inject to the grid), and the batteries will inject their energy to the grid at the following time step.



In the main screen we can see the only constraint to be considered in the type of projects of maximizing NPV: the maximum investment cost, in this case 1E10 k€, that is this constraint by default is not considered:



If we optimize we obtain:



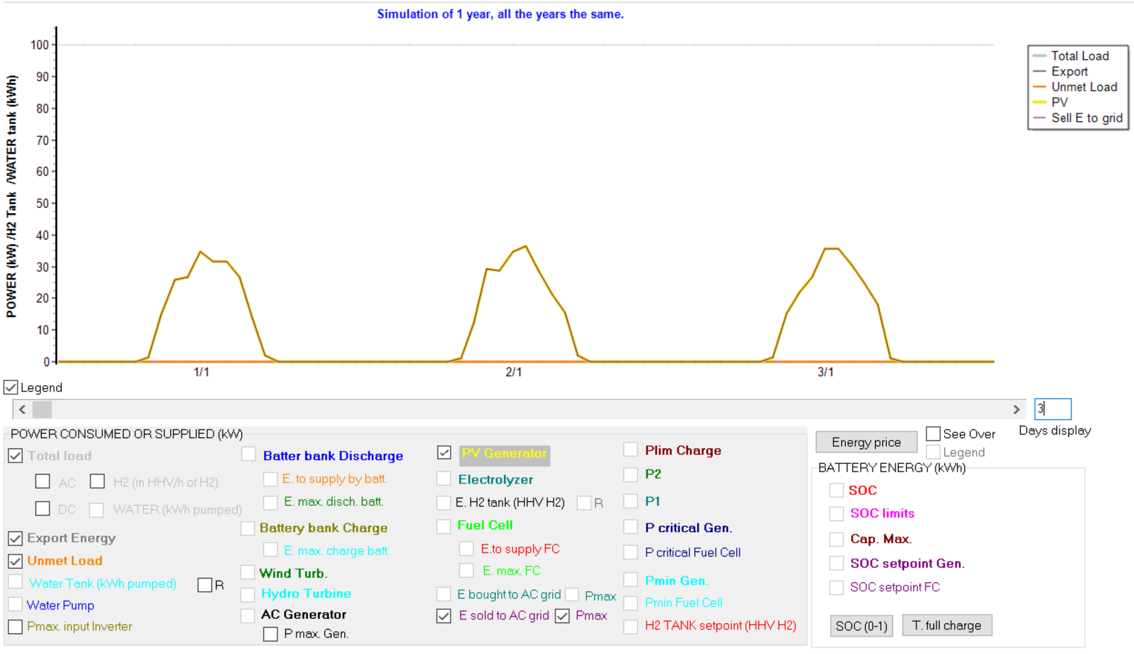
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	89.027	2.56	0	14.4	100	15.13	0.0738	SIMULATE..	REPORT...	COST
2	86.571	2.56	0	14.1	101.875	15.13	0.0754	SIMULATE..	REPORT...	COST
3	85.753	2.56	0	14.01	102.5	15.13	0.076	SIMULATE..	REPORT...	COST
4	82.479	2.56	0	13.63	105	15.13	0.0781	SIMULATE..	REPORT...	COST
5	77.899	2.24	0	14.4	87.5	15.13	0.0738	SIMULATE..	REPORT...	COST
6	76.855	2.74	0	13	109.375	15.13	0.0819	SIMULATE..	REPORT...	COST
7	75.443	2.24	0	14.06	89.375	15.13	0.0757	SIMULATE..	REPORT...	COST
8	74.625	2.24	0	13.95	90	15.13	0.0763	SIMULATE..	REPORT...	COST
9	74.464	2.74	0	12.74	111.25	15.14	0.0835	SIMULATE..	REPORT...	COST

COMPONENTS: PV gen: PV10 (10 kWp)x 8 (100% PV#1: slope 60º, azimuth 0º) // Unmet load = 0 % // Total Net Present Value (NPV) = 89.027 k€, IRR = 14.4%.

STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

The optimal result is a generator of 80 kWp, without batteries and without inverter-charger, with NPV 89.027 k€, investment of 100 k€ and internal rate of return (IRR) 14.4%.

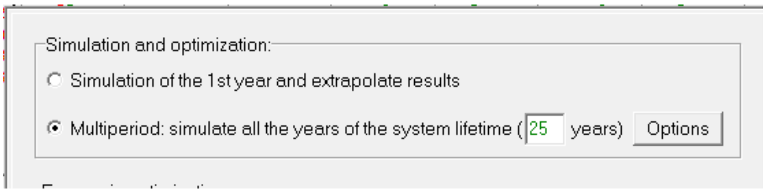
The simulation of the optimal result:



45. High power project, maximization of NPV, multiperiod.

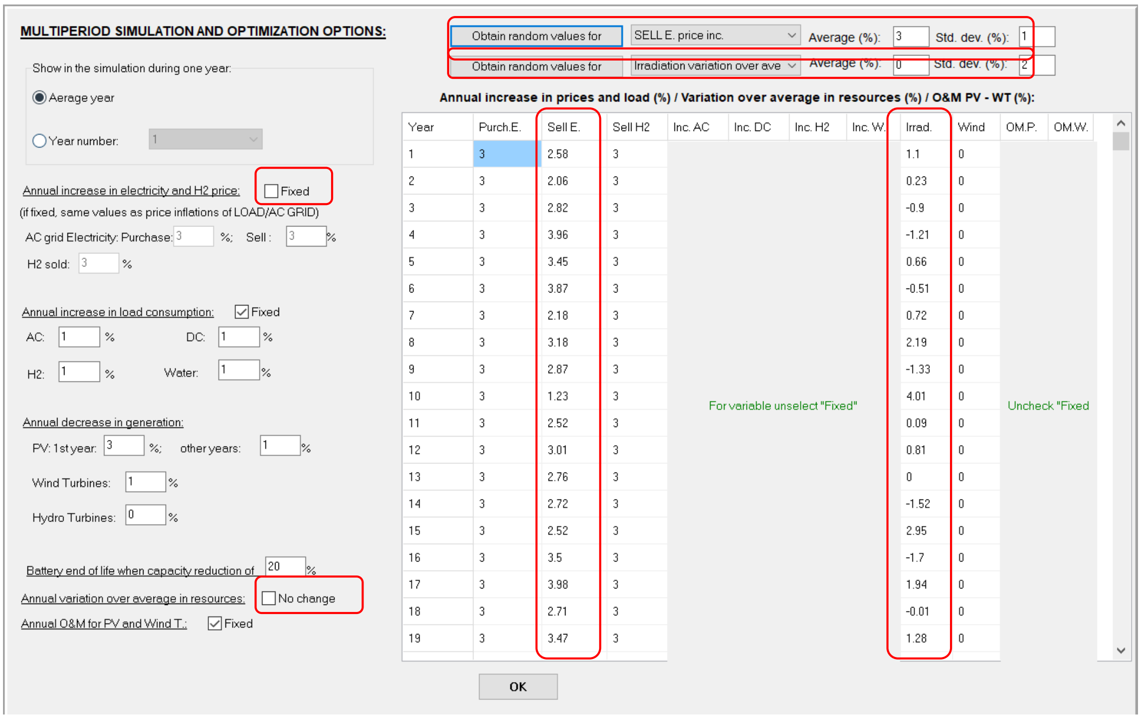
Save the project and save as with the name “High1-multi”.

Project-> Options, change to Multiperiod optimization:



Click Options and:

- Uncheck “Fixed” of the Annual increase in electricity and H2 price.
- Select “SELL E. price inc.”, average 3% and std. dev. 1% in the upper right box, and click in its button “Obtain random values for”, obtaining a variable inflation for each year for the electricity sell price, with average 3% and std. dev. 1%.
- Uncheck “No change” of the Annual variation over average in resources.
- Select “Irradiation variation over average”, average 0% and std. dev. 2% in the second upper right box, and click in its button “Obtain random values for”, obtaining a variable variation for each year for the irradiation, with average 0% and std. dev. 2%.

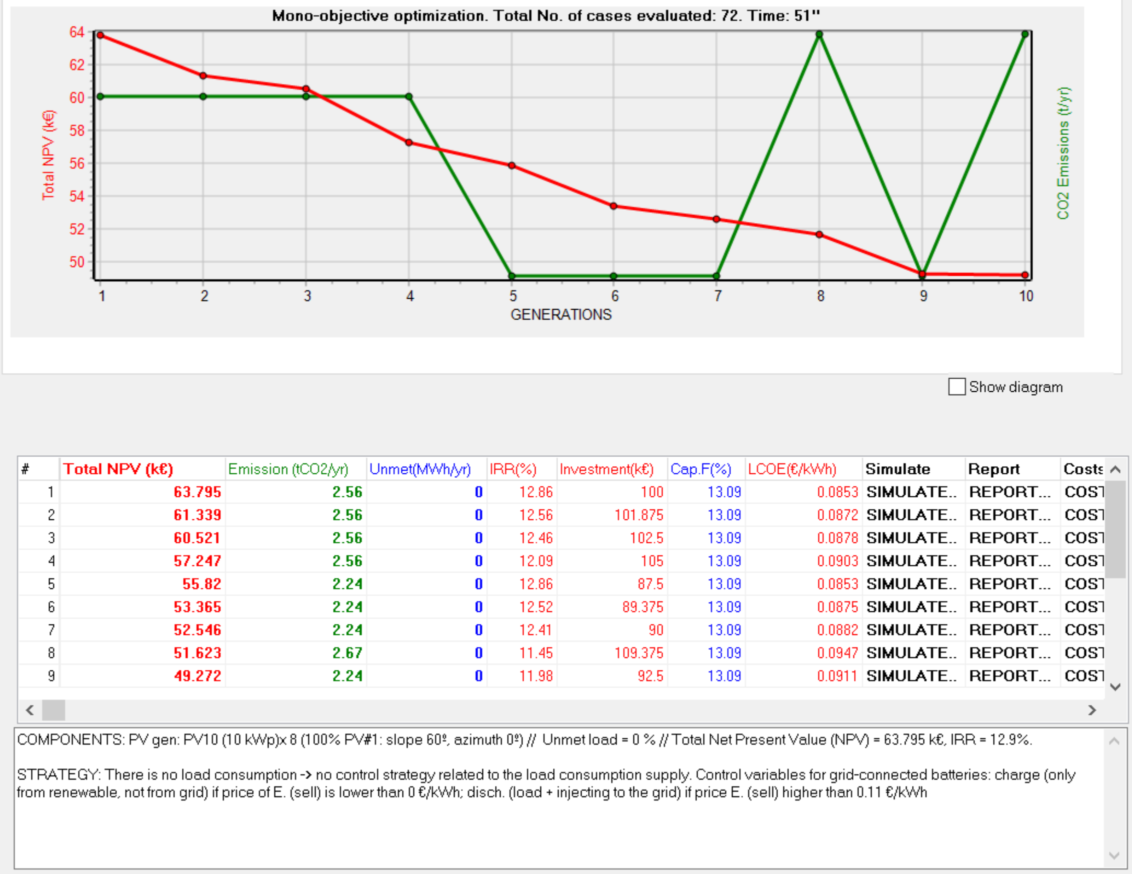


Note that the values obtained randomly of your project will be different from the ones of the figure, due to the randomness.

Then click in the first row of the results (the optimal solution), with multiperiod we can see it changes to a much lower NPV (in your project it will be different as random values will be different).

Therefore, we can see multiperiod affects much in this case.

We optimize again, considering mutiperiod:



#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	63.795	2.56	0	12.86	100	13.09	0.0853	SIMULATE..	REPORT...	COST
2	61.339	2.56	0	12.56	101.875	13.09	0.0872	SIMULATE..	REPORT...	COST
3	60.521	2.56	0	12.46	102.5	13.09	0.0878	SIMULATE..	REPORT...	COST
4	57.247	2.56	0	12.09	105	13.09	0.0903	SIMULATE..	REPORT...	COST
5	55.82	2.24	0	12.86	87.5	13.09	0.0853	SIMULATE..	REPORT...	COST
6	53.365	2.24	0	12.52	89.375	13.09	0.0875	SIMULATE..	REPORT...	COST
7	52.546	2.24	0	12.41	90	13.09	0.0882	SIMULATE..	REPORT...	COST
8	51.623	2.67	0	11.45	109.375	13.09	0.0947	SIMULATE..	REPORT...	COST
9	49.272	2.24	0	11.98	92.5	13.09	0.0911	SIMULATE..	REPORT...	COST

COMPONENTS: PV gen: PV10 (10 kWp)x 8 (100% PV#1: slope 60º, azimuth 0º) // Unmet load = 0 % // Total Net Present Value (NPV) = 63.795 k€, IRR = 12.9%.

STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

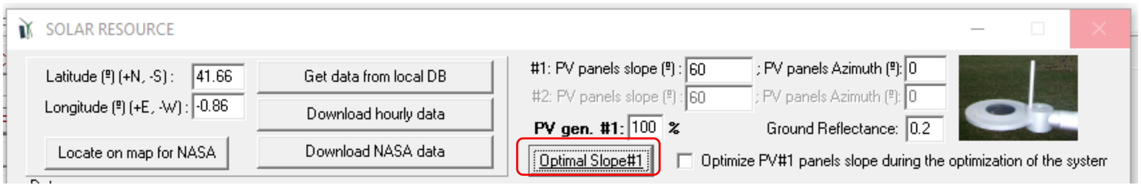
The optimal system is the same as without multiperiod, but with much lower NPC.

46. Variant: change PV slope and maximum power to be injected to the AC grid.

Save the project and save as with the name "High1-multi-2".

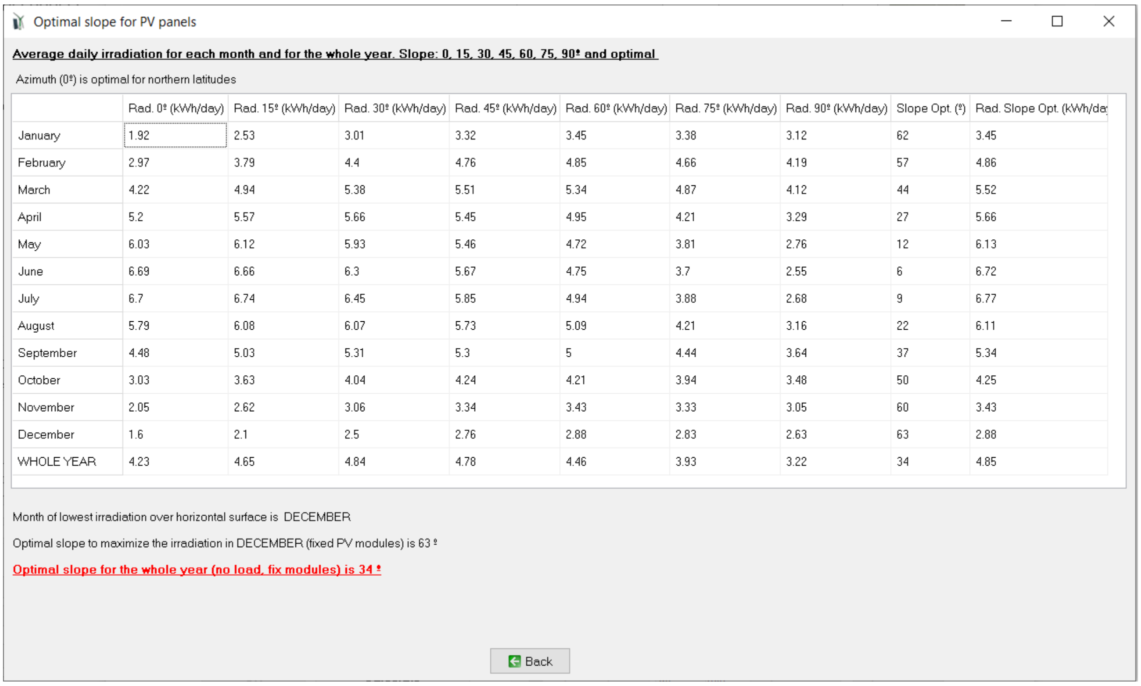
Now we can reconsider several aspects:

1) Is the PV slope optimal for grid-connected systems, that is, optimal for maximizing the energy injected to the AC grid?
   Go to the irradiation screen and optimize the slope:



   After some seconds, we obtain the following screen, where it is shown that for this location the optimal slope for grid-connected systems is 34º.

   On some occasions, the progress bar stops and it seems that the program does not respond, be patient and wait until the screen shown below appears. If the following screen does not appear, but the main screen of the program appears, click on the iHOGA icon in the Windows taskbar (lower part of the computer screen) and the screen shown below will appear


Optimal slope for PV panels

Average daily irradiation for each month and for the whole year. Slope: 0, 15, 30, 45, 60, 75, 90º and optimal

Azimuth (0º) is optimal for northern latitudes

	Rad. 0º (kWh/day)	Rad. 15º (kWh/day)	Rad. 30º (kWh/day)	Rad. 45º (kWh/day)	Rad. 60º (kWh/day)	Rad. 75º (kWh/day)	Rad. 90º (kWh/day)	Slope Opt. (º)	Rad. Slope Opt. (kWh/da
January	1.92	2.53	3.01	3.32	3.45	3.38	3.12	62	3.45
February	2.97	3.79	4.4	4.76	4.85	4.66	4.19	57	4.86
March	4.22	4.94	5.38	5.51	5.34	4.87	4.12	44	5.52
April	5.2	5.57	5.66	5.45	4.95	4.21	3.29	27	5.66
May	6.03	6.12	5.93	5.46	4.72	3.81	2.76	12	6.13
June	6.69	6.66	6.3	5.67	4.75	3.7	2.55	6	6.72
July	6.7	6.74	6.45	5.85	4.94	3.88	2.68	9	6.77
August	5.79	6.08	6.07	5.73	5.09	4.21	3.16	22	6.11
September	4.48	5.03	5.31	5.3	5	4.44	3.64	37	5.34
October	3.03	3.63	4.04	4.24	4.21	3.94	3.48	50	4.25
November	2.05	2.62	3.06	3.34	3.43	3.33	3.05	60	3.43
December	1.6	2.1	2.5	2.76	2.88	2.83	2.63	63	2.88
WHOLE YEAR	4.23	4.65	4.84	4.78	4.46	3.93	3.22	34	4.85

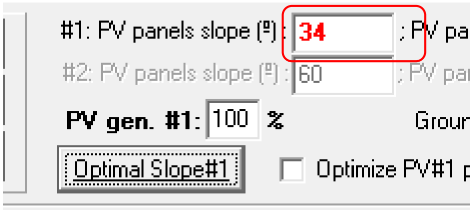
Month of lowest irradiation over horizontal surface is DECEMBER

Optimal slope to maximize the irradiation in DECEMBER (fixed PV modules) is 63 º

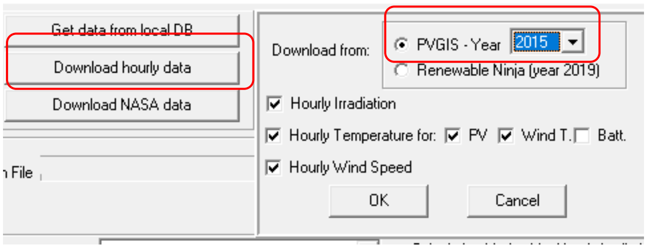
Optimal slope for the whole year (no load, fix modules) is 34 º

Back

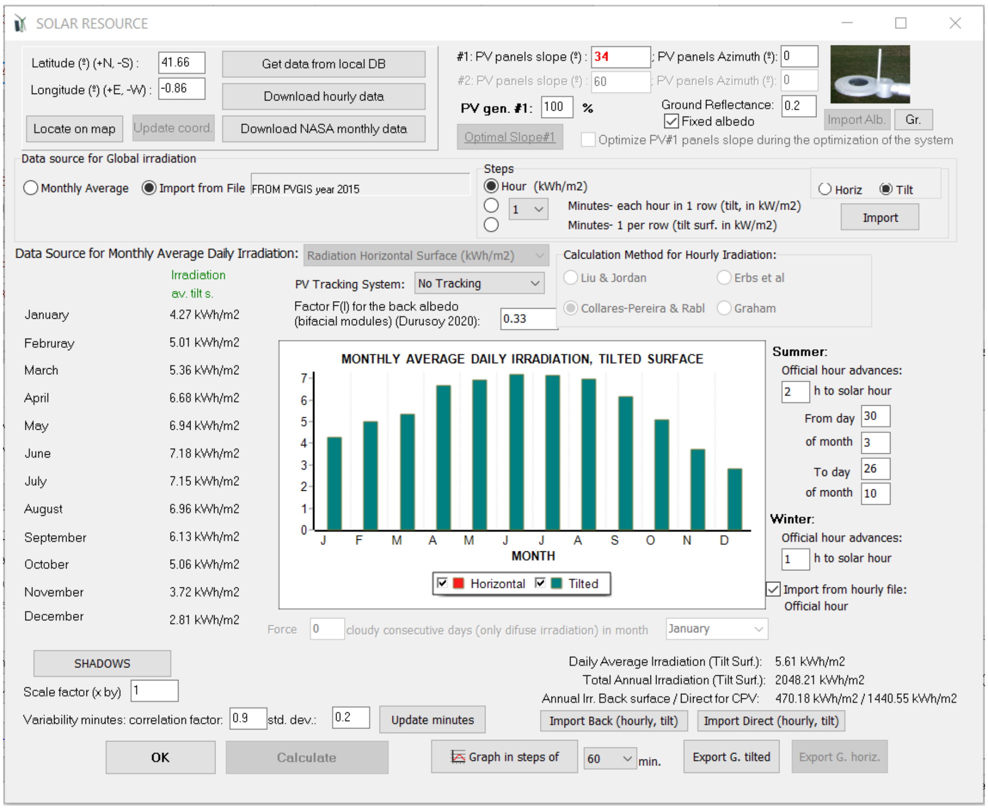
This optimal slope is updated automatically in the irradiation screen.



