GETTING STARTED. iHOGA 4.0.

Updated Dec. 21, 2024

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

This guide is designed to follow sequentially.

Users of the EDU version can perform all the steps up to section 25. From this section it is only possible to continue with the PRO+ version.

Sections 28 and 29 can be skipped if you are not interested in them.

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iHOGA needs to run:

- Internet connection to check the license validity (and to download from web databases the values of irradiation, temperature and wind speed data).

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 (<u>http://www.dopdf.com/es/</u>)

Virtual machines:

iHOGA software does not run under virtual machines or hypervisors.

Even if you do not use it, virtualization is enabled by default in many new computers BIOS.

Deactivate virtual machines or hypervisors if, after installing, when you open the software you obtain the following message "Failed to start the trial: The function failed because this instance of your program is running inside a viertual machine / hypervisor and you've prevented the function from running inside a VM."

(it can happen due to the default virtualization activation in the computer BIOS, in this case you must disable it in BIOS, see the last page of the following document):

How to deactivate virtual machine / hypervisor

Screen settings:

In Windows, select Settings > System > Display > Scale and layout (in your language).

Usually the optimal display resolution is the recommended value, but in some cases the software visualization improves with other values. Also, in the field "**Change the size of text, apps, and other items**" usually it is better to use 125% or even higher. We recommend using at least 125 percent scaling on 1080p display resolutions and higher to make it easier on your eyes, but find the scaling that works best for you. If you see the software screen much lower than your display, change that value to 150% or even higher.

Depending on these settings, the visualization of the software will be better or worse.

← Settings		7	×
ம் Home	Display		
Find a setting	Scale and layout		^
System	Change the size of text, apps, and other items		
	125% ~		
🖵 Display	Advanced scaling settings		
ゆり) Sound	Display resolution		
Notifications & actions	2560 × 1440 (Recommended) ~		
· · · · · · · · · · · · · · · · · · ·	Display orientation		
J Focus assist	Landscape \lor		
() Power & sleep	Multiple displays		
📼 Storage	l Multiple displays		
CB Tablet	Extend these displays \sim		
曰† Multitasking	Make this my main display		
Projecting to this PC	Advanced display settings		~

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 set 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 (<u>https://ihoga.unizar.es/en/descarga/</u>). In that case the economic results that will appear later in this guide (in \in) will be different from yours (in another currency).

After selecting the default currency, the following window appears.

	iHOGA type of project					
IOW POWER PROJECT: load in W, energy in kWh, currency in its m.u. (.hoga project)						
⊖ HIGH POWER PR	OJECT: load in kW, energy in MWh, currency in k m.u. (.kho project)					

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 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.

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 will occur.



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

Note that, in some computers, writing in C: needs administrator permission. If iHOGA reports an error related to writing access, you should close the software, open it again, create the project again and save it in another root (D:, E:...).

You can check that 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.

Simulation and optimization:	
Simulation of the 1st year and extrapolate results	
) Multiperiod: simulate all the years of the system lifetime (years)	
conomic optimization:	
) Minimize Net Present Cost (NPC), usually for off-grid systems and high load on-grid ——>	Min. NPC Min. LCOH Min. Payback period Max. IRR savings vs AC only
) Maximize Net Present Value (NPV), usually for low load or no-load on-grid systems	
□ When saving the project update all the results of the table to the present conditions	Max. NPV Min. LCOE Min. LCOH Max. Cap.F. min. LCOE Max. IRR Min. Payback period
$oxed{\Box}$ In the simulation window, show the probability density function (PDF) of the main results	
When clicking a component in a table, update the component with the values of the database	e
Number of decimal places in results of costs 1	
Number of decimal places in results of energy 1 V	

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 consumption) or maximizing the net present value (NPV) of the system (for grid-connected power generators without load or with low load). NPV optimization is only possible for PRO+ version. We leave the default value (minimization of NPC, which is the only option available in EDU version).

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.