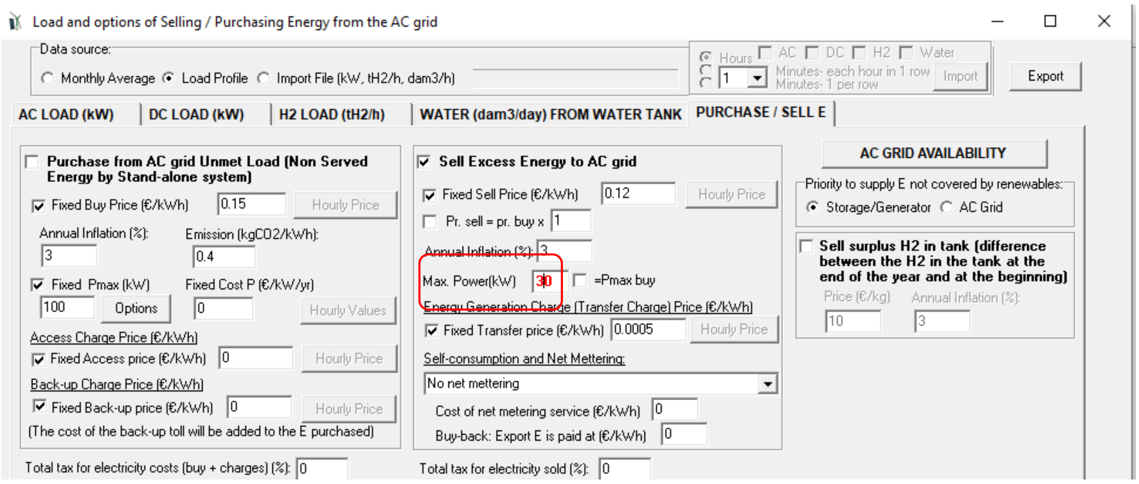
We download hourly data from PVGIS, year 2015:



Obtaining:

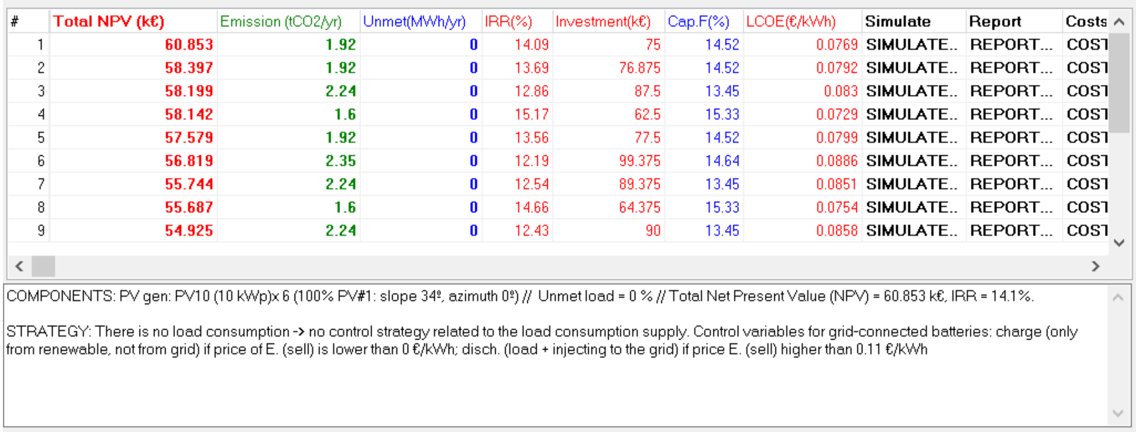


2) Let's suppose that the maximum power that can be injected to the AC grid is 30 kW: Go to LOAD / AC GRID, tab PURCHASE / SELL E., change the Max. Power for the sell excess energy to AC grid to 30 kW:



Now we optimize again:

The optimal system is a PV generator of 60 kW, without storage:



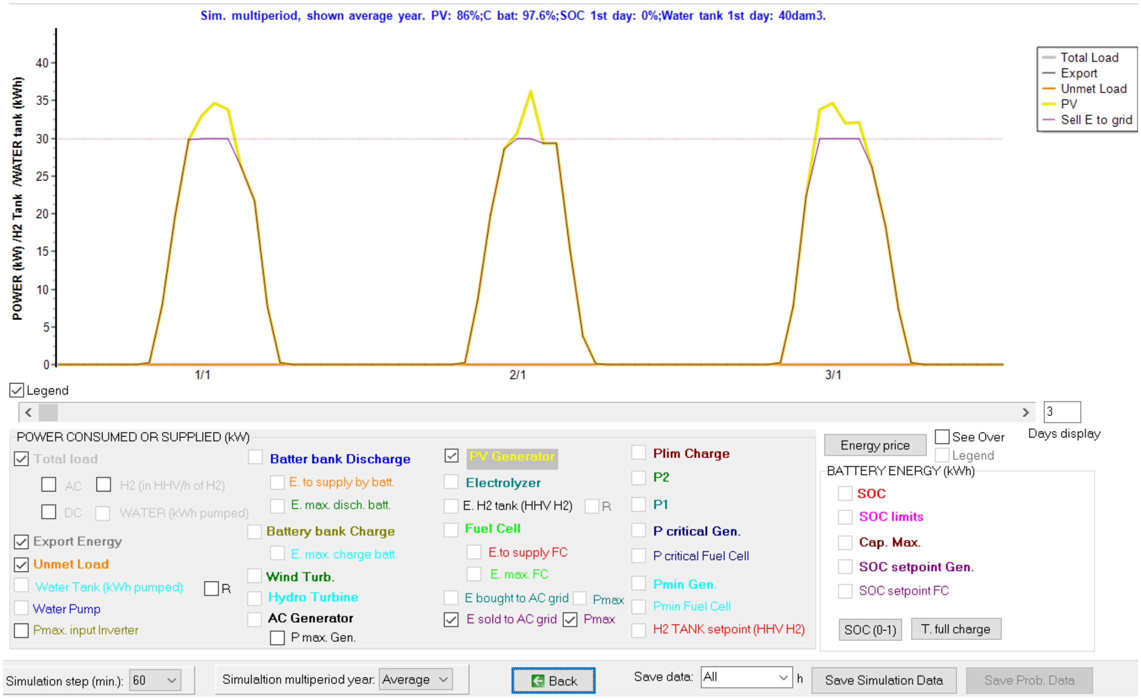
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	60.853	1.92	0	14.09	75	14.52	0.0769	SIMULATE..	REPORT...	COST
2	58.397	1.92	0	13.69	76.875	14.52	0.0792	SIMULATE..	REPORT...	COST
3	58.199	2.24	0	12.86	87.5	13.45	0.083	SIMULATE..	REPORT...	COST
4	58.142	1.6	0	15.17	62.5	15.33	0.0729	SIMULATE..	REPORT...	COST
5	57.579	1.92	0	13.56	77.5	14.52	0.0799	SIMULATE..	REPORT...	COST
6	56.819	2.35	0	12.19	99.375	14.64	0.0886	SIMULATE..	REPORT...	COST
7	55.744	2.24	0	12.54	89.375	13.45	0.0851	SIMULATE..	REPORT...	COST
8	55.687	1.6	0	14.66	64.375	15.33	0.0754	SIMULATE..	REPORT...	COST
9	54.925	2.24	0	12.43	90	13.45	0.0858	SIMULATE..	REPORT...	COST

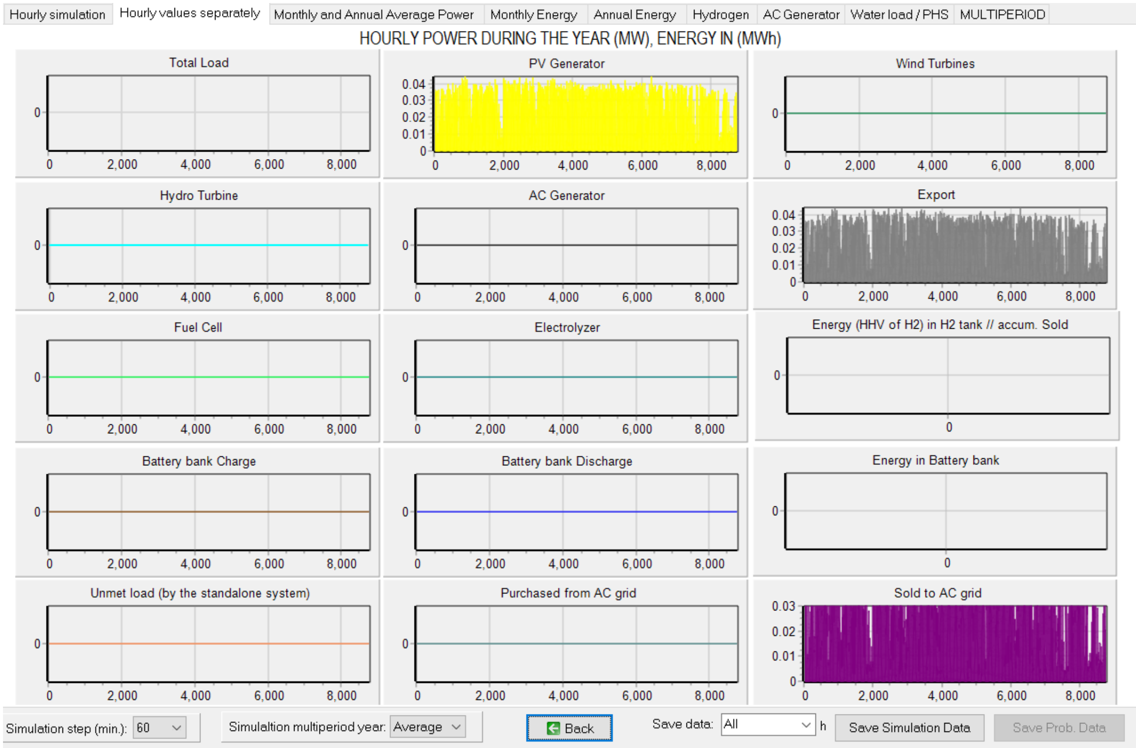
COMPONENTS: PV gen: PV10 (10 kWp)x 6 (100% PV#1: slope 34º, azimuth 0º) // Unmet load = 0 % // Total Net Present Value (NPV) = 60.853 k€, IRR = 14.1%.

STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

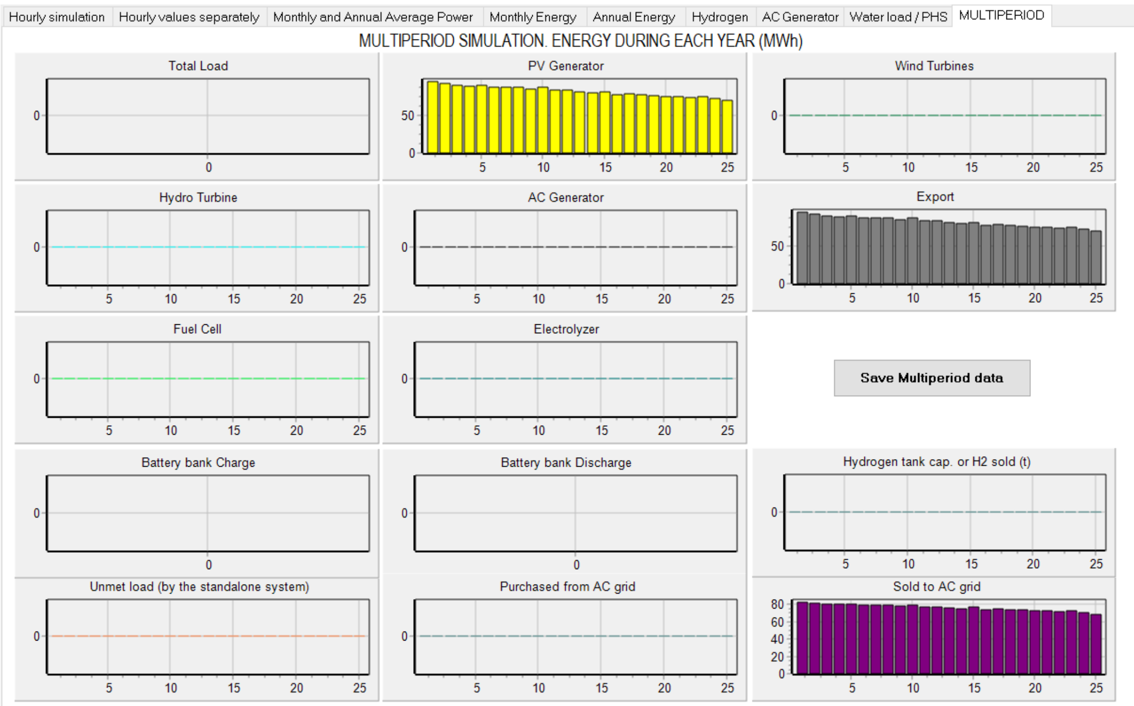
Remember, the values obtained randomly of your project will be different from the ones of the figure, due to the randomness. Therefore, your results will be different (at least NPC).

The simulation of the best solution, year 1:





The MULTIPERIOD tab:



If we click in “**Save Multiperiod data**”, we obtain an Excel file:

Project: High1-multi-2.kho. Solution # 1

RESULTS DURING THE YEARS OF THE SYSTEM LIFETIME, MULTIPERIOD SIMULATION.

Costs and incomes are cash flow of each year (not present value)

Year	Cum. Inf. Purch. E(%)	Cum. Inf. Sell E(%)	Cum. Inf. Sell H2(%)	AC load(%)	DC load(%)	H2 load(%)	Water load(%)	Irrad.(%)	Wind(%)
1	103	102.58	103	100	100	100	100	1.1	0
2	106.09	104.69	106.09	101	101	101	101	0.23	0
3	109.27	107.65	109.27	102.01	102.01	102.01	102.01	-0.9	0
4	112.55	111.91	112.55	103.03	103.03	103.03	103.03	-1.21	0
5	115.93	115.77	115.93	104.06	104.06	104.06	104.06	0.66	0
6	119.41	120.25	119.41	105.1	105.1	105.1	105.1	-0.51	0
7	122.99	122.87	122.99	106.15	106.15	106.15	106.15	0.72	0
8	126.68	126.78	126.68	107.21	107.21	107.21	107.21	2.19	0
9	130.48	130.42	130.48	108.29	108.29	108.29	108.29	-1.33	0
10	134.39	132.02	134.39	109.37	109.37	109.37	109.37	4.01	0
11	138.42	135.35	138.42	110.46	110.46	110.46	110.46	0.09	0
12	142.58	139.42	142.58	111.57	111.57	111.57	111.57	0.81	0
13	146.85	143.27	146.85	112.68	112.68	112.68	112.68	0	0
14	151.26	147.17	151.26	113.81	113.81	113.81	113.81	-1.52	0
15	155.8	150.88	155.8	114.95	114.95	114.95	114.95	2.95	0
16	160.47	156.16	160.47	116.1	116.1	116.1	116.1	-1.7	0
17	165.28	162.37	165.28	117.26	117.26	117.26	117.26	1.94	0
18	170.24	166.77	170.24	118.43	118.43	118.43	118.43	-0.01	0
19	175.35	172.56	175.35	119.61	119.61	119.61	119.61	1.28	0
20	180.61	177.49	180.61	120.81	120.81	120.81	120.81	-0.06	0
21	186.03	185.23	186.03	122.02	122.02	122.02	122.02	1.12	0
22	191.61	190.92	191.61	123.24	123.24	123.24	123.24	0.17	0
23	197.36	194.6	197.36	124.47	124.47	124.47	124.47	3.74	0
24	203.28	201.96	203.28	125.72	125.72	125.72	125.72	2	0
25	209.38	208.79	209.38	126.97	126.97	126.97	126.97	-0.5	0

multip-high2

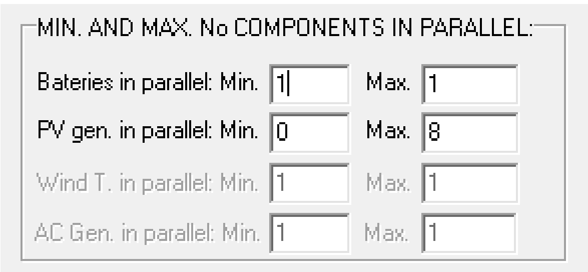
E Renew(MWh/yr)	E Photov(MWh/yr)	E Wind(MWh/yr)	E Hydro(MWh/yr)	E Export(MWh/yr)	E Charge Bat(MWh/yr)	E Disch Bat(MWh/yr)	E AC Gen(MWh/yr)	E Fuel Cell(MWh/yr)	E Electrol(MWh/yr)	E Buy(MWh/yr)	E Sell(MWh/yr)
94.536	94.536	0	0	94.536	0	0	0	0	0	0	82.422
91.882	91.882	0	0	91.881	0	0	0	0	0	0	81.373
90.053	90.053	0	0	90.053	0	0	0	0	0	0	80.585
88.875	88.875	0	0	88.875	0	0	0	0	0	0	80.069
89.368	89.368	0	0	89.367	0	0	0	0	0	0	80.33
87.534	87.534	0	0	87.534	0	0	0	0	0	0	79.491
87.51	87.51	0	0	87.511	0	0	0	0	0	0	79.511
87.641	87.641	0	0	87.64	0	0	0	0	0	0	79.606
84.109	84.109	0	0	84.109	0	0	0	0	0	0	77.852
87.017	87.017	0	0	87.017	0	0	0	0	0	0	79.365
83.256	83.256	0	0	83.256	0	0	0	0	0	0	77.458
82.818	82.818	0	0	82.818	0	0	0	0	0	0	77.249
81.301	81.301	0	0	81.301	0	0	0	0	0	0	76.452
79.305	79.305	0	0	79.305	0	0	0	0	0	0	75.292
81.413	81.413	0	0	81.413	0	0	0	0	0	0	76.555
77.317	77.317	0	0	77.317	0	0	0	0	0	0	74.109
78.807	78.807	0	0	78.807	0	0	0	0	0	0	75.072
76.568	76.568	0	0	76.568	0	0	0	0	0	0	73.676
76.459	76.459	0	0	76.459	0	0	0	0	0	0	73.63
74.645	74.645	0	0	74.645	0	0	0	0	0	0	72.42
74.446	74.446	0	0	74.446	0	0	0	0	0	0	72.304
72.899	72.899	0	0	72.899	0	0	0	0	0	0	71.211
74.142	74.142	0	0	74.142	0	0	0	0	0	0	72.136
72.116	72.116	0	0	72.116	0	0	0	0	0	0	70.669
69.657	69.657	0	0	69.657	0	0	0	0	0	0	68.755

Save the project.

47. Variant: force batteries.

Save the project and save as with the name “High1-multi-3”.

We can now force to have batteries in the system: In the main screen, minimum number of batteries in parallel 1:



We optimize again:

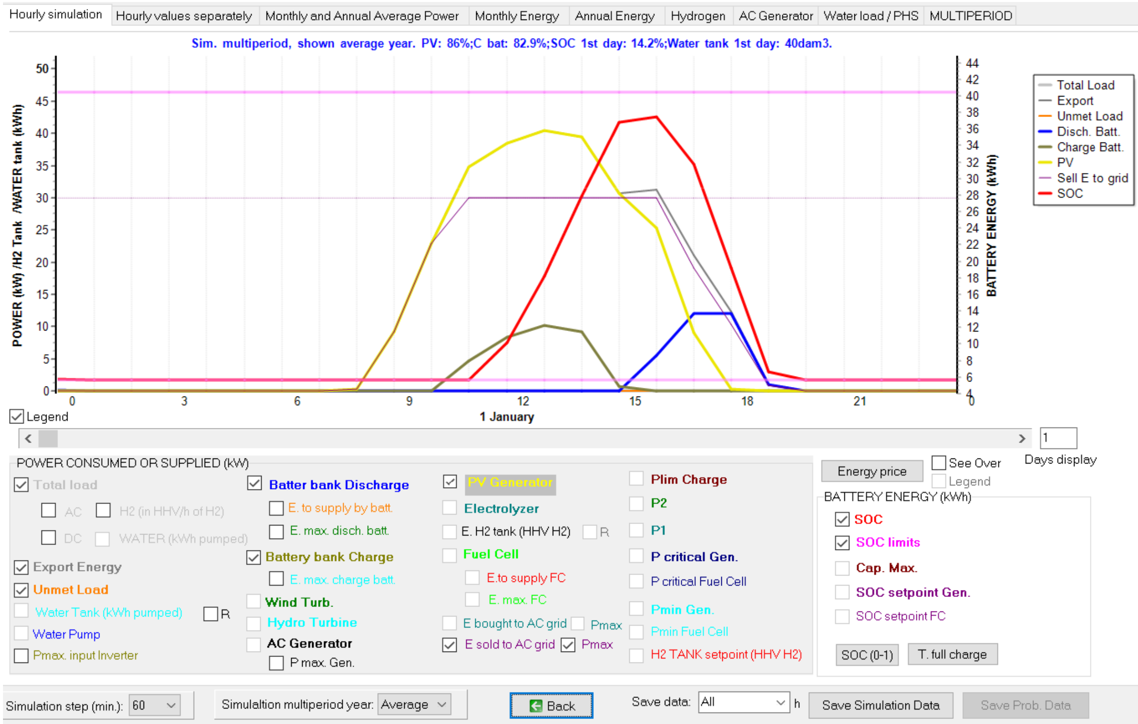
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	56.819	2.35	0	12.19	99.375	14.64	0.0886	SIMULATE..	REPORT...	COST
2	54.87	2.35	0	12.04	98.75	14.39	0.0893	SIMULATE..	REPORT...	COST
3	53.878	2.35	0	11.84	101.875	14.69	0.091	SIMULATE..	REPORT...	COST
4	53.76	2.03	0	12.69	86.875	15.28	0.0868	SIMULATE..	REPORT...	COST
5	53.166	2.67	0	11.32	111.875	13.68	0.0935	SIMULATE..	REPORT...	COST
6	53.012	2.03	0	12.62	86.25	15.13	0.0867	SIMULATE..	REPORT...	COST
7	51.85	2.67	0	11.25	111.25	13.47	0.094	SIMULATE..	REPORT...	COST
8	50.757	2.03	0	12.27	89.375	15.3	0.0895	SIMULATE..	REPORT...	COST
9	50.595	2.67	0	11.04	114.375	13.74	0.0956	SIMULATE..	REPORT...	COST

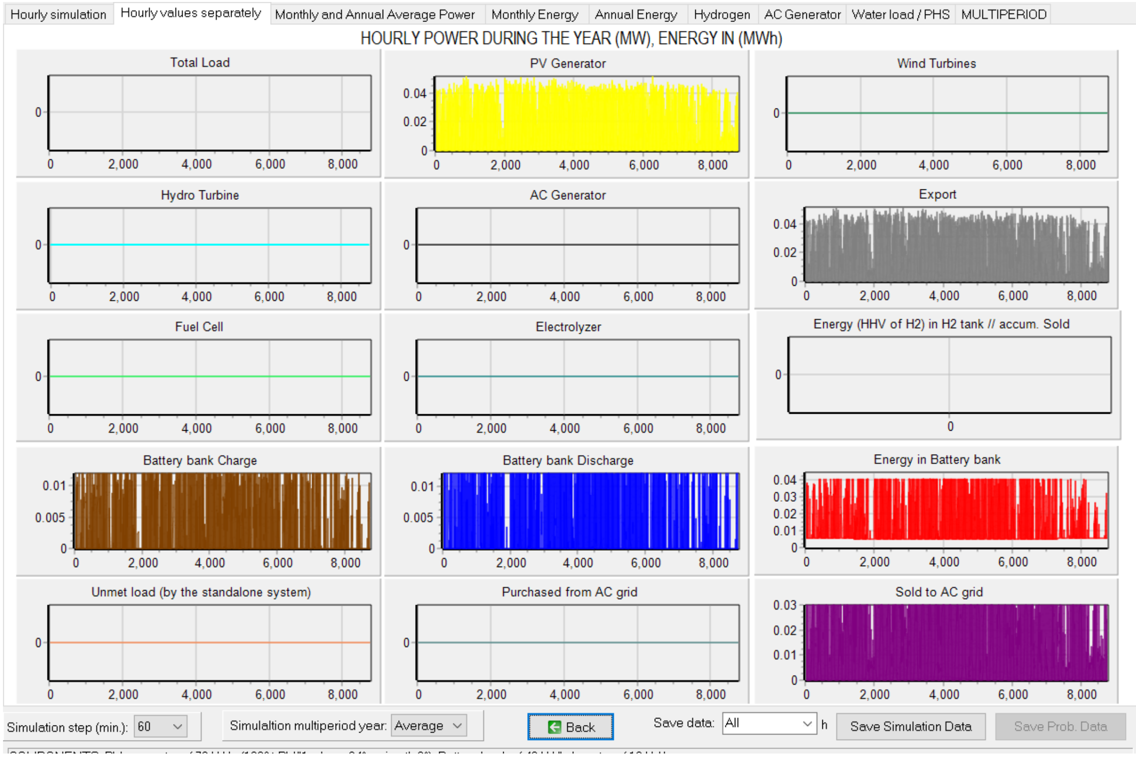
COMPONENTS: PV gen: PV10 (10 kWp)x 7 (100% PV#1: slope 34º, azimuth 0º) // Batteries Bat48kWh (1 kAh): 1s. x 1p. // Inverter Inv-Ch10kW of 10 kVA // Unmet load = 0 % // Total Net Present Value (NPV) = 56.819 k€, IRR = 12.2%.

STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. SOC min.: 10 %. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

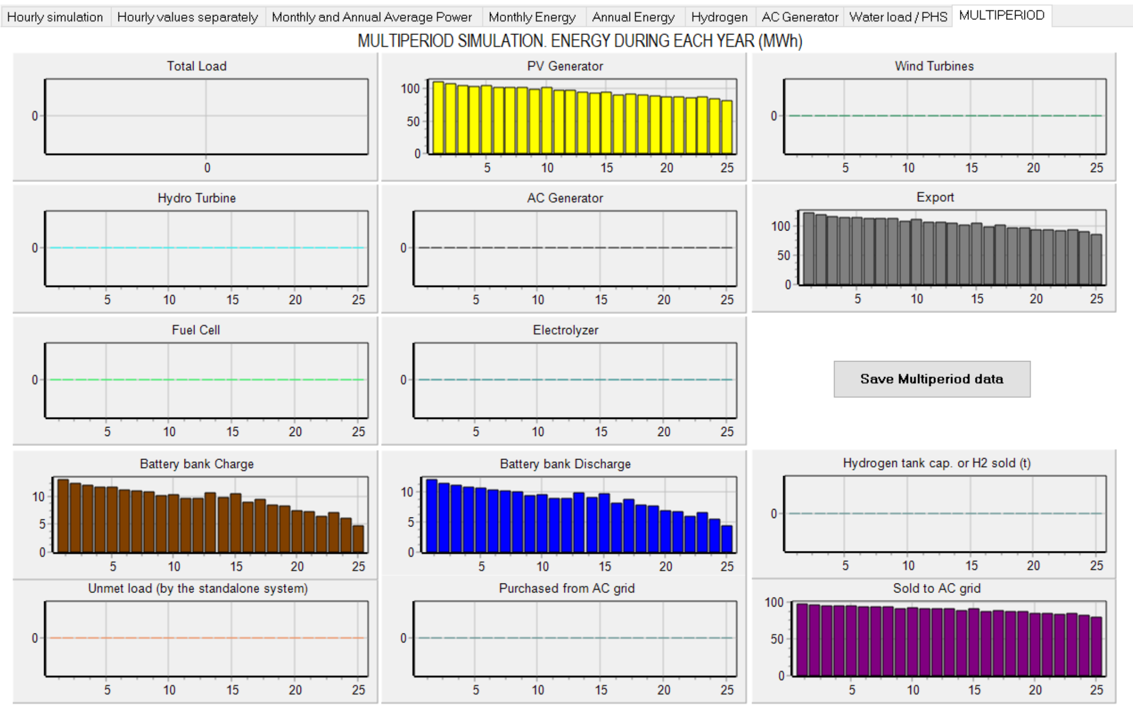
The optimal system now includes a PV gen. of 70 kW, batt. of 48 kWh and inverter-charger of 10 kVA.

In the simulation of the optimal system, we can see the batteries control strategy: batteries are charged when there is power that cannot be injected to the AC grid and when the power injected is lower than the maximum, batteries inject power to the grid by means of the inverter-charger of 10 kVA:





The multiperiod tab:



Save the project.

48. Variant: optimize control strategy for grid-connected batteries.

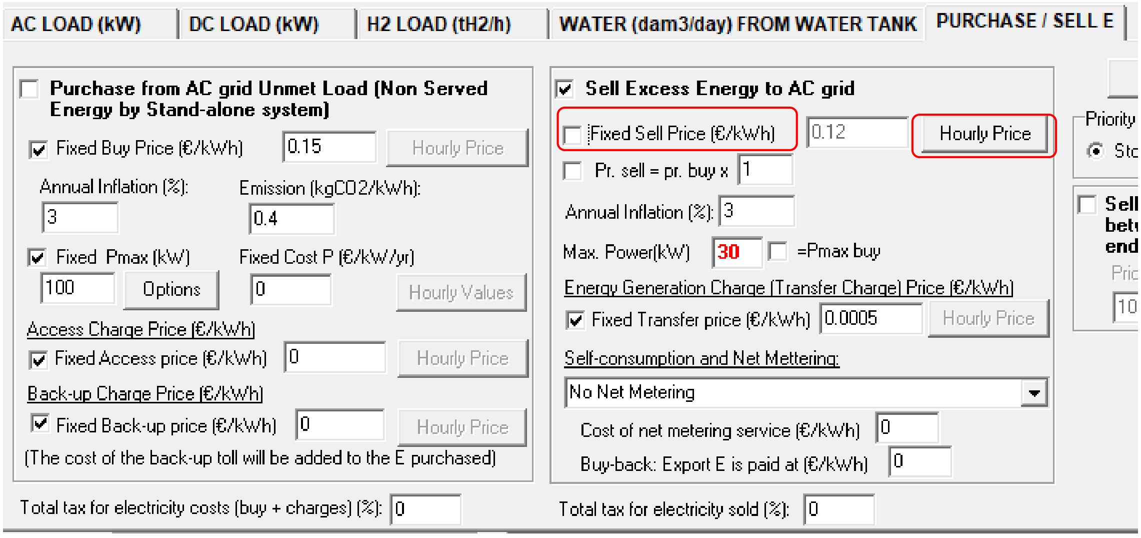
Save the project and save as with the name "High1-multi-4".

Now let's suppose that the electricity sell price is hourly (real time pricing tariff) and it has high differences between the minimum and maximum hourly price of each day. This hypothetical hourly price file can be downloaded here:

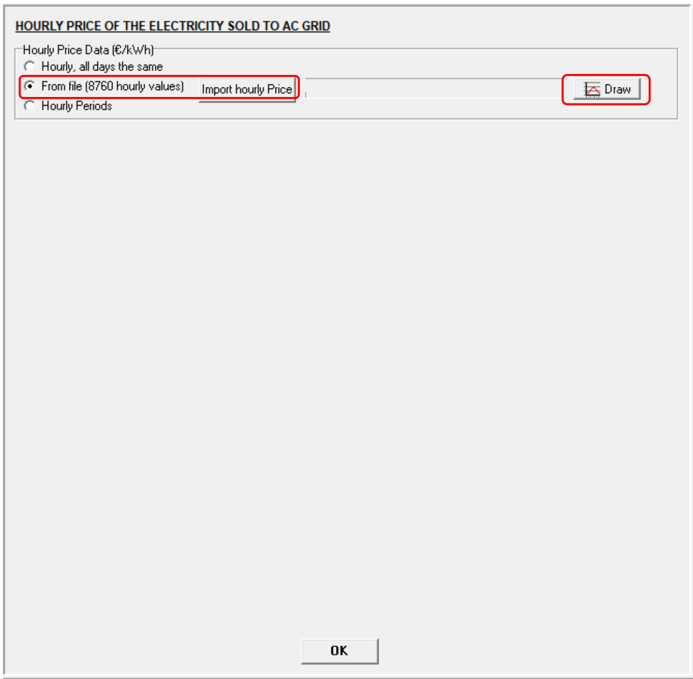
http://ihoga.unizar.es/Desc/Hypothetical_hourly_pirce.zip

Download and unzip, you will get "Hypothetical_hourly_pirce.txt" file.

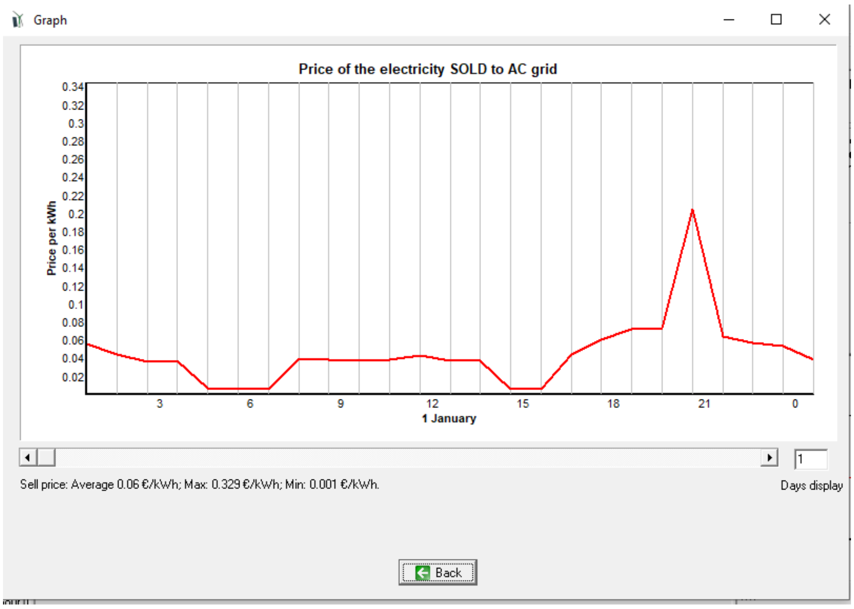
In the LOAD / AC GRID window, PURCHASE / SELL E tab, uncheck "**Fixed Sell Price**" and click in "**Hourly Price**" button.



A small window appears, where you can import the downloaded hourly file. Click in "**From file (8760 hourly values)**" and click in the button "**Import hourly file**" and import the "Hypothetical_hourly_pirce.txt" file.



After importing the file, you can click in the button "**Draw**" and see the hourly sell price:



We can see that average hourly price is 0.06 €/kWh, half than when we had fixed price (it was 0.12 €/kWh).

Back, OK and OK to return to the main screen.

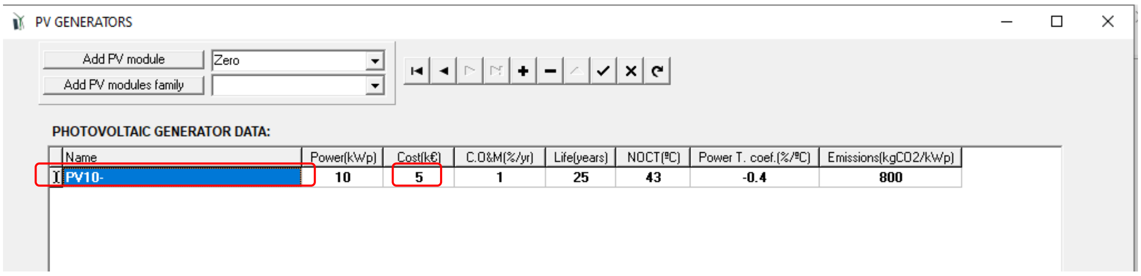
If we click in the first row of the results table, it updates to the new conditions:

#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	-11.953	2.35	0	0	99.375	14.3	0.0906	SIMULATE..	REPORT...	COST

And the NPV now is -11.953 k€, that is, it is a not profitable system.

Remember, all the results in your case it can be different due to the random variables defined in the multiperiod options.

Let's suppose that the PV generator cost is much lower, for example 50% of the default cost: in the PV generators window, change the name to "PV10-" (just adding "-") and then change the cost from 10 k€ to 5 k€:

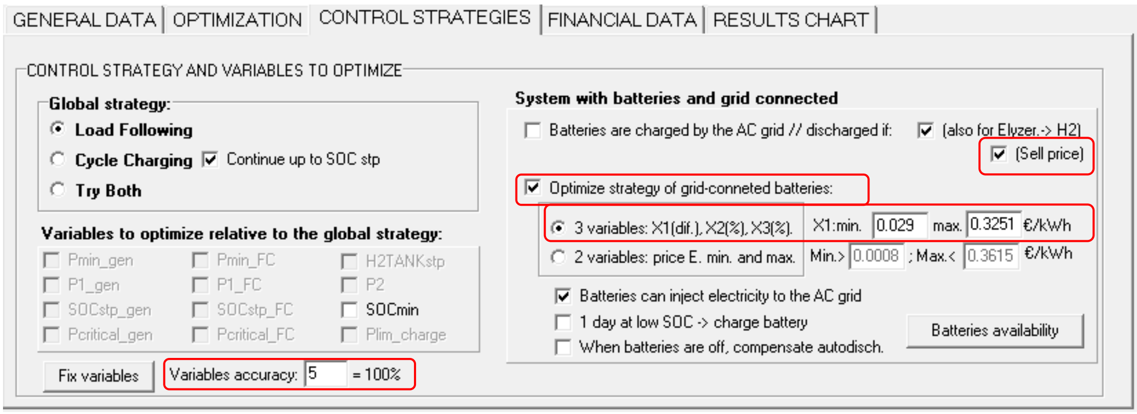


Then OK and return to the main screen. Click in the first row of the results table so that it updates, and we get NPV of 36.778 k€, i.e., profitable system.