Project: D:\Pr1.hoga			– 🗆 X
Project Data Calculate Data Base	Report Help		
🖌 LOAD / AC GRID	ENERAL DATA OPTIMIZATION (CONTROL STRATEGIES FINANCIAL DATA RES	SULTS CHART
VIDD / ALCHID ULL RECURSOS ✓ SOLAR WIND HYDRO COMPONENTES ✓ PY PANELS WIND TURB HYDRO TURB #YORO TURB ✓ AC GENERATOR H2 (F.C Elycer) ✓ CHARGE BAT. DC Voltage 48 V CHARGE BAT. DC Voltage 48 V AC GENERATOR H2 (F.C Elycer) ✓ CHARGE BAT. DC Voltage DC Voltage 48 V AC Gene parallel > P min. Max K/D en. parallel > P min. Max K/D en. parallel > P min. HDI and Jobs Sensitivity Analysis Probability Analysis Probability Analysis @ CALCULATE I REPORT I REPORT	COMPONENTS PV panels Wind Turbines Battery bank AC Generator 1 Nevter 1 Nevter	MIN. AND MAX. No COMPONENTS IN PARALLEL Bateries in parallet Min. 1 Max. 1 Pypen. in parallet Min. 0 Max. 8 Wind T. in parallet Min. 1 Max. 1 AC Gen. in parallet Min. 1 Max. 1 CONSTRAINTS: Maximum Ummel Load allowed. 1 % annual (Ummet load can be covered by AC grid if it exists and it is allowed in "LOAD / AC GRID" window) More Constraints	OPTIMIZATION PARAMETERS SELECTED BY: HOGA USER Maximum execution time: Hommum time for the Genetic Algorithms Simulation: Simulation: Simulation starts: BO hour () day (1 month 1) Compare with Worth Month Method (PV-bet.) Days of battery autonomy (4) COMPARE with Worth Month Method (PV-bet.) Days of battery autonomy (4)

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.

G	ENERAL DATA	OPTIMIZATION	CO
	COMPONENTS	-	
\langle	Wind Turbines		>
	Hydro Turbine	4	
	🗹 Battery bank		
	AC Generator		
	🗹 Inverter		
	🗌 H2 (F.C Elyz	er.) 🕂	

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. We will do it later.

🕅 Project: D:\Pr1.hoga		
Project Data Calculate Data B	Base Report Help	
🖌 LOAD / AC GRID	GENERAL DATA OPTIMIZATION	CONTROL ST
RECURSOS ✓ SOLAR ! WIND HYDRO	COMPONENTS PV panels Wind Turbines	MIN. AND Bateries in PV pan. in
COMPONENTES	Hydro Turbine	Wind T. in AC Gen. in
WIND TURB.	AC Generator	CONSTRA Maximum
V BATTERIES	🗹 Inverter	(Unmet I and it is
✓ INVERTERS ✓ AC GENERATOR	H2 (F.C Elyzer.)	
H2 (F.C Elyzer)		
V CHARGE BAT.		۵

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.

DC Voltage	48	V 🗌 SOC d.
AC Voltage	230	V

If the checkbox "SOC d." is checked, 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 and/or water consumption pumped from a river or a well to the water storage tank or reservoir) and the data of purchasing and selling electrical energy to the AC grid or selling surplus hydrogen.



We obtain the following window (in EDU version only AC LOAD tab is visible):



For each type of load, we could introduce the data by importing from a table file with the hourly load profile of each month or importing from a file with the data of the whole year in hourly or in lower time steps (see the user manual, section 3.2). However, in this case we will use the default tables.

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 (instead of 308 W)
- Every day of the year, between 20 and 21 h the consumption is 370 W (instead of 286 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:

				1 d	1 st step: Enter the new value at the desired time of the month of JANUARY				2 nd or l	step: (eft	Click on	the bo	k to the	e right		
AC LOAD (W)	DC	LOAD (W))	H2 LOAD	(kg/h)	WATER	(m3/day)	FROM V	ATER T	ANK (PR	EVIOUS	Y Р ИМ Р	E0) P	URCHAS	E 7 SELI	E
Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11,72.0	12-13h	13-14h	14-15h	15-16 ^
I 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 (the lower graph, which shows the load consumption, will automatically be updated). In this way we avoid having to enter all the data in the column one by one:

	\sim								
10-11h	11-12h	2-13h		13-14h	14-15h	15-16			
110	308	450		220	176	1!			
110	308	450		220	176	15			
110	308	450	Π	220	176	15			
110	308	450	Π	220	176	- 15			
110	308	450	Π	220	176	- 15			
110	308	450	П	220	176	- 15			
110	308	450	Π	220	176	- 15			
110	308	450	Π	220	176	15			
110	308	450		220	176	- 15			
110	308	450		220	176	15			

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	ĺ			
2	264	370	264	242	Ī			
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 this case we won't do it, but we could change any other value of the table, and we could have different values for each month, just changing the corresponding value. Also, we could import a table with all the data as shown in the user manual, section 3.2. And we could also import a file with hourly data of all the year, or even using lower time steps (up to 1 minute), see user manual, section 3.2.