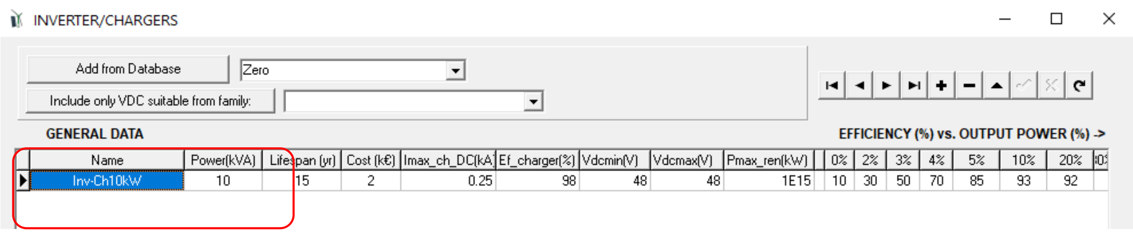
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	36.778	2.35	0	12.96	55.625	14.3	0.0516	SIMULATE..	REPORT...	COST

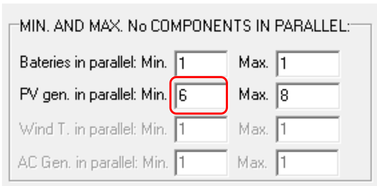
Maybe the optimal control strategy is not the one that was set. In the main screen, CONTROL STRATEGIES tab, "(**Sell Price**)" is checked as we are considering sell prices and the strategy will be related to sell prices; we will optimize the control strategy with 3 variables (see the user manual for more info), check "**Optimize strategy of grid-connected batteries**" and "**3**

variables:..”. The search space for the values of X1 will be between the min. and max, which are the minimum and maximum difference between the min. and max. hourly price of a day, they are obtained by iHOGA and we don’t change them.

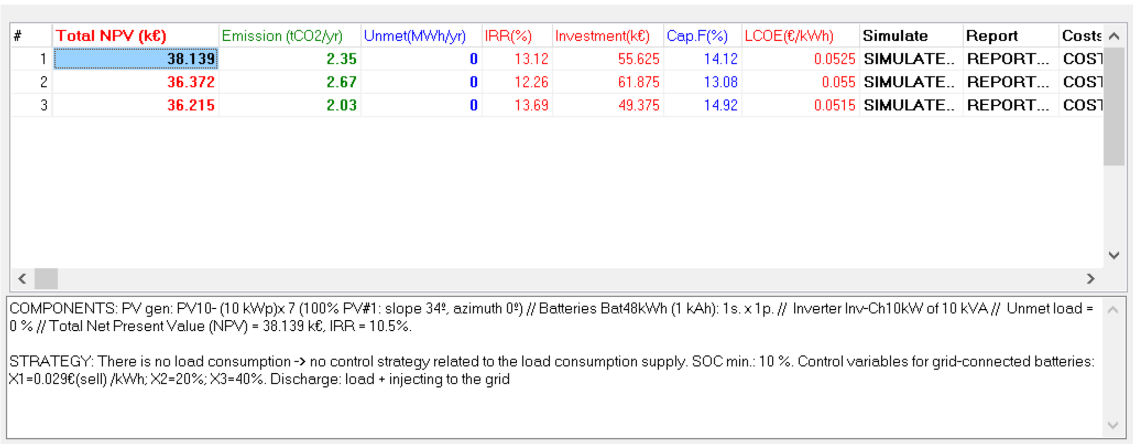


Including the optimization of the grid-connected strategy will highly increase the optimizing time, multiplying the time by a factor of 216 (that is, 6^3, as there are 3 variables and each variable can take 6 values, because variables accuracy 5 = 100%, therefore each variable can take the values 0, 20%, 40%, 60%, 80% and 100%). To reduce the optimizing time, we will allow only one inverter-charger (the one of 10 kVA, the rest must be deleted from the inverter-chargers table) and the minimum number of PV generators in parallel will be 6:



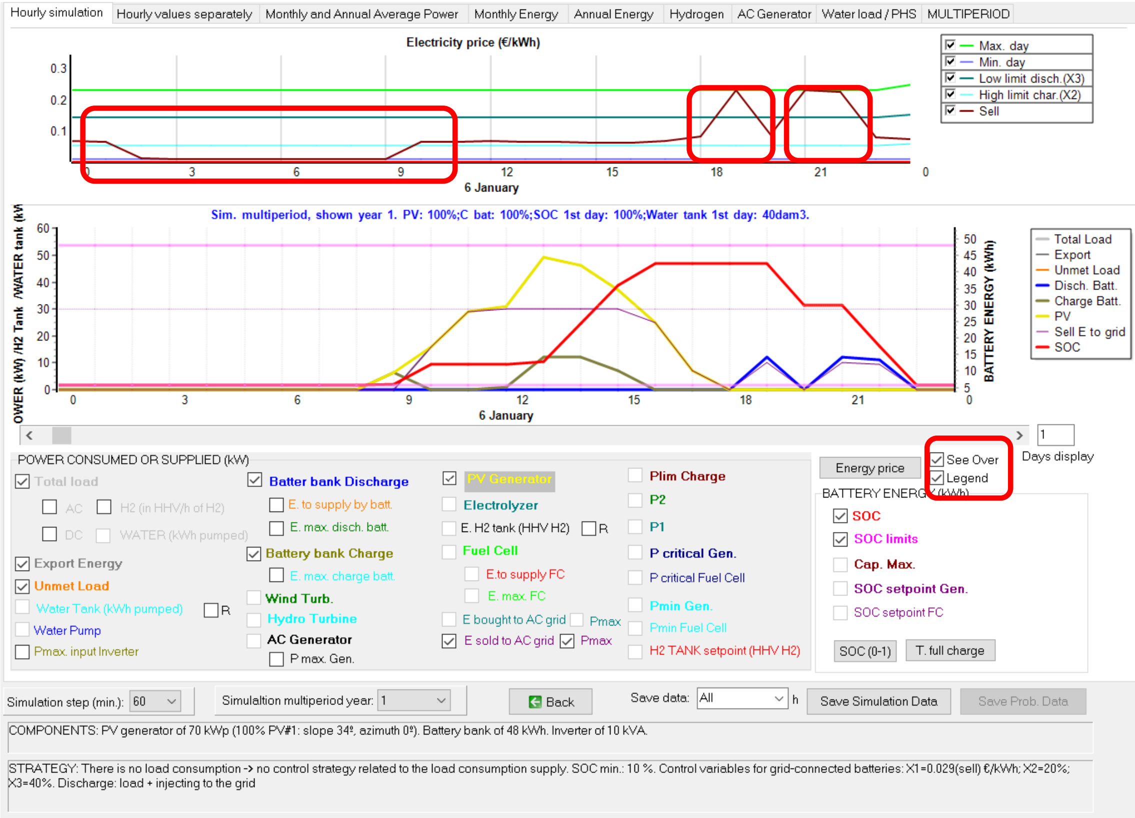


Now the optimizing time will be several minutes. We calculate:



The optimal system has a better NPV than the previous one, as the battery strategy obtained is optimal.

In the simulation of the year 1, we can see for example for the day January 6th that between 2 a.m. to 9 a.m. sell electricity price is lower than the higher limit for charging (X2), however, as during these hours there is no electricity generation and it is not allowed to buy electricity from the AC grid, batteries are not charged. We can see that at 19 h and 21-22 h, electricity price is higher than the low limit for discharge (X3), so they will be discharged at their maximum power (considering the limit of 10 kW as they inject power to the grid by means of the inverter-charger).



In the REPORT of the first row, we can see:

CONTROL STRATEGY:

THERE IS NO LOAD CONSUMPTION -> NO CONTROL STRATEGIES RELATED TO THE LOAD CONSUMPTION SUPPLY

SOC min. batteries = 10 %

CONTROL STRATEGY FOR CHARGE/DICHARGE (load + injecting to the grid) OF GRID-CONNECTED BATTERIES:

X1=0.029 €/kWh (sell price); X2=20 %; X3=40 %

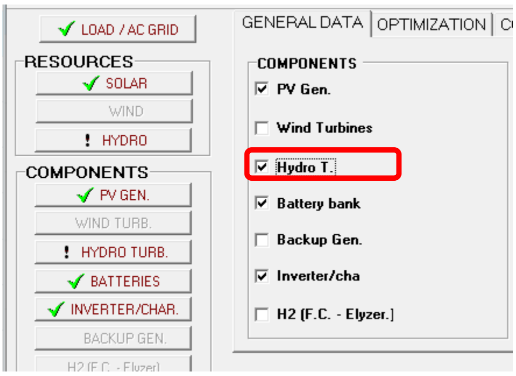
Save the project.

49. Pumped hydro storage (PHS).

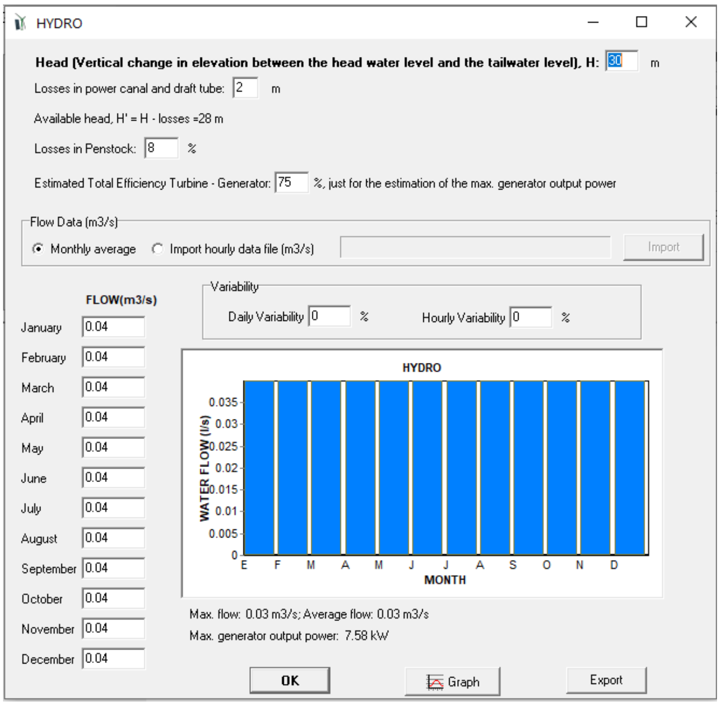
Save the previous project (High1-multi-4) as "High1-multi4-PHS".

Now let's suppose that we include pumped hydro storage (PHS). We build a water tank or reservoir so that water can be pumped to the water reservoir when the renewable power is higher than the maximum power to be injected to the AC grid and the turbine will run when the sell electricity price is high. Let's suppose that the water reservoir maximum capacity is 80 dam^3 and the elevation head is 34 m.

In the main screen, click in the checkbox "**Hydro T.**". Then, the buttons "HYDRO" and "HYDRO TURB" are enabled and "!" is added (it means that the data of these buttons should be introduced).

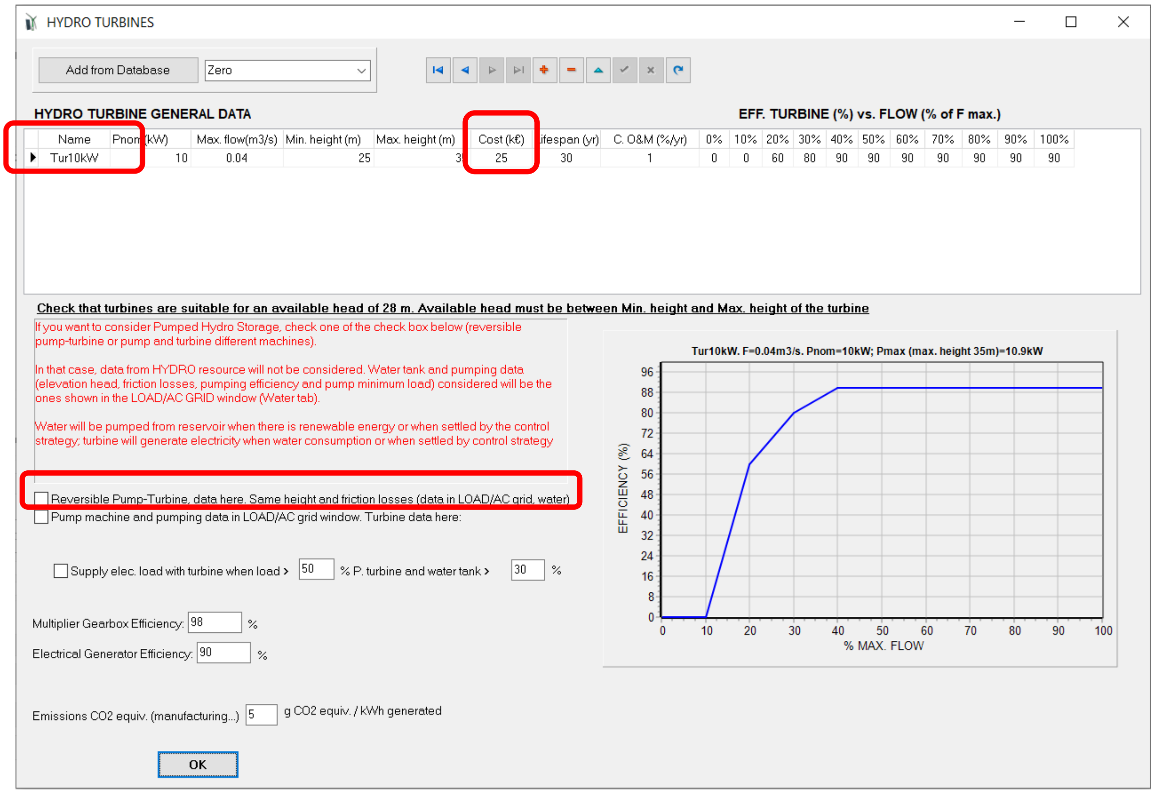


First click in "**! HYDRO**" button.



We accept all the default data with OK. In our case (PHS) the data of this window will not be considered (available head and water flow of this window would be considered if we had just a turbine that generates power with the available water flow; this is not our case).

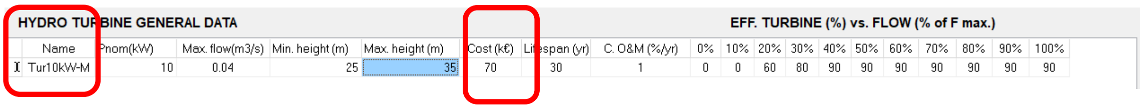
Now, in the main screen, click in "**! HYDRO TURB**" button.



For PHS, we can define a reversible pump-turbine or two different machines (pump and turbine).

Let's suppose that we will install a reversible pump-turbine, click in "**Reversible Pump-Turbine, data here….**"

The data of the reversible machine is in this window, that is, in the table. Let's suppose that in our case is the one of 10 kW that is by default, however let's suppose that the total cost (including the building of the reservoir, penstock, etc.) is 70 k€. Then, change the name of the machine (for example "Tur10kW-M") and later change the cost to 70 k€.



We can see that this machine the maximum flow is 0.04 m^3/s, and the minimum and maximum height are 25 and 35 m. In our case the height will be 34 m so it is correct.

The efficiency vs. flow data of the table is for the turbine, the pump efficiency will be defined later.

The maximum power of this machine is (including turbine, multiplier gearbox and electrical generator efficiencies):

$$P = Water\_flow \cdot density \cdot g \cdot height\_max \cdot Total\_Efficiency =$$

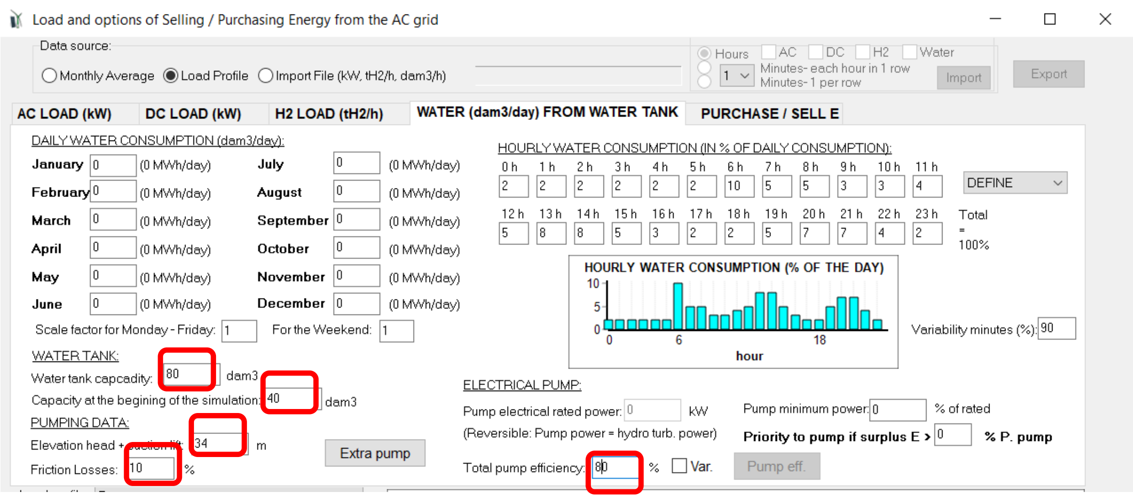
$$=0.04 m^3/s \cdot 1000 kg/m^3 \cdot 9,81 m/s^2 \cdot 35 m \cdot 0.9 \cdot 0.98 \cdot 0.9 = 10902\ W = 10.9\ kW$$

Click OK and return to the main screen.

The reservoir capacity, height, penstock losses and pumping efficiency must be defined in the "LOAD / AC GRID" window, WATER tab.

In the main screen, click "**LOAD / AC GRID**", and, in the WATER tab, we must define the reservoir maximum capacity (80 dam^3), the capacity at the beginning of the simulation (let's suppose it is at 50%, that is, 40 dam^3), the elevation head (34 m), friction losses (let's suppose 10%) and the total pump efficiency (including multiplier and electrical generator efficiencies, let's suppose a total pumping efficiency of 80%; we could use variable pump efficiency but in this case we will keep the fixed efficiency value).

The box of the Pump electrical rated power is disabled as this power is the same as the power of the turbine (it is the same machine), which was defined in the HYDRO T. window. However, the data of the pump efficiency must be defined here, because the pumping efficiency can be different than the turbine efficiency defined in the HYDRO T. window.



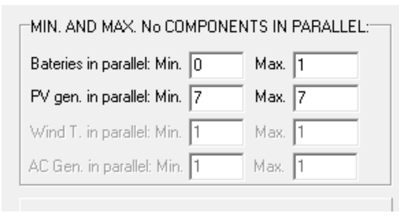
After changing any data of the reservoir or pumping data, the "OK" button is disabled, we must click in "**Generate**" to consider the new data, and later click in "**OK**".

The maximum water pumped energy in the reservoir (when it is full) is:

$$E = volume \cdot density \cdot g \cdot height \cdot (1+friction\_losses)/Efficiency =$$

$$=80000m^3 \cdot 1000kg/m^3 \cdot 9.81m/s^2 \cdot 34m \cdot (1+0.1)/0.8 = 3.66984 \cdot 10^{10}\ J = 10.1915\ MWh$$

In the main screen, we will just allow 7 PV generators in parallel (to reduce the computation time), as it was the optimal previously. And we will allow between 0 and 1 battery banks in parallel (to allow the possibility of having or not having batteries in the system):



Click in CALCULATE, we obtain 2 cases:

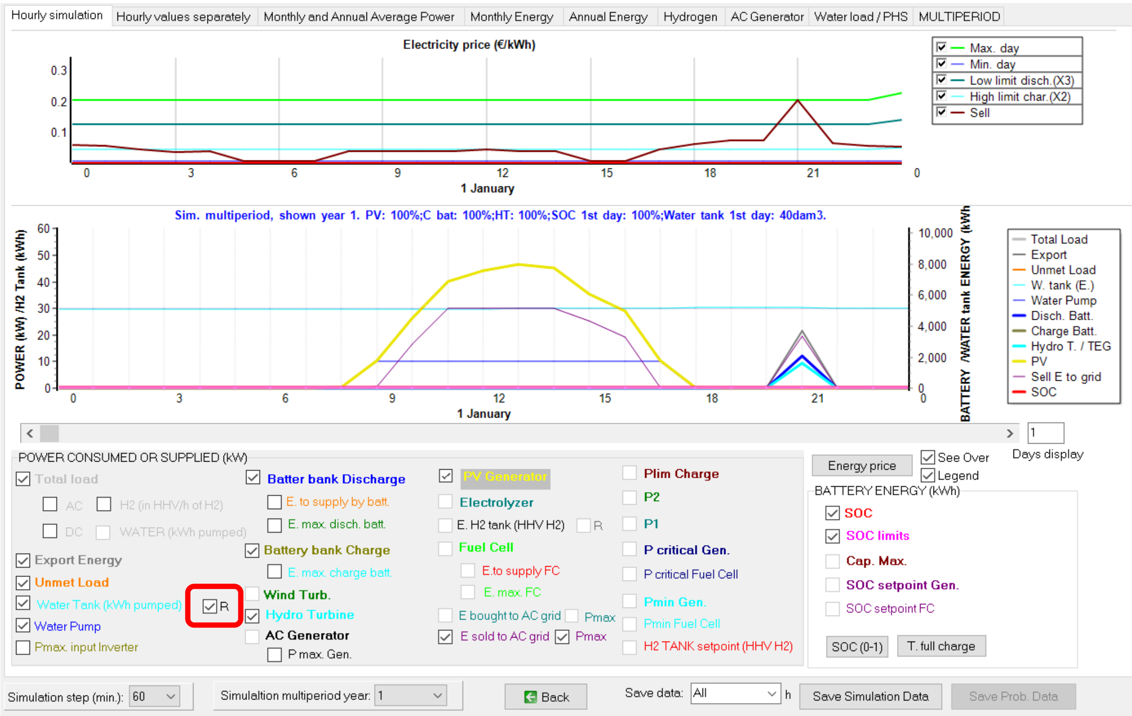
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	-42.237	2.28	0	0	133.75	12.13	0.1236	SIMULATE..	REPORT...	COST
2	-44.796	2.39	0	0	143.125	12.22	0.1328	SIMULATE..	REPORT...	COST

COMPONENTS: PV gen: PV10- (10 kWp)x 7 (100% PV#1: slope 34º, azimuth 0º) // Hydro Turb. AC Tur10kW-M of 10 kW, 0.04 m3/s // Inverter Inv-Ch10kW of 10 kVA // Unmet load = 0 % // Total Net Present Value (NPV) = -42.237 k€, IRR = 0%.

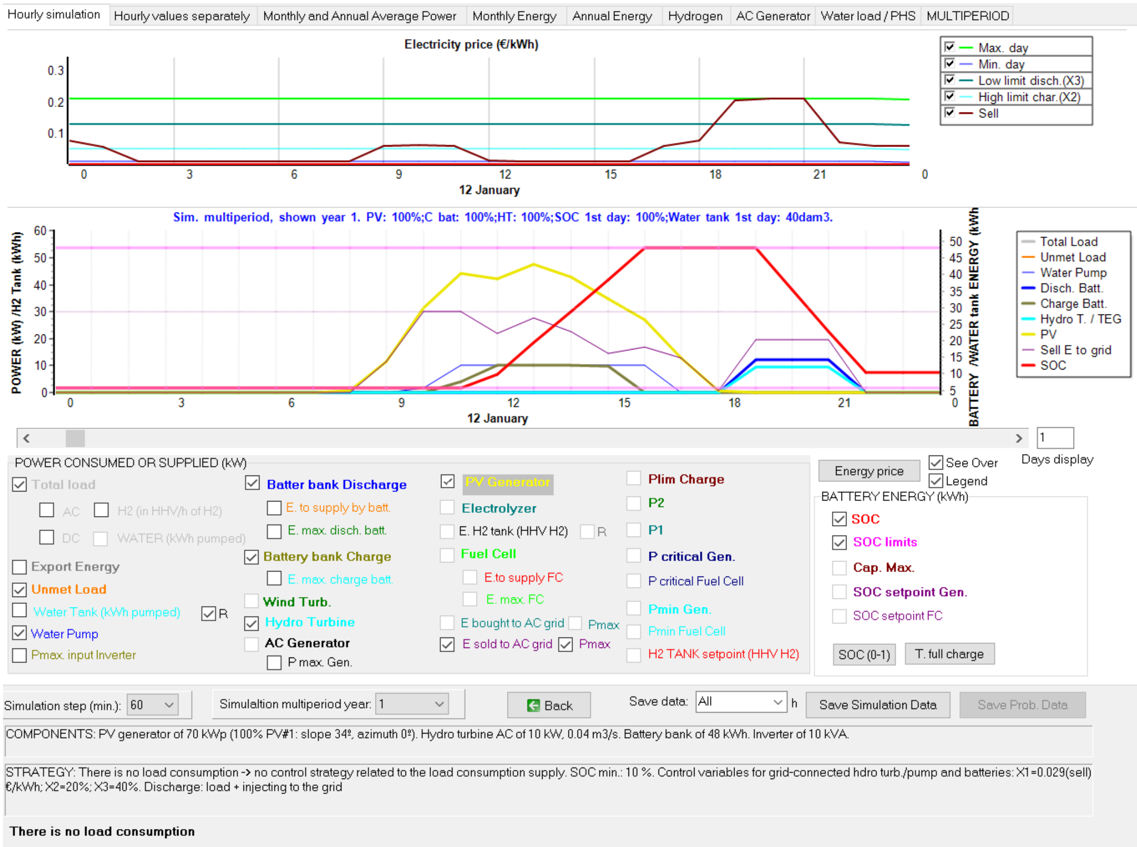
STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Control variables for grid-connected hdro turb./pump and batteries: X1=0.029(sell) €/kWh; X2=20%; X3=20%. Discharge: load + injecting to the grid

The optimal system does not include battery. In both cases the total NPV is negative therefore the system is not profitable (the high cost of the PMH in this case is not compensated).

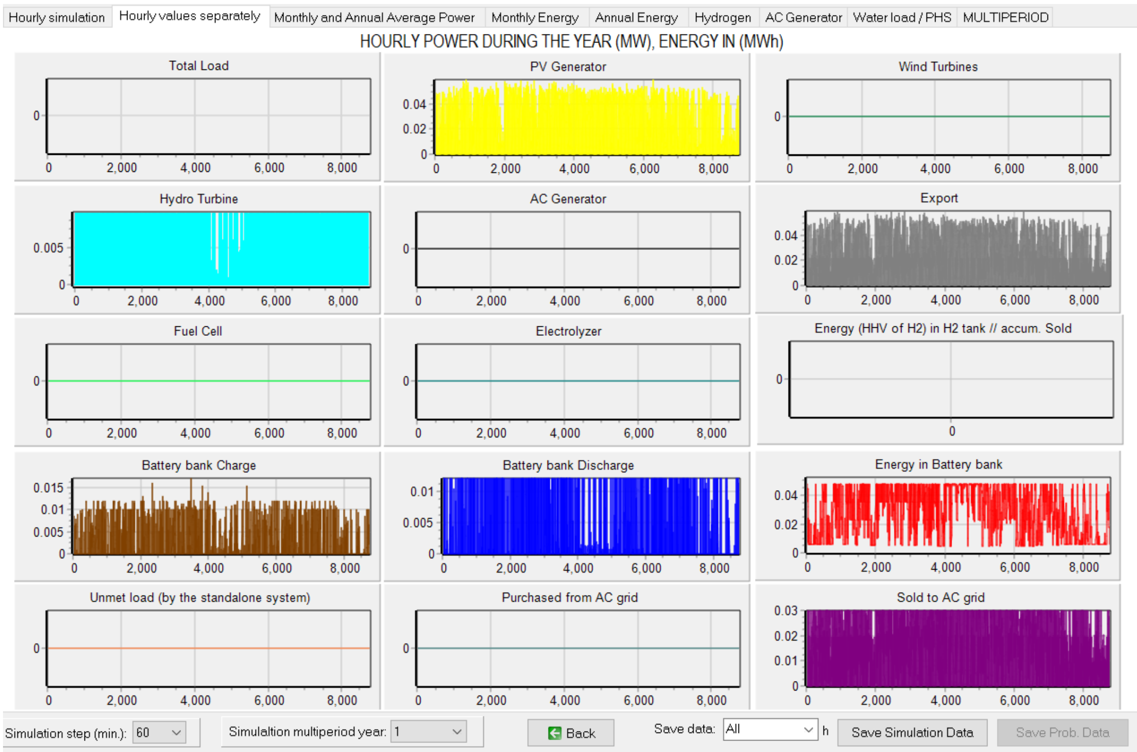
Let's see the simulation of the second system, as it includes batteries and PHS (year 1). Click the "R" checkbox close to the "Water Tank (kWh pumped)" so that it is shown in the right axis.



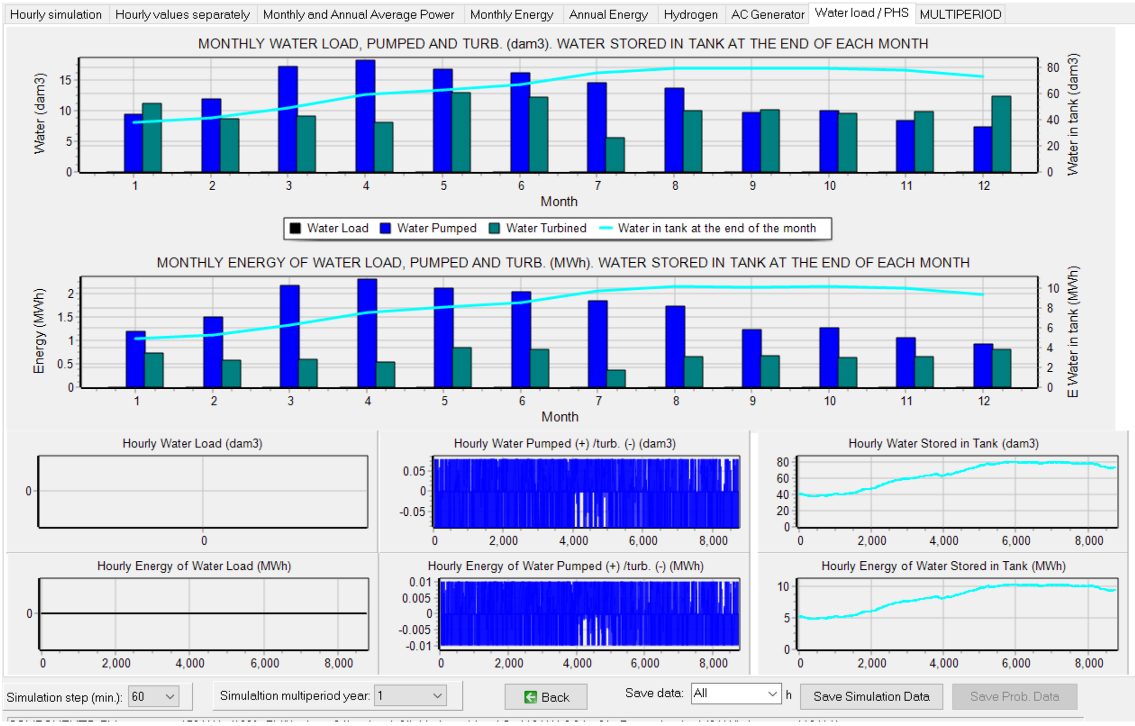
January the 12th:



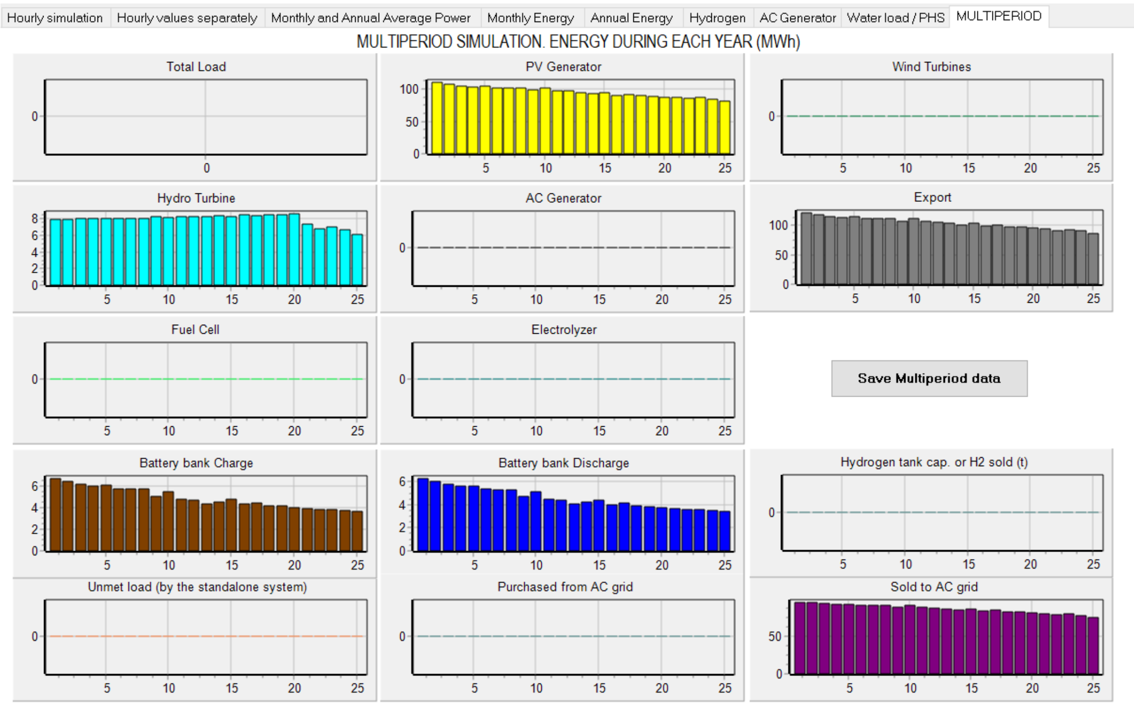
We can see that when there is energy that cannot be injected to the AC grid, it is used in pumping water and, if there is still energy (if it exceeds the 10 kW of the pump), it charges batteries. Also, when electricity price is lower than the higher limit for charging (for example the day January 12th from 12 a.m. to 16 h), the renewable electricity priority use is for pumping and charging batteries, and the rest is injected to the AC grid. On the other hand, when the electricity price is higher than the lower limit for discharge, the turbine runs using the stored water and batteries are discharged to inject electricity to the AC grid.



The “Water load” tab for the 1st year:



And the multiperiod tab:



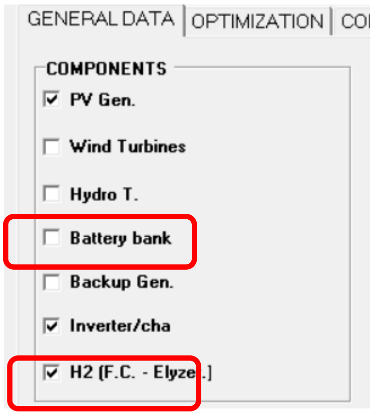
Save the project.

50. Green H2.

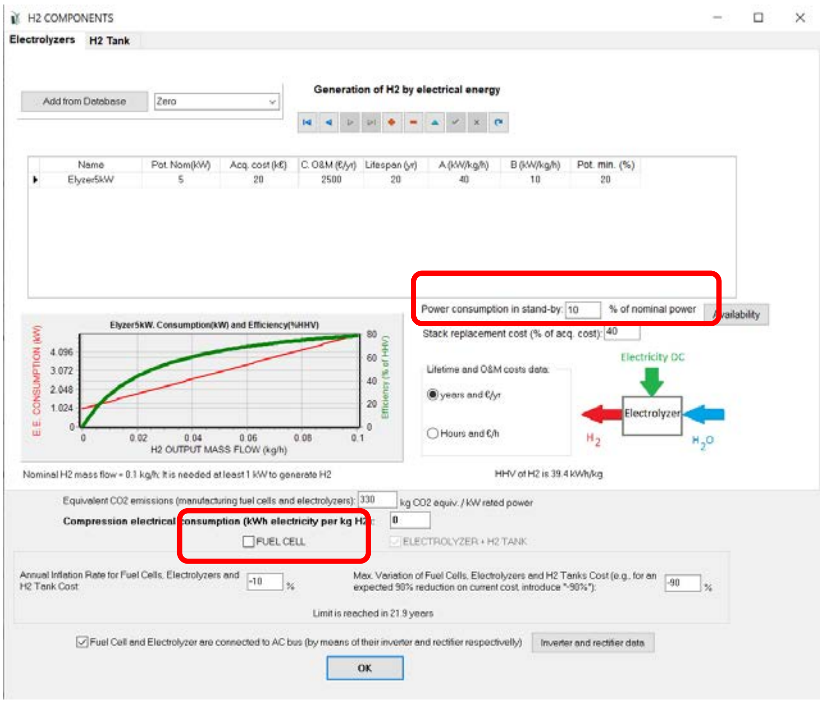
Open the project High1-multi2.kho and save it as “High1-multi2-greenH2”.

Now let's suppose that we want to generate hydrogen (by means of an electrolyzer) with the electricity that cannot be injected to the AC grid (because the renewable generation is higher than the maximum grid power during some hours). The hydrogen generated will be sold.

In the main screen, select "**H2 (F.C. – Elyzer.)**" and uncheck "**Battery bank**", as we will not consider the batteries in our system. Also we could uncheck "**Inverter/cha**", as the electrolyzer has its own rectifier defined in its screen, but we can leave it checked and the optimal will not include inverter/charger.



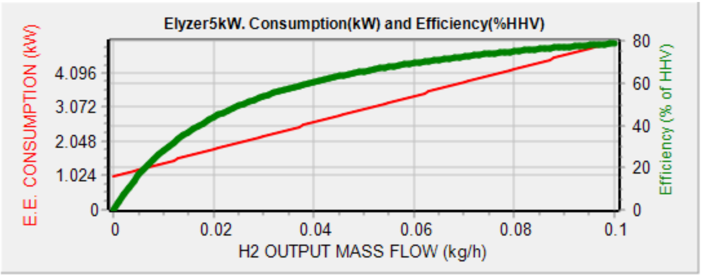
And then click in the button "**H2 (F.C. – Elyzer.)**":



In high power projects, by default there is no Fuel cell considered in the system ("FUEL CELL" checkbox is unchecked), we have just electrolyzer. Also by default no H2 tank is considered (all the hydrogen generated will be sold).

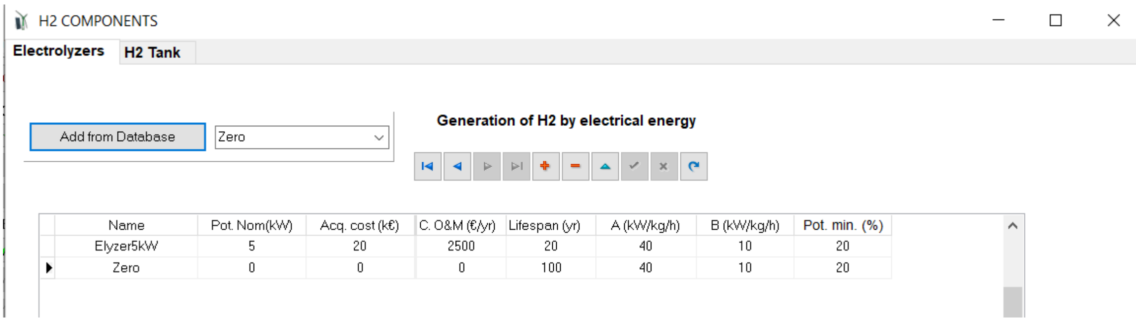
Let's leave the default electrolyzer (of 5 kW), without any change. You can see that by default a power consumption in stand-by of 10% of the nominal power of the electrolyzer is considered (all the hours when the electrolyzer is not generating hydrogen, it consumes 5·0.1= 0.5 kW).