It is important to note that, when you change the values of the tables (not only the tables of the load, but also the tables of the components), the changes done in the tables will remain even if you do not save the project.

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.

In all iHOGA data boxes, the decimal spacing must be entered as defined in your computer 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".

Scale factor for Monday to Friday:	1
------------------------------------	---



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 will be randomly modified between +5 and -5%) and 3% per hour (the energy envisaged for each hour will be randomly 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</u> <u>computer are slightly different from those obtained in this guide, since the AC load will not be</u> <u>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).

Generate	AC load power factor (cos fi): 1
Generate	AC load power factor (cos fi); 1
	· · · · · · · · · · · · · · · · · · ·

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.



If 60 min. is selected (default), clicking the "Graph in steps of" button we obtain:



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", default 1 day. 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.

You can see the horizontal grid by clicking on the "Horizontal grid" checkbox. Horizontal axis labels can be seen in alternate positions by clicking on "Alt" checkbox (if you have select less than 60 min. for the graph, you will see the hours and the half hours). Vertical grid is shown by clicking on "Vertical grid" checkbox. Scroll change in days can be set for small changes (changes in the screen when you click in the arrow of the scroll) and for large changes (changes in the screen when you move the scroll cursor or when you click in the scroll bar).

For example, we can see 3 days at the same time (3 Days display), with horizontal grid (darker grey at 12:00 h of each day if more than 1 day displayed) and vertical grid, and each time we click in the scroll arrow the graph will move 0.1 days, and each time we move the scroll cursor the graph will move 1 day):



You can zoom in the graph (draw a window with your mouse over the area to be enlarged: click from top left to bottom right). For example:



To undo the zoom window, click and drag from bottom right to top left.

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

Select "1 minute":



And then click again on the "**Graph in steps of**" button the load curve is displayed (it can take some seconds to appear). In the example 15 days are seen. We can see the first two days of the year are weekend days (higher load), next 5 days are weekdays (lower load).



By clicking "Back" button 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 7:00:00 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 1 day), 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 the LOAD/AC GRID 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 iHOGA, 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 <u>https://www.google.com/maps</u> 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 -15.51° (west, negative). Enter these values (top left corner of the screen):

SOLAR RESOURCE	
Latitude (*) (+N, -S) :	Get data from local DB
Longitude (º) (+E, -W) : -15.51	Download hourly data
Locate on map Update coord.	Download NASA monthly data

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 1° lat x 1° long. around the location (solar data source is a global 1° x 1° latitude/longitude grid while the meteorological data sources are $\frac{1}{2}^{\circ}$ x $\frac{1}{2}^{\circ}$ 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:

	Irradiation av. horiz. s
January	β.6
Februray	4.92
March	5.38
April	6.28
Мау	5.86
June	7.26
July	6.02
August	6.21
September	5.92
October	4.33
November	3.58
December	3.44

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". (Available in <u>https://www.dropbox.com/s/p3sd0t3ru19lros/RESOURCES-EDU-eng.exe?e=1&dl=0</u>). 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 could 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/m² of each hour), a file with data in minutes (inclined surface) or average monthly data (12 data, one for each month, in different formats). In our case, when downloading from NASA (monthly values), we obtain average daily data per month in kWh/m², so we don't change the default option "**Monthly average**", Radiation Horizontal Surface (kWh/m²).

Data source for Global irradiation	rom File	Steps	A Horiz
Generat (equiva	ion of PV gen. (kW) normalized to 1 kWp Ilent to irradiance kW/m2 x PR)	Minutes- each hour in 1 row (tilt, in kW/m2) Minutes- 1 per row (tilt surf. in kW/m2)	Import
Data Source for Monthly Average	Daily Irradiation: Radiation Horizontal Surface (kWh/m2) calculation Method for Hourly Iradiation:	
Irradiation Irradia	etion PV Tracking System: No Track	ing VOLiu & lordan OErbs et al	
January [3.6] 3.48 k	Wh/m2 Factor F(I) for the back albedo (bifacial modules) (Durusoy 202	20): 0.33 Collares-Pereira & Rabl Graham	

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 & 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 (#1 and #2) 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 0^o (for northern hemisphere, that is, orientation towards the south) and the optimal inclination for our case will be obtained by pressing the button "<u>Optimal slope#1</u>" (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 40^o:



Shadows that affect our PV generator must be defined before calculating the irradiation or before downloading hourly 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):

Variability minutes, conclation ractori, 10.0 1, stu, dev., 10.4	Variability minutes: correlation factorn:	0.9	; std. dev.:	0.2
--	---	-----	--------------	-----

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:

OK	(Calculate)	🔄 Graph in steps of	60 ~ min.	Export horiz.	Export tilted
					-		

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 (40^o) 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**" we obtain the following curve, without minute variability.