A and B parameters (40 and 10 kW/kg/h, respectively) of the table are the consumption parameters, with them the electrical energy consumption (kW) vs. H2 generated mass flow (kg/h) is shown in the graph (red line, left axis); the green line (right axis) is the efficiency in % of higher heating value (HHV) of the hydrogen.

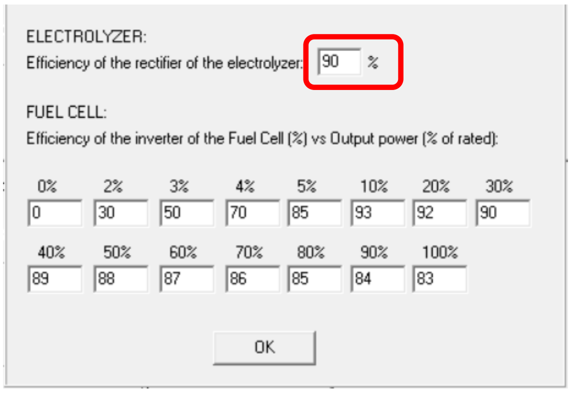


Nominal H2 mass flow = 0.1 kg/h; It is needed at least 1 kW to generate H2

We will add the "Zero" electrolyzer to consider the possibility of not having electrolyzer (add the "Zero" electrolyzer from the database)>



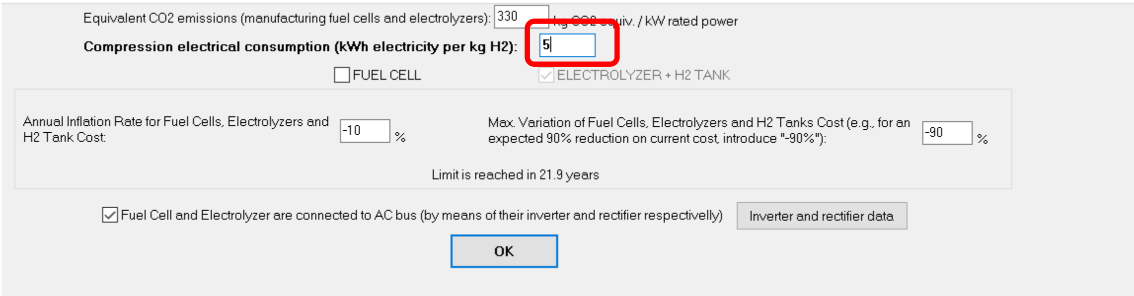
In the botton right corner of the screen, click in "**Inverter and rectifier data**" button, the next window appears:



The electrolyzer rectifier efficiency is 90% by default, and its cost must be included in the electrolyzer cost. We leave the data by default. The fuel cell efficiency is not considered as in our case there is no fuel cell. Click OK to close this little window.

In the "**H2 tank**" tab, leave the default checkbox checked. No H2 tank will be considered, that is, all the hydrogen generated will be sold for external use, therefore no cost for the H2 tank will be considered. In the simulation, the H2 generated will be shown as the H2 in the tank, that is, in the H2 tank we really will see the H2 generated that will be sold.

The costs of the real tank which will be in our facility to store the H2 before selling it, the cost of compressors, rectifier etc. must be included in the electrolyzer costs. The efficiency of compressing the H2 generated and other auxiliary processes will be considered as 5 kWh per kg:

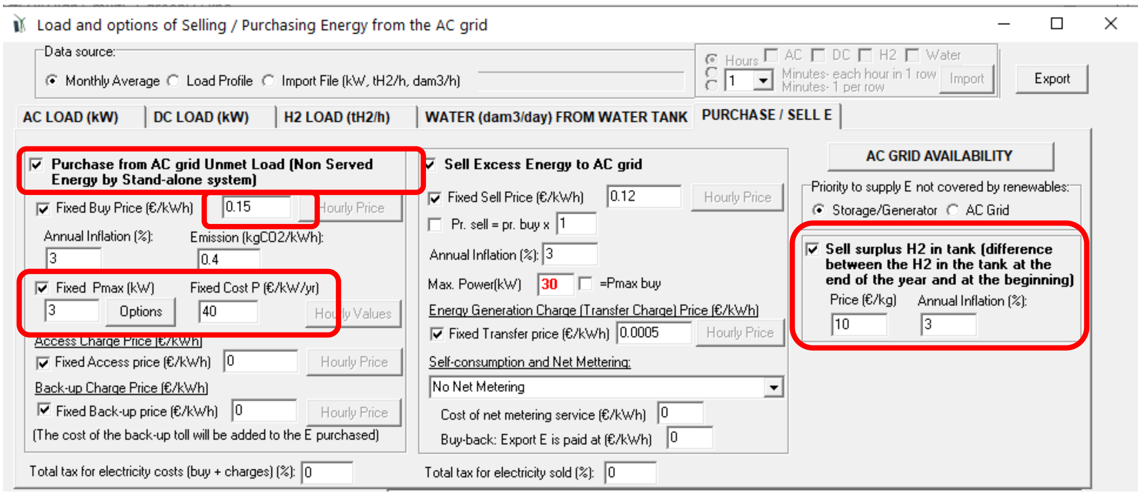


OK and return to the main screen.

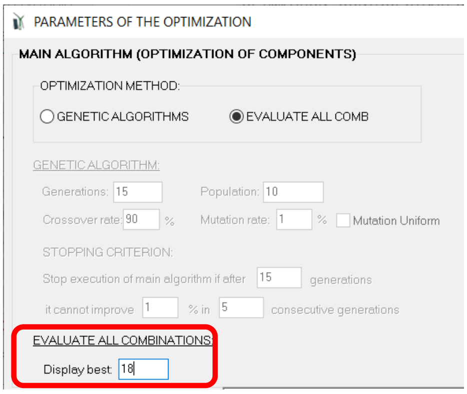
As there is an AC load consumption due to the electrolyzer (when it is in stand-by), we will include the option to purchase electricity from the AC grid.

In the main screen, click "**LOAD / AC GRID**", and, in the **PURCHASE / SELL E** tab, select "**Purchase from AC grid Unmet Load…**", the purchase price will be the default value (0.15 €/kWh) and the sell price also the default value (0.12 €/kWh). We need to contract the power from the grid, which will be in this case for example 3 kW, with an annual cost of the power of 40 €/kW.

Also click on "Sell surplus H2 in tank…" to indicate we want to sell the H2 produced, and leave the default price of 10 €/kg and annual inflation of 3% for that price.

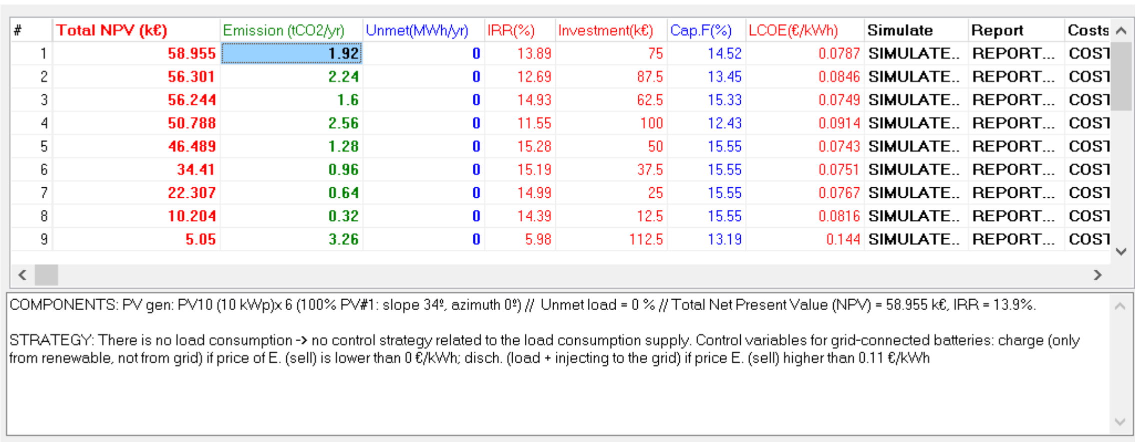


OK to return to the main screen. In the main screen, click in button "**Parameters**", and in the window that appears set the value 18, that is all the combinations in "Display best" so all the results will be shown in the result table.



OK and then CALCULATE.

The optimal system is the same as the one of project "High1-multi-2", but with a higher cost due to the extra cost of the power for purchasing electricity from AC grid.



#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs
1	58.955	1.92	0	13.89	75	14.52	0.0787	SIMULATE..	REPORT...	COST
2	56.301	2.24	0	12.69	87.5	13.45	0.0846	SIMULATE..	REPORT...	COST
3	56.244	1.6	0	14.93	62.5	15.33	0.0749	SIMULATE..	REPORT...	COST
4	50.788	2.56	0	11.55	100	12.43	0.0914	SIMULATE..	REPORT...	COST
5	46.489	1.28	0	15.28	50	15.55	0.0743	SIMULATE..	REPORT...	COST
6	34.41	0.96	0	15.19	37.5	15.55	0.0751	SIMULATE..	REPORT...	COST
7	22.307	0.64	0	14.99	25	15.55	0.0767	SIMULATE..	REPORT...	COST
8	10.204	0.32	0	14.39	12.5	15.55	0.0816	SIMULATE..	REPORT...	COST
9	5.05	3.26	0	5.98	112.5	13.19	0.144	SIMULATE..	REPORT...	COST

COMPONENTS: PV gen: PV10 (10 kWp)x6 (100% PV#1: slope 34º, azimuth 0º) // Unmet load = 0 % // Total Net Present Value (NPV) = 58.955 k€, IRR = 13.9%.

STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

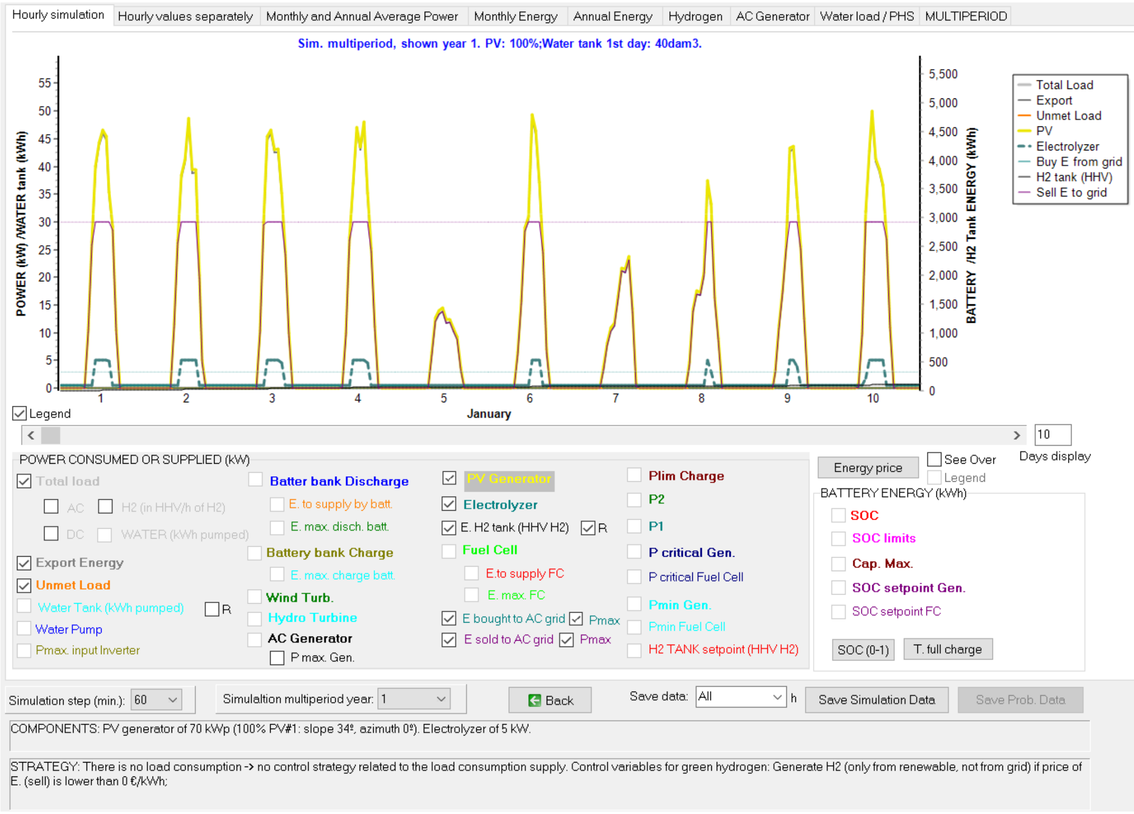
The first solution that includes electrolyzer is the number 9. In this case, we can see in the 9th row that the "H2 tank" column value is 0.108 tons, that means that the H2 sold during each year is that value (annual average value of the 25 years).

P. PV (kWp)	Slope#1 (º)	Cn Bat. (kAh)	P. Gen (kW)	P. Inv (kW)	P. Wind T. (kW)	F. Turb (m3/s)	P. FC (kW)	P. Elyz. (kW)	H2 tank (t)
6x10	34	0	1x0	0	1x0	0	0	0	0
7x10	34	0	1x0	0	1x0	0	0	0	0
5x10	34	0	1x0	0	1x0	0	0	0	0
8x10	34	0	1x0	0	1x0	0	0	0	0
4x10	34	0	1x0	0	1x0	0	0	0	0
3x10	34	0	1x0	0	1x0	0	0	0	0
2x10	34	0	1x0	0	1x0	0	0	0	0
1x10	34	0	1x0	0	1x0	0	0	0	0
7x10	34	0	1x0	0	1x0	0	0	5	0.108

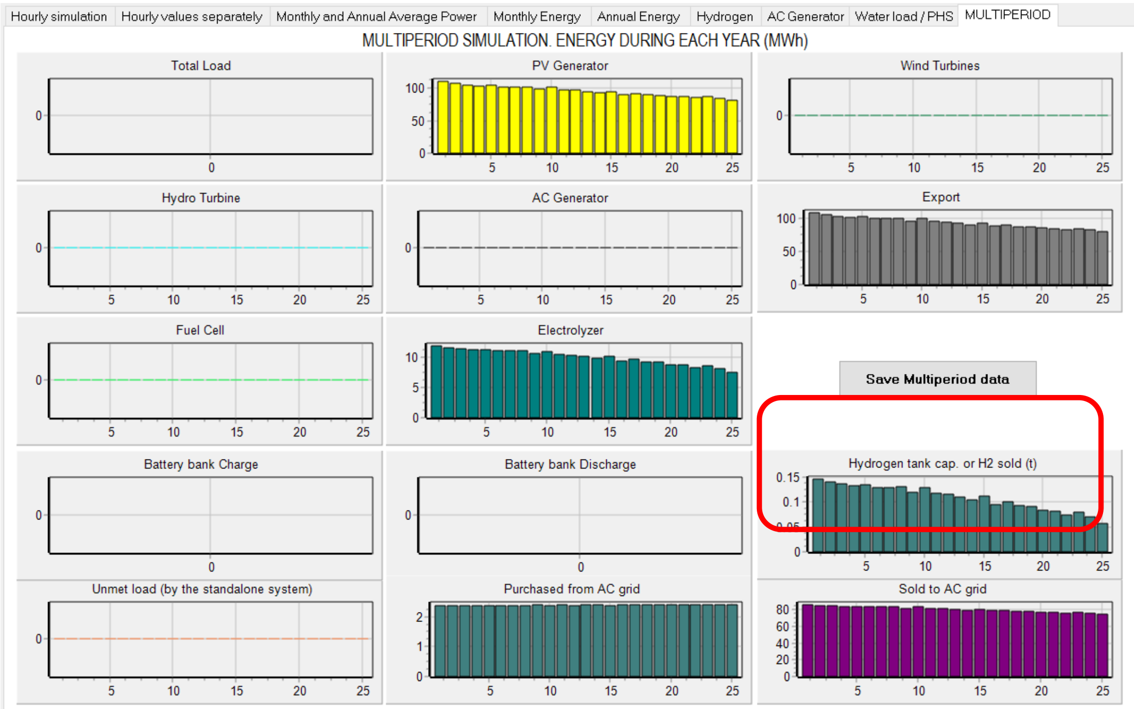
Solution number 9 NPV is 5.05 k€, much lower than the optimal solution, therefore in this case it is not optimal generating H2 with the excess energy.

9	5.05	3.26	0	5.98	112.5	13.19	0.144	SIMULATE...	REPORT...	COST

We click in SIMULATE of row 9th and we can see the simulation of that solution, for example the first 10 days of year 1:



And the multiperiod tab, where we can see the H2 sold each year (in tons):



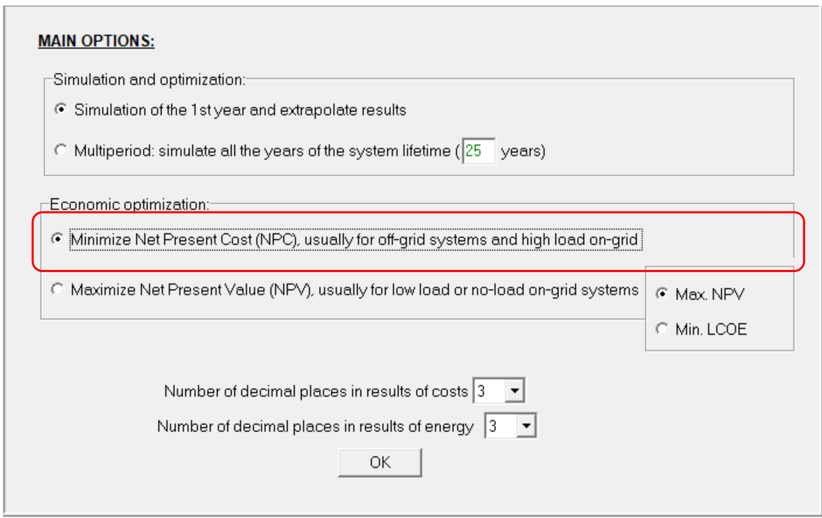
Save the project.

51. High power project, minimization of NPC.

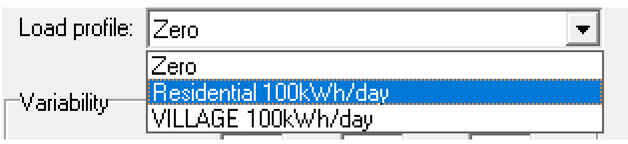
Open High1 project and save as with the name "High2".

Now we will modify the previous project considering there is AC load and trying to minimize the NPC.

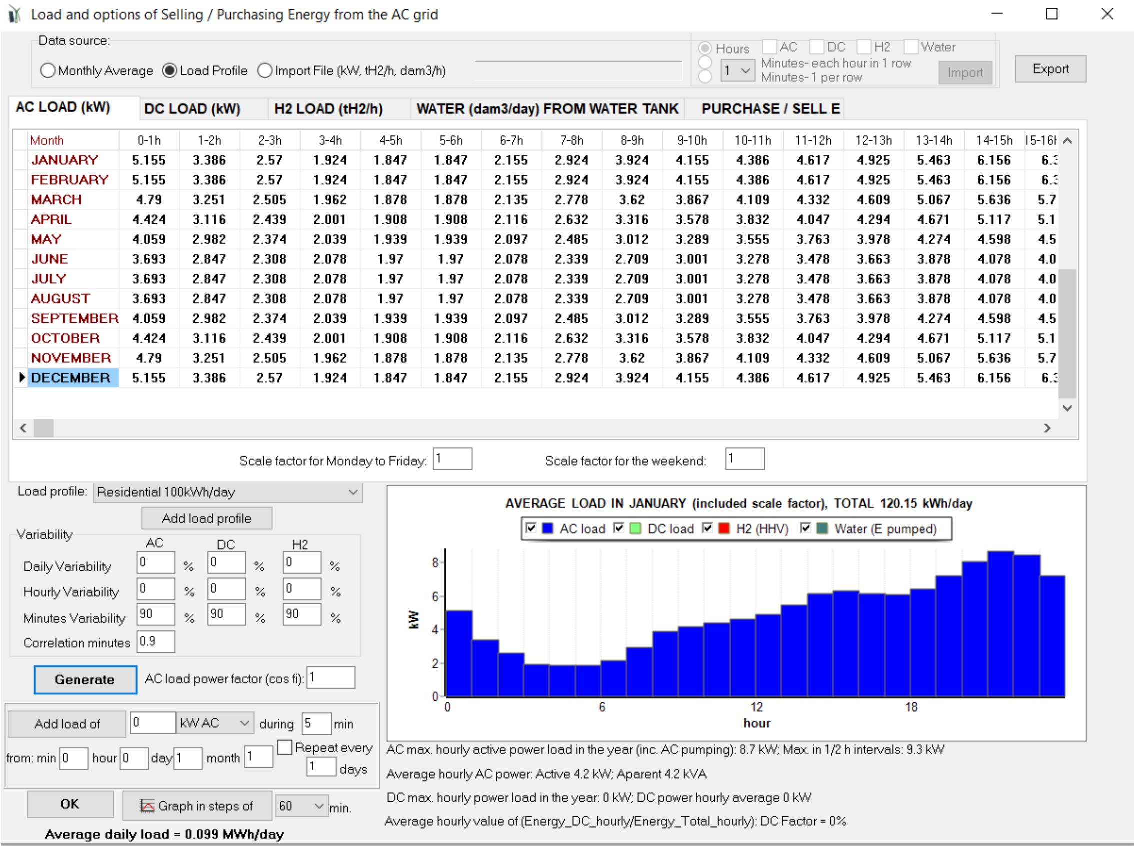
Project-> Options:



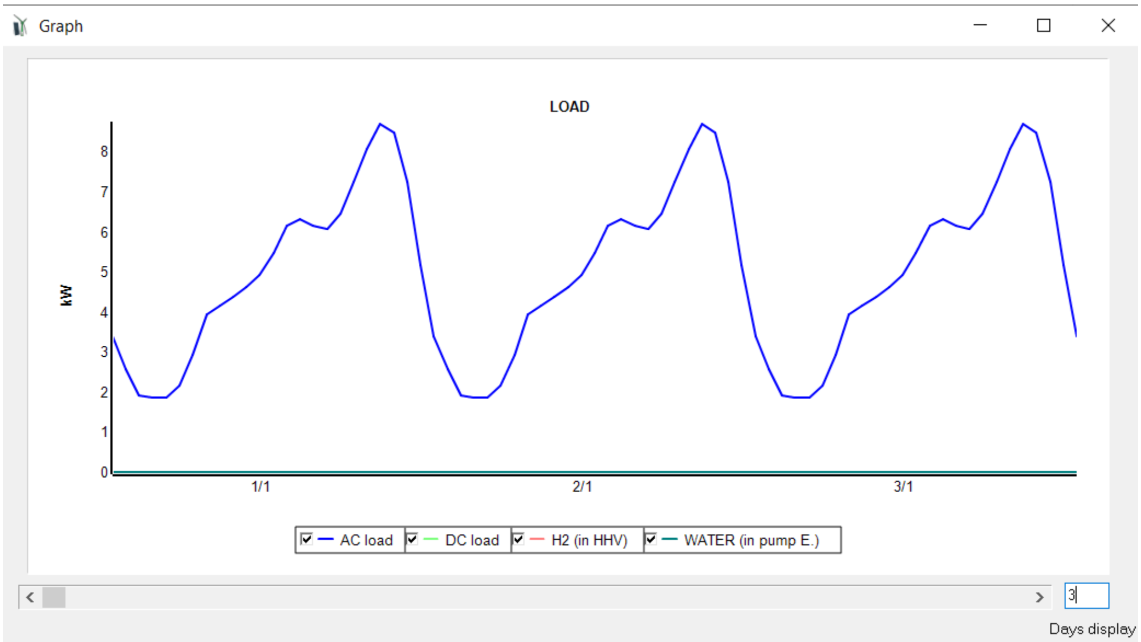
In the **LOAD/ AC GRID** screen, we add AC load, residential load of 100 kWh/day:



We click on **Generate** and approx. 0.1 MWh/day is obtained.

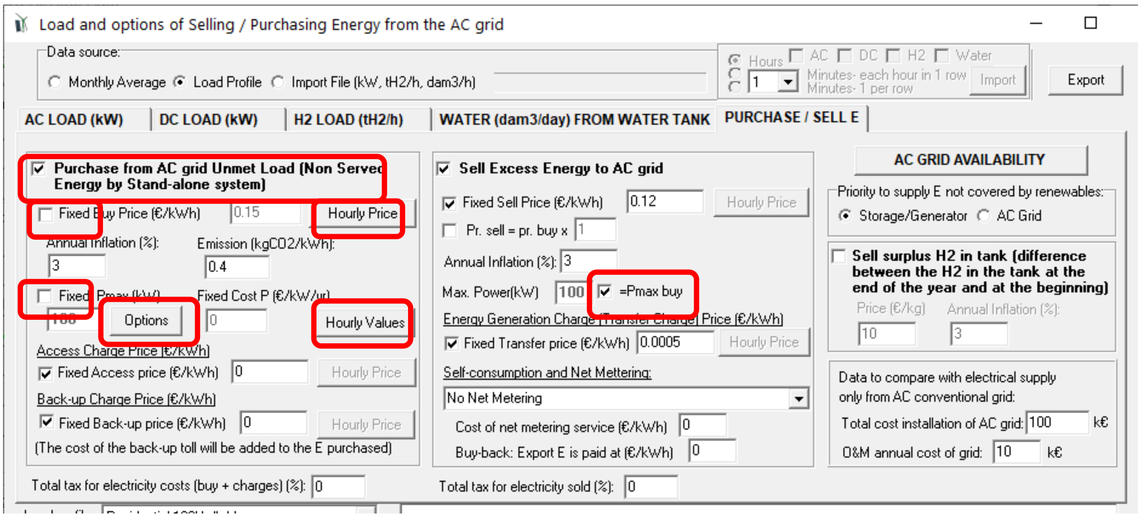


In the graph we can see the load:

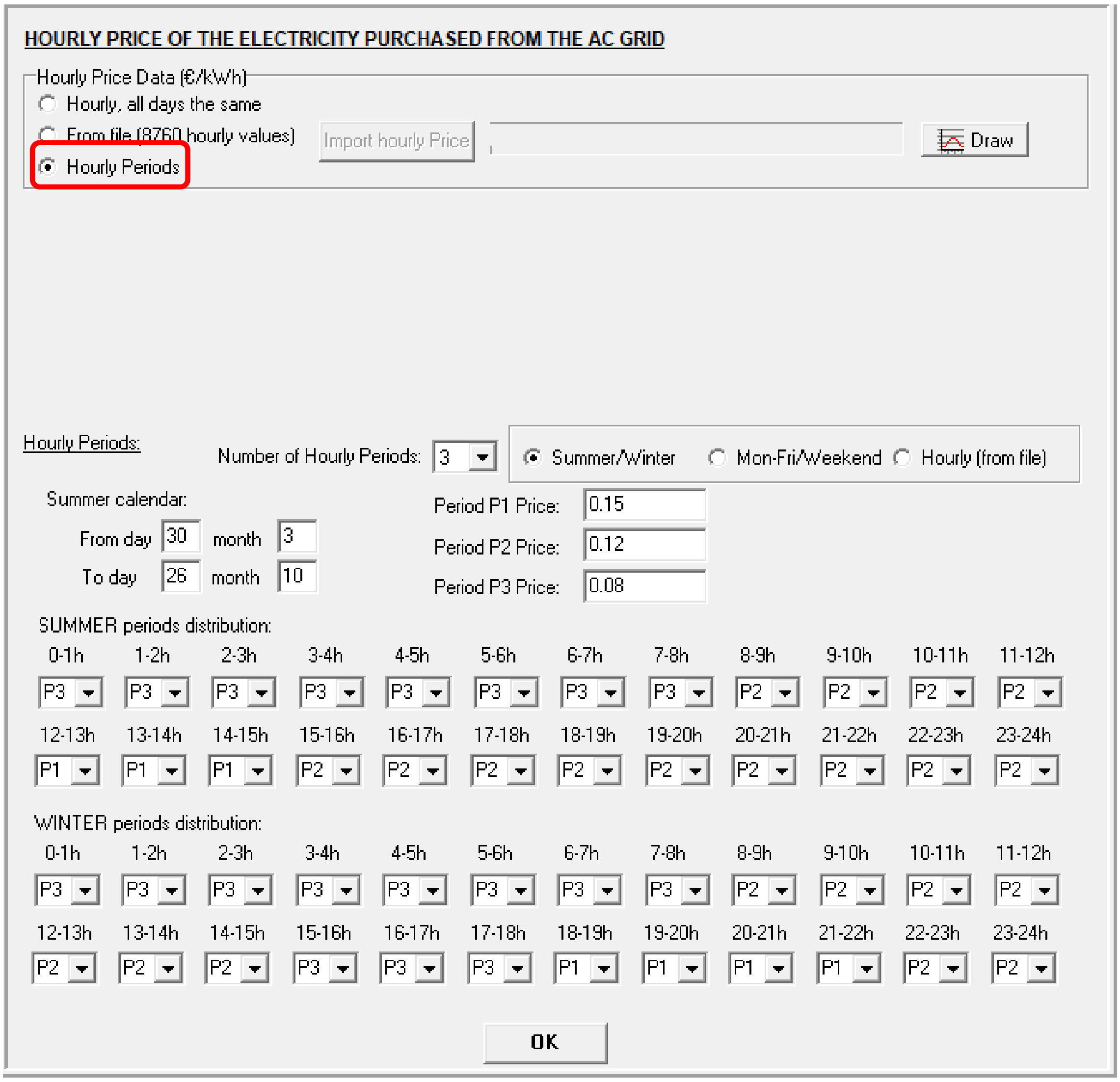


In **PURCHASE / SELL E** tab, let's suppose that the electricity price will be hourly, by periods, and the contracted power also by periods. Select "**Purchase from AC grid Unmet load ….**" and Uncheck "**Fixed Buy Price**" and "**Fixed Pmax**".

In the Sell excess energy to AC grid panel, select “**=Pmax buy**”, this way the maximum power to be injected to the AC gris will be the same as the defined power to purchase from the AC grid.

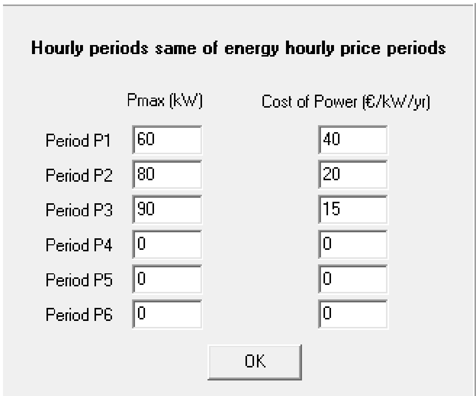


Then click on “**Hourly Price**” button close to the buy price. Select **Hourly Periods** and accept all the default values (3 periods):

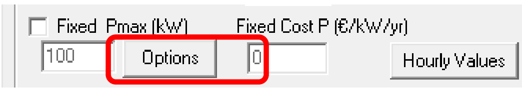


OK and, in the **PURCHASE / SELL E** tab, click “**Hourly Values**” close to the options of the contracted power Pmax.

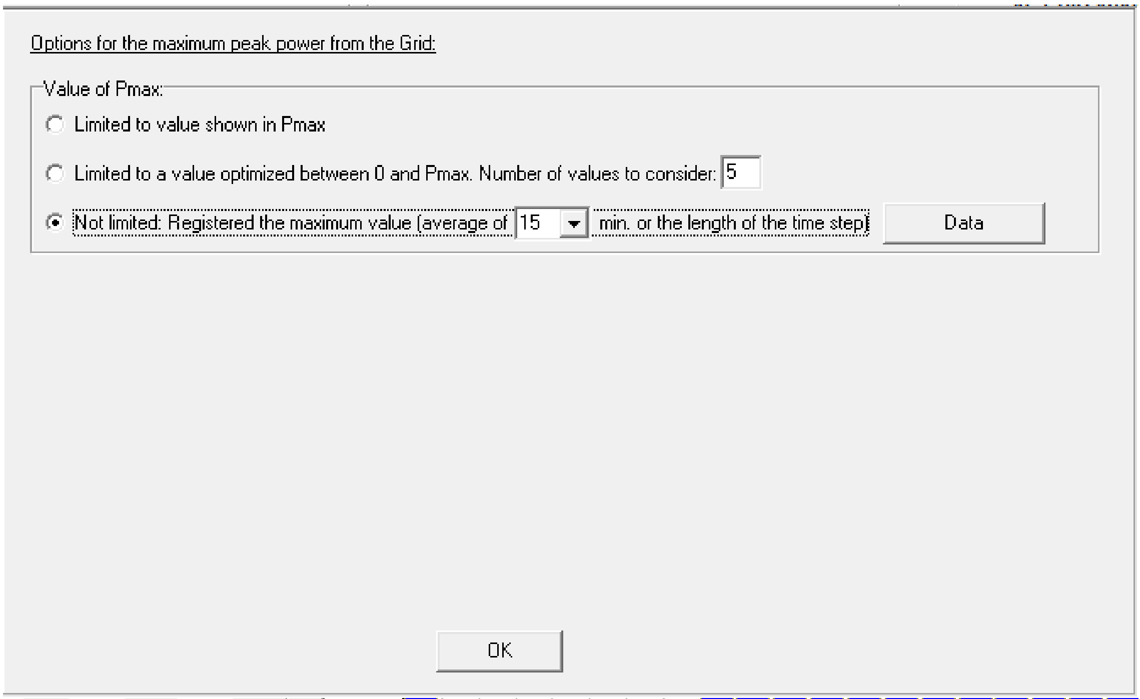
A small window appears. Change the values to the following Pmax and costs for the different peridos P1 to P3 (note that P4-P6 are not considered, anyway we write 0 in them):



OK and, in the **PURCHASE / SELL E** tab, click "**Options**" close to the options of the contracted power Pmax.

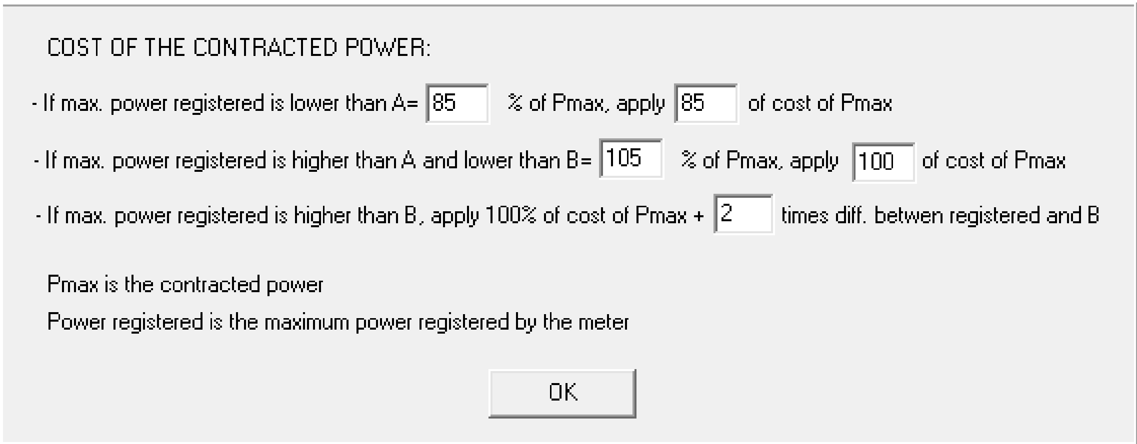


A window appears. We can choose among: Power limited to the value shown in Pmax; Limited to an optimized value (it will be optimized during the opitmization, only valid for period P1), or the third option, which will be the one selected "**Not limited: Registered the maximum value (average of….**"



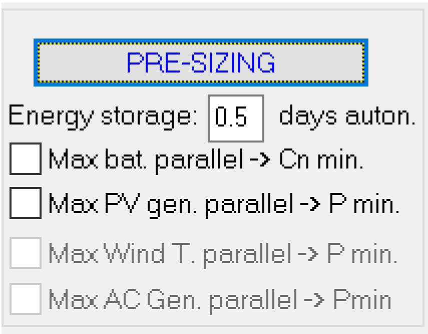
By using this option, the contracted power to buy electricity from the grid will not be the power defined, it will be the maximum power registered during the simulation for each period. However, the maximum power for selling electricity to the AC grid will be the values defined for each period.

And click in the button **Data**, leaving the default values (the way in Spain the cost of power is applied in the electrical bill, when we have the option of registering the maximum value of the power, called "*maximetro*" in Spain):

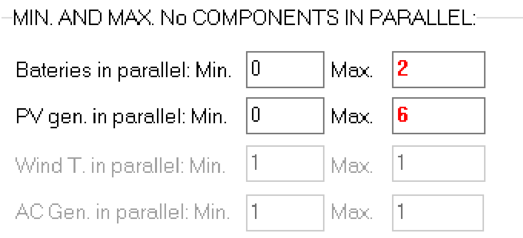


Click OK, OK and OK to return to the main screen.

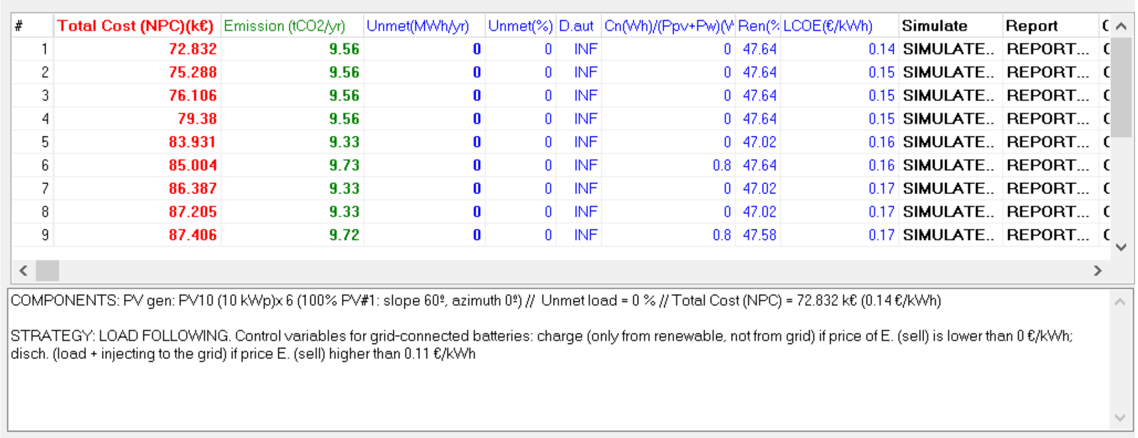
In the main window, in **PRE-SIZING** change to 0.5 days autonomy and and click the button **PRE-SIZING**:



We obtain:



We calculate:



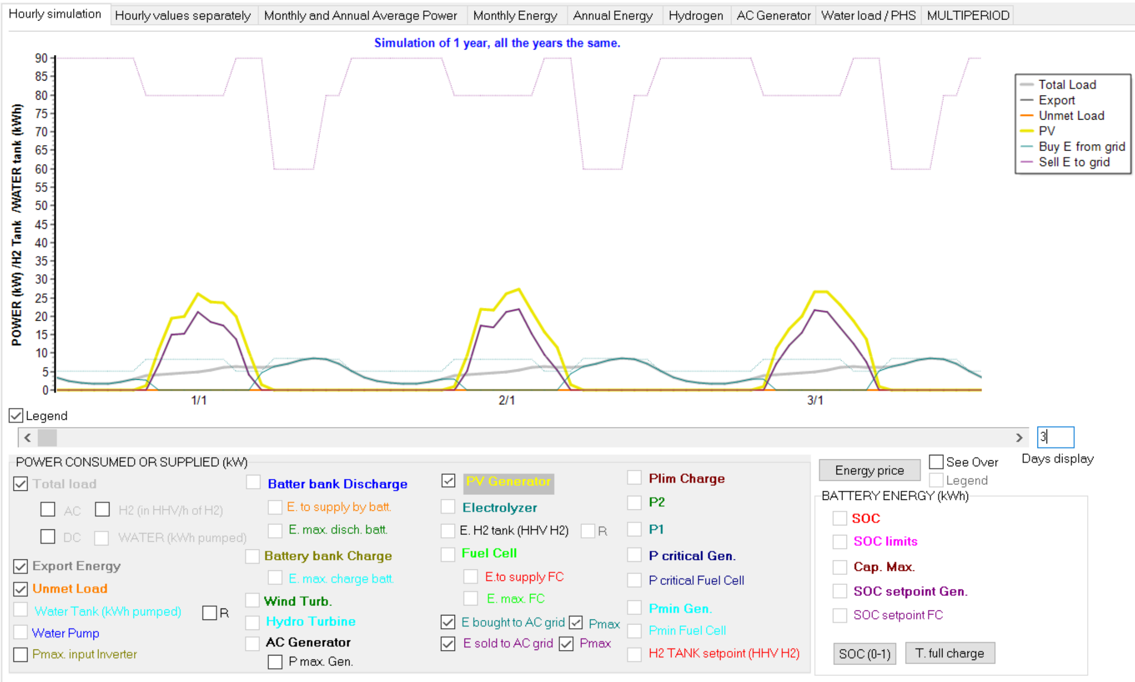
#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	72.832	9.56	0	0	INF	0	47.64	0.14	SIMULATE..	REPORT...
2	75.288	9.56	0	0	INF	0	47.64	0.15	SIMULATE..	REPORT...
3	76.106	9.56	0	0	INF	0	47.64	0.15	SIMULATE..	REPORT...
4	79.38	9.56	0	0	INF	0	47.64	0.15	SIMULATE..	REPORT...
5	83.931	9.33	0	0	INF	0	47.02	0.16	SIMULATE..	REPORT...
6	85.004	9.73	0	0	INF	0.8	47.64	0.16	SIMULATE..	REPORT...
7	86.387	9.33	0	0	INF	0	47.02	0.17	SIMULATE..	REPORT...
8	87.205	9.33	0	0	INF	0	47.02	0.17	SIMULATE..	REPORT...
9	87.406	9.72	0	0	INF	0.8	47.58	0.17	SIMULATE..	REPORT...