By clicking "**Back**" we return to the irradiation screen. Change again the variability to the original values:



Then we click again the "**Calculate**" button, and see the graph again:



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

6. Wind speed data.

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

👔 Project: D:\Pr1.hoga					
Project	Data	Calculate	Data		
	🖊 LOAI	D / AC GRID			
VIND					
	HY	DRO			

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).

\checkmark		
82		Hourly wind sp. data: Shape factor (b):
date min	m/s	Calculation of wind speed for each minute; std. dev.
_	11/2	Calculation of wind speed for each minute, std. dev. j.

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:

Surface	Rou	Ighne	SS		
Class	1	\sim	Length	0.03	m
Agricul neither buildin	tural hedi gs. C	open ges a)nly si	area with Ind with ve moothly re	iout fenc ery dispe ounded l	es ersed hills

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

Surface Roughne	SS		
Class 2 💙	Length	0.1	m
Agricultural area v and preserving h with an approxime	with some edges 8 r ate distan	e building: meters hig nce of 500	s gh m.

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.

Data to download: Year 2019 🗸 🗸
 Monthly Average Irradiation Monthly Average Temperature For Bat. ✓ Monthly Average Wind Speed ✓ At 10 m height ✓ Consider roughness At 50 m height Wind Speed Weibull Shape Factor Altitude above sea level
OK Cancel

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

nput 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).

Data source		
 Monthly Average 	◯ Import data file (in m/s)	Hours Minutes (60 per row) Import Minutes (1 per row)

In our case we are using monthly data from NASA, so 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:

	Monthly Average Data:
<	Monthly Average Speed
	Night speed, Amplitude, F Factor and Hour max speed

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).

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		
			Y
ourly wind sp.	data: Shape factor	(b): 2.9	0.82

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:

	K < F H + - A	~ × (•				
Name	Imax(A)	Vdcmin(V)	Vdcmax(V)	Acq. cost (€)	MPPT	^	
STECA: PR 1010	10	12	24	95	NO		
STECA: PR 1515	15	12	24	113	NO		
STECA: PR 2020	20	12	24	122	NO		
STECA: PR 3030	30	12	24	147	NO		
STECA: TAROM 235	35	12	24	237	NO		
STECA: TAROM 245	45	12	24	278	NO		
STECA: TAROM 440	40	48	48	298	NO		
STECA: P TAROM 2070	70	12	24	1320	NO		
STECA: P TAROM 2140	140	12	24	1700	NO		
STECA: P TAROM 4055	55	48	48	1500	NO		
STECA: P TAROM 4140	149	48	48	2215	NO		
STECA: 2 x P TAROM 4140	298	48	48	4430	NO		
STECA: 3 x P TAROM 4140	447	48	48	6645	NO		
STECA: TAROM MPPT 6000	60	48	48	206	OK		
STECA: SOLARMIX MPPT 2010	20	12	24	206	OK.		
VICTRON: BLUESOLAR MPPT 70/15	15	12	24	90	OK.		
VICTRON: BLUESOLAR MPPT 40	40	12	24	279	OK.		
VICTRON: BLUESOLAR MPPT 75/50	50	12	24	315	OK		
VICTRON: BLUESOLAR MPPT 150/70	70	12	48	800	OK		
MORNINGSTAR: TRI STAR MPPT 45	45	12	48	528	ОК	~	
1	Multiply costs of PV Batt. Ch. Controll	er by factor	1				
		Dall Charge		_			Ī

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".

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).

It should be noted that, for each type of component, there are thousands of commercial units in the market. The database only includes several commercial or generic components. The prices of the components vary by country, even within the same country it depends on different variables. Therefore, the designer must define its own database, changing the components to his/her needs, and verifying or modifying the prices conveniently. We will leave everything as it is by default, later the designer can change what he/she wants.

It is important to note that, when you change the values of the tables, the changes done in the tables will remain even if you do not save the project.

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:

PHOTOVOLTAIC MODULES DATA:					'				
DVGUUM	Nom Volt (V) Iscú	 A) Power(6/n) 	Cost(f)	COSMIRAN	Life(vpars)	NOCTOC	Power T. coef (%80)	BIFACIALITY(0-1)	re
aSi12-Schott: ASI100	12 6.7	9 100	110	1.1	25	49	-0.2	0	N
Efficiency due to degradation of the module Standard conditions	is, losses in wires, dirt in Includes Meximum Power	panels, etc. 03 Point Tracking (MPR	PTJ					Fixed Oper Maintenanc 40	> ation and ce Cost €/yr
PV generator is connected to AC bus (Annual Inflation Rate for PV Generator Cost:	it has its own inverter) → -2%	Number of PV mo	odules in seri Max. Ve reductio d in 59.6 years	al: 4	PV inverter (. Cost (e.g., for yen. cost introc	an expected 7 iuce "-70%"):	70% -70 %		

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). Note that the acquisition cost or CAPEX (5th column, "Cost(\in)") of the PV modules should include the proportional cost of the mounting structure, cabling, connectors, etc. (and the installation cost if it is not defined later in the financial data).

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".

V PV PANELS		
Add PV panel Add PV panels family Name Add PV panels family Name asi12-Schott: ASI100	Zero SiM12-Atersa: A10U SiM12-Atersa: A20U SiP12-Atersa: A20U SiP12-Atersa: A35P SiP12-Atersa: A135P SiP24-Atersa: A135P SiP24-Atersa: A280P SiM124sofoton:1s10 SiM124sofoton:1s20 SiM124sofoton:1s20 SiM124sofoton:1s50 SiP12-Suntech:STP-50 SiP12-Suntech:STP-50 SiP12-Suntech:ST-130 SiP12-Suntech:ST-130 SiP12-Suntech:ST-130 SiP24-Schott:Mono190	

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

PHOTOVOLTAIC MODULES DATA:									
Name	Nom.Volt.(V)	lsc(A)	Power(Wp_dc)	Cost(€)	C.O&M(€/yr)	Life(years)	NOCT(°C)	Power T. coef.(%/#C)	BIFACIALITY(0-1) (🔨
aSi12-Schott: ASI100	12	6.79	100	110	1.1	25	49	-0.2	1 0
SiP12-TAB:PV-135	12	8.73	135	247	2.47	25	45	-0.47	10

Suppose in our case we want to consider that the cost of the new module (including the proportional cost of the mounting structure, cabling, connectors, etc.) 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 (and it will remain modified for other projects) and then, in the PV screen, add it from the database (if in Project->Options it is checked the box "When clicking a component in a table...", by clicking on the row of this PV panel, its cost would be updated).

Another option is to change the name on the screen (for example, add "mod") and change the price. If in Project->Options it is checked the box "When clicking a component in a table...", 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 will use the second option to change the cost: 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 \notin 160 and the O&M cost to \notin 1.6 (we want to keep the O&M cost of each individual module as 1% of the acquisition cost):

	Name	Nominal Voltage	Shortcu Current	t Nominal Power	Acquistion Cost	O&M Cost (unit)
Γ	Name	(V)	(A)	(Wp)	(€)	(€/year)
	aSi12-Schott: ASI100	12	6.79	100	110	1.1
Ð	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), the button "Standard conditions" (where the standard conditions for the PV and CPV data are set) and the option to consider MPPT.

Efficiency due to degradation of the modules langest in using distinguishing at 0.8	Fixed Operation and
	Maintenance Cost
Standard conditions	40 €/yr
PV inverter or battery charge regulator includes Maximum Power Point Tracking (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 (it would only be available in PRO+ version).



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 consider 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 (only available in PRO+ version). In our case the PV generator will be connected to the DC bus so that checkbox remains unchecked.

F	∛ generator is connected to AC bus (it	has its own inverter)>	Number of PV modules in serial: 4 PV inverter data
	Annual Inflation Rate for PV modules Cost :	-2 %	Max. Variation of PV moduless Cost (e.g., for an expected 70% reduction on current PV modules cost, introduce ''-70%''): $$70\$
		Limi	t is reached in 59.6 years

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). Of course, these

values could be changed. 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.

-C	OMPONENTS	
	V PV PANELS	
	WIND TURB.	

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								Outpu	t Power	(W) vs \	Wind Sp	eed				
Γ	Name	Туре	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
Þ	Southwest:Whisper100	DC	2865	2315	85	15	11	650	0	0	2	25	55	100	192	284	442
Г																	

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 15°C, that is, 1.225 kg/m³) and the height above sea level of our location (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 of our location (in our case 1.212 kg/m³) 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.

Surface Roughness
Class 2 V Length 0.1 m
Agricultural area with some buildings and preserving hedges 8 meters high with an approximate distance of 500 m.
Power curve measured at air density (kg/m3): 1.225
Height above sea level: 109 m
Air density at that height is (ISA) 1.212 kg/m3



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/m³). We don't change it.

When simulating, adjust power c	urve with air	density:
Use height above sea level a	und temp. 🤇	Graph
◯ Import air density (kg/m3)	Import	

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.

Do not cons	ider reduction in Power after:
14 m/s 💌	(check if wind t. are pitch controlled)

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).

Do not consider reduction in Power after: 14 m/s (check if wind t. are pitch controlled)	Annual Inflation Rate expected for Wind 1	Max. Variation of Wind Turbines Cost expected (e.g., for an expected 35% reduction on current Wind Turbines cost, introduce "-35%"): 35 - 35
ОК	Limit	is reached in 42.9 years

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	e at 20	°C		Cycles	to Failu	re vs. D	epth of	Discha	rge (%)				
	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	۷ ۸
	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	
Þ	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	
																					~
<																					>

The cycles to failure vs depth of discharge of the battery which is clicked in the table is shown in the graph below (red curve, left axis). Also, in the green curve (right axis) we can see the total energy cycled during the battery lifetime, depending on the depth of discharge (calculated with the battery capacity and the cycles to failure).



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

Add Battery	Zero	~

Now the "Zero" is added:

		C.nom.	Vn	/ (
	Name	(A·h)	(V)	
	OPZS-Hawker:TLS-3	180	2	
	OPZS-Hawker:TLS-5	270	2	
	OPZS-Hawker:TVS-5	390	2	
Þ	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 group above the table:

Add Battery	Zero			~		-			
Add Batteries family	OPZS-H	awker	~		▶ +(-)	▲ ✓ :	× C		
BATTERIES DATA							FIG	at life a	• 20
BATTERIES DATA:	a (11)		0	0.0414/01	000 1 00	0 K 1911 1	Flo	at life a	at 20
BATTERIES DATA: Nome	Cnom.(Ah)	Volt.(V)	Cost(€)	C.O&M(€/yr)	SOCmin(%)	Self_d(%/mon.)	Flo Imax(A)	at life a Eff(%)	t 20 Floe
BATTERIES DATA: Name OPZS-Hawker:TLS-3	Cnom.(Ah) 180	Volt.(V) 2	Cost(€) 127	C.08M(6/yr) 1.27	SOCmin(%) 20	Self_d(%/mon.) 3	Flo Imax(A) 36	at life a Eff(%) 85	nt 20 Floe 1
BATTERIES DATA: Nome OPZS-Hawker:TLS-3 OPZS-Hawker:TLS-5	Cnom.(Ah) 180 270	Volt.(V) 2 2	Cost(€) 127 178	C.0&M(€/yr) 1.27 1.78	SOCmin(%) 20 20	Self_d(%/mon.) 3 3	Flo Imax(A) 36 54	at life a Eff(%) 85 85	Floe 1
BATTERIES DATA: Name OPZS-Hawker:TLS-3 OPZS-Hawker:TLS-5 OPZS-Hawker:TLS-5	Cnom.(Ah) 180 270 390	Volt.(V) 2 2 2	Cost(6) 127 178 164.9	C.08M(6/yr) 1.27 1.78 1.65	SOCmin(%) 20 20 20	Self_d(%/mon.) 3 3 3	Flo Imax(A) 36 54 78	at life a Eff(%) 85 85 85	nt 20 Floe 1 1

Once removed the other ones remain:

		C.nom.	Vn
	Name	(A·h)	(V)
	OPZS-Hawker:TLS-3	180	2
	OPZS-Hawker:TLS-5	270	2
Þ	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 (usually batteries are into a building). The lifespan of the lead-acid batteries will be calculated according to the Rainflow model of cycle count.

	Battaries Model Ah KiBaM (Manwell-McGowan 1993) Copetti 1994