COMPONENTS: PV gen: PV10 (10 kWp)x 6 (100% PV#1: slope 60º, azimuth 0º) // Unmet load = 0 % // Total Cost (NPC) = 72.832 k€ (0.14 €/kWh)

STRATEGY: LOAD FOLLOWING. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

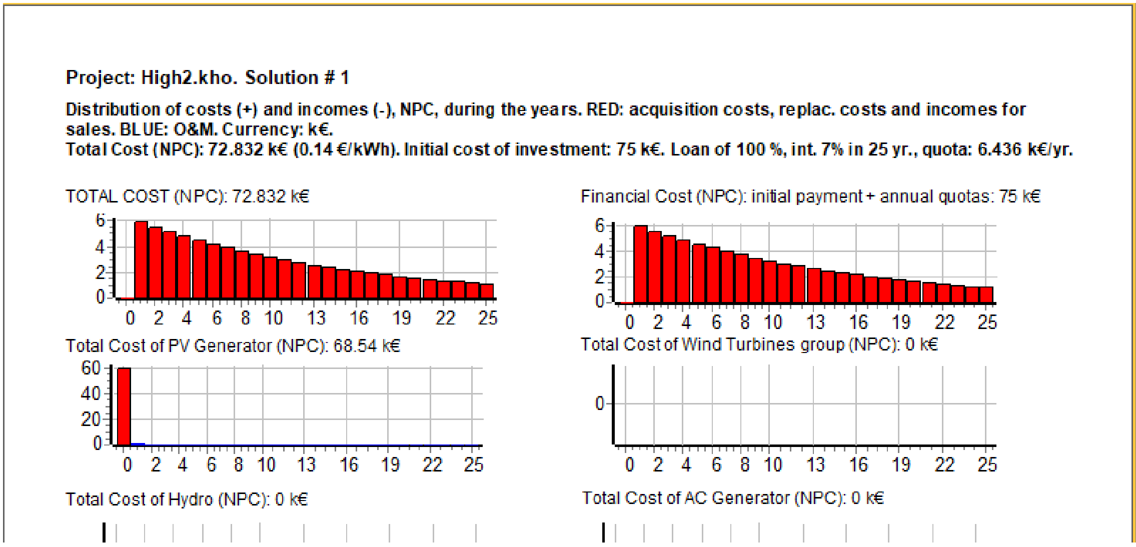
The optimal system is a grid-connected PV generator of 60 kW.

The simulation of the optimal system:



We can see in purple dotted line the contracted power for the different periods (60, 80 and 90 kW), which is the same for purchasing or for selling electricity. In turquoise dotted line we can see the maximum consumed power from the grid, registered for each period and for each month. We can see these values are much lower than the contract power values, so probably the contract power values are not optimal.

In the main screen, in the first row of the results, if we click **COSTS**, we see the report of the costs of the optimal solution.



After closing, it asks for saving the cash flow. We say yes, and then we open it with Microsoft Excel. At the bottom we can see the results of the power registered and the power costs, for the different periods and months. We see the maximum power registered, the power to calculate the cost of the bill and the cost of the bill, for the different periods and months.

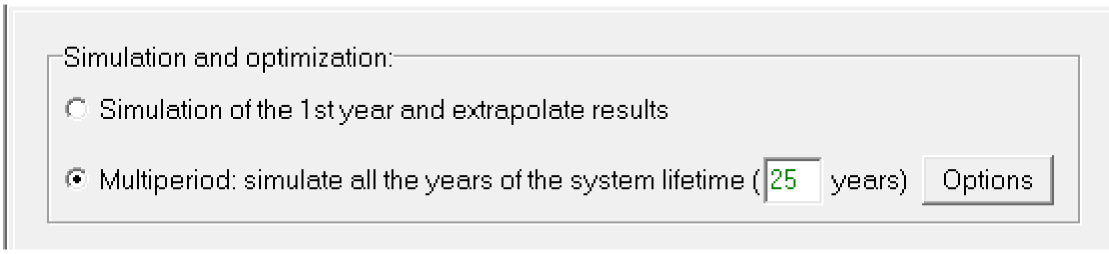
At the end it shows us the optimal contracted power so that the power cost in the bill would be minimized, in this case 6.26 kW for P1, 0 for P2 and 4.36 kW for P3.

	A	B	C	D	E	F	G
43	RESULTS OF THE POWER REGISTERED AND THE POWER COSTS:						
44							
45	*RESULTS OF THE MAXIMUM POWER (kW) FROM THE GRID REGISTERED, 1st YEAR:						
46	MONTH	Period P1	Period P2	Period P3			
47	1	8.695	8.464	5.155			
48	2	8.695	8.464	5.155			
49	3	7.66	7.66	4.79			
50	4	0	6.641	4.424			
51	5	0	5.729	4.059			
52	6	0	4.817	3.693			
53	7	0	4.817	3.693			
54	8	0	4.817	3.693			
55	9	0	5.729	4.059			
56	10	6.625	6.641	4.424			
57	11	7.66	7.552	4.79			
58	12	8.695	8.464	5.619			
59	*Actual contract power is, for the different peridos: 60 kW; 80 kW; 90 kW;						
60	*RESULTS OF THE VALUE OF THE POWER (kW) TO CALCULATE THE COST OF THE POWER IN THE BILL, AND COSTS (k€), 1st YEAR:						
61	MONTH	Period P1(kW	Cost 1st yr.(k	Period P2(kW	Cost 1st yr.(k	Period P3(kW	Cost 1st yr.(k€)
62	1	51	0.1733	68	0.1155	76.5	0.0975
63	2	51	0.1733	68	0.1155	76.5	0.0975
64	3	51	0.1733	68	0.1155	76.5	0.0975
65	4	51	0.1733	68	0.1155	76.5	0.0975
66	5	51	0.1733	68	0.1155	76.5	0.0975
67	6	51	0.1733	68	0.1155	76.5	0.0975
68	7	51	0.1733	68	0.1155	76.5	0.0975
69	8	51	0.1733	68	0.1155	76.5	0.0975
70	9	51	0.1733	68	0.1155	76.5	0.0975
71	10	51	0.1733	68	0.1155	76.5	0.0975
72	11	51	0.1733	68	0.1155	76.5	0.0975
73	12	51	0.1733	68	0.1155	76.5	0.0975
74	*Total cost of the power, 1st year: 4.635 k€						
75	*If not considering that contract power of period P1 <= power of P2 <= power of P3....						
76	Optimal contract power would be: 6.35 kW; 0 kW; 4.78 kW; With a total cost of the power, 1st year: 0.636 k€						
77	*If considering that contract power of period P1 <= power of P2 <= power of P3....						
78	Optimal contract power would be: 6.35 kW; 6.35 kW; 6.35 kW; With a total cost of the power, 1st year: 1.613 k€						

<u>52. High power project, minimization of NPC, multiperiod.</u>

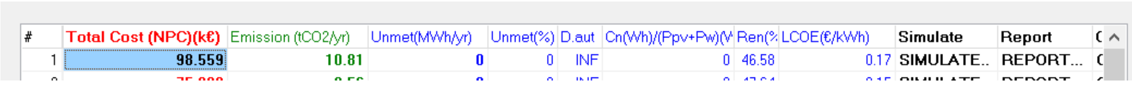
Save the project and then save as with the name “High2-multi”.

We change to multiperiod (**Project->Options**):



With the default options of multiperiod.

We click in the first row of the results and the NPC of the optimal system is much higher:

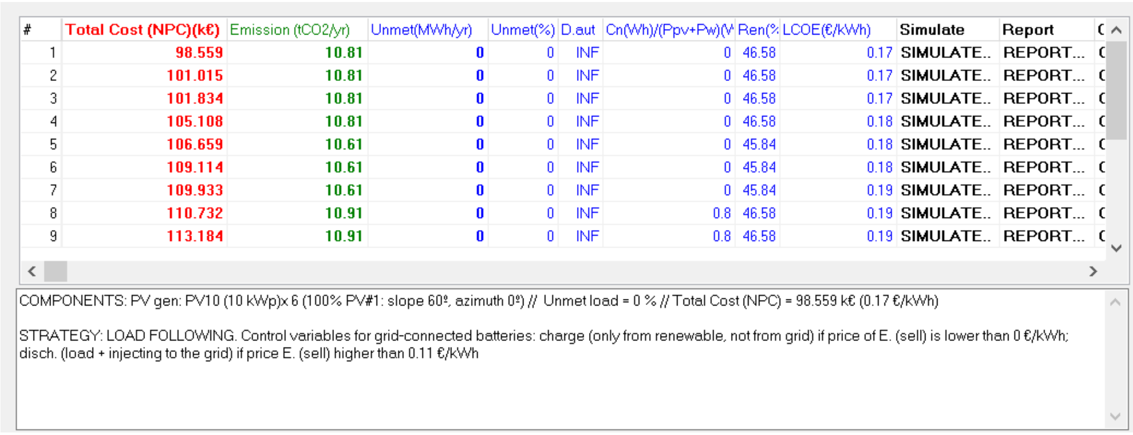


#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	98.559	10.81	0	0	INF	0	46.58	0.17	SIMULATE..	REPORT...	C

So multiperiod affects considerably.

We optimize with multiperiod:

The optimal is the same as in previous section, but with higher cost:



#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C
1	98.559	10.81	0	0	INF	0	46.58	0.17	SIMULATE..	REPORT...	C
2	101.015	10.81	0	0	INF	0	46.58	0.17	SIMULATE..	REPORT...	C
3	101.834	10.81	0	0	INF	0	46.58	0.17	SIMULATE..	REPORT...	C
4	105.108	10.81	0	0	INF	0	46.58	0.18	SIMULATE..	REPORT...	C
5	106.659	10.61	0	0	INF	0	45.84	0.18	SIMULATE..	REPORT...	C
6	109.114	10.61	0	0	INF	0	45.84	0.18	SIMULATE..	REPORT...	C
7	109.933	10.61	0	0	INF	0	45.84	0.19	SIMULATE..	REPORT...	C
8	110.732	10.91	0	0	INF	0.8	46.58	0.19	SIMULATE..	REPORT...	C
9	113.184	10.91	0	0	INF	0.8	46.58	0.19	SIMULATE..	REPORT...	C

COMPONENTS: PV gen: PV10 (10 kWp)x 6 (100% PV#1: slope 60º, azimuth 0º) // Unmet load = 0 % // Total Cost (NPC) = 98.559 k€ (0.17 €/kWh)

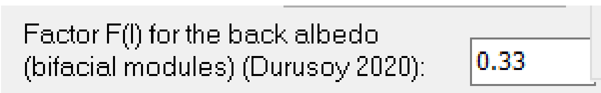
STRATEGY: LOAD FOLLOWING. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

53. High power project, minimization of NPC, multiperiod. Include bifacial PV modules.

Save the previous project and then save as with the name "High2-multi-bifacial".

We want to consider bifacial PV modules. Let's suppose that they are 10% more expensive than the normal PV modules, and the bifaciality is 0.7. We want to consider the previous PV generator of 10 kWp but also a new PV generator of bifacial PV modules, of 10 kWp nominal power (of the front surface) with a bifaciality of 0.7 and the cost of 11 k€ (10% higher).

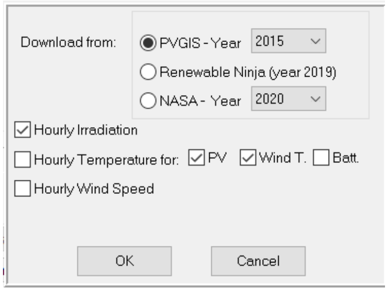
To consider bifacial PV modules, you first need to calculate the irradiation over the back surface of the PV modules. Go to the irradiation screen. We will consider the default value for the factor for the back albedo, F(l) = 0.33:



Then press CALCULATE. We accept. It calculates and we obtain similar irradiation as before for the front surface. For the back surface, 471 kWh/m^2 is the total irradiation of the year.

Daily Average Irradiation (Tilt Surf.): 4.46 kWh/m2
Total Annual Irradiation (Tilt Surf.): 1629.26 kWh/m2
Annual Irr. Back surface / Direct for CPV: 471.29 kWh/m2 / 1304.51 kWh/m2

Now download the irradiation hourly data from PVGIS-2015 (only irradiation).



We obtain the following (back surface irradiation remains):

Daily Average Irradiation (Tilt Surf.): 5.25 kWh/m2
Total Annual Irradiation (Tilt Surf.): 1918.61 kWh/m2
Annual Irr. Back surface / Direct for CPV: 471.29 kWh/m2 / 1310 kWh/m2

Accept and go to the PV generators screen. Add from the database the bifacial PV generator PV10BIF of 10 kWp, cost 11 k€ and bifaciality 0.7.

Name	Power(kWp)	Cost(k€)	C.O&M(%/yr)	Life(years)	NOCT(ºC)	Power T. coef.(%/ºC)	BIFACIALITY(0-1)	CPV	missions(kgCO2/kWp
PV10	10	10	1	25	43	-0.4	0	NO	800
PV10BIF	10	11	1	25	43	-0.4	0.7	NO	800

Therefore, we will consider two PV generators: the normal one and the bifacial one.

Accept and, in the main screen of the software, CALCULATE.

The optimal system includes the bifacial generator PV10BIF (6 in parallel), in this case, although the cost of the PV generator is 10% higher, the increase in PV production compensates it.

#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report	C
2	84.056	10.61	0	0	INF	0	47.73	0.14	SIMULATE..	REPORT...	C
3	84.874	10.61	0	0	INF	0	47.73	0.14	SIMULATE..	REPORT...	C
4	88.148	10.61	0	0	INF	0	47.73	0.15	SIMULATE..	REPORT...	C
5	92.543	10.41	0	0	INF	0	47.07	0.16	SIMULATE..	REPORT...	C
6	93.772	10.72	0	0	INF	0.8	47.73	0.16	SIMULATE..	REPORT...	C
7	94.998	10.41	0	0	INF	0	47.07	0.16	SIMULATE..	REPORT...	C
8	95.817	10.41	0	0	INF	0	47.07	0.16	SIMULATE..	REPORT...	C
9	96.225	10.72	0	0	INF	0.8	47.73	0.16	SIMULATE..	REPORT...	C
10	97.043	10.72	0	0	INF	0.8	47.73	0.16	SIMULATE..	REPORT...	C

COMPONENTS: PV gen: PV10BIF (10 kWp)x 6 (100% PV#1: slope 60º, azimuth 0º) // Unmet load = 0 % // Total Cost (NPC) = 81.6 k€ (0.14 €/kWh)

STRATEGY: LOAD FOLLOWING. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

54. High power project, minimization of NPC, multiperiod. Include CPV.

Save the previous project and then save as with the name "High2-multi-CPV".

Let's consider a normal PV generator of 10 kWp and a Concentrating PV generator (CPV) of 10 kWp from de database. Both will be with sun tracking in both axes.

In the irradiation screen, select for the PV tracking system: both axes:

PV Tracking System: Both Axes

Now download hourly data from PVGIS, 2015, only irradiation. The irradiation for the both axes tracking system will be downloaded:

Daily Average Irradiation (Tilt Surf.):	7.61 kWh/m2
Total Annual Irradiation (Tilt Surf.):	2780.53 kWh/m2
Annual Irr. Back surface / Direct for CPV:	471.29 kWh/m2 / 2050.35 kWh/m2

Global annual irradiation is 2780.5 kWh/m2 (for the normal PV with 2 axes tracking) while direct is 2050.3 (for the CPV).

In the PV screen, change the bifacial PV for the CPV of the database (CPV10). Then, modify the name of the generator PV10, adding "-T2axes" to increase the costs to 14 k€, adding the cost of the tracking in two axes (let's suppose that the CPV10 already includes the tracking cost).

PHOTOVOLTAIC GENERATOR DATA:

Name	Power(kWp)	Cost(k€)	C.O&M(%/yr)	Life(years)	NOCT(ºC)	Power T. coef.(%/ºC)	BIFACIALITY(0-1)	CPV	missions(kgCO2/kWp
PV10-T2axes	10	14	1	25	43	-0.4	0	NO	800
CPV10	10	12	1	25	43	-0.14	0	OK	800

Optimize the system. In this case, the optimal solution includes the normal PV (higher cost but much higher irradiation). The optimal system includes 6 generators of 10 kWp.

#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W	Ren(%	LCOE(€/kWh)	Simulate	Report
1	53.388	10.01	0	0	INF	0	51.34	0.09	SIMULATE..	REPORT...
2	55.844	10.01	0	0	INF	0	51.34	0.09	SIMULATE..	REPORT...
3	56.662	10.01	0	0	INF	0	51.34	0.1	SIMULATE..	REPORT...
4	59.936	10.01	0	0	INF	0	51.34	0.1	SIMULATE..	REPORT...
5	65.56	10.12	0	0	INF	0.8	51.34	0.11	SIMULATE..	REPORT...
6	68.013	10.12	0	0	INF	0.8	51.34	0.11	SIMULATE..	REPORT...
7	68.831	10.12	0	0	INF	0.8	51.34	0.12	SIMULATE..	REPORT...
8	69.047	9.85	0	0	INF	0	50.4	0.12	SIMULATE..	REPORT...
9	71.503	9.85	0	0	INF	0	50.4	0.12	SIMULATE..	REPORT...

COMPONENTS: PV gen: PV10-T2axes (10 kWp)x 6 (Track. Both axis) // Unmet load = 0 % // Total Cost (NPC) = 53.388 k€ (0.09 €/kWh)

STRATEGY: LOAD FOLLOWING. Control variables for grid-connected batteries: charge (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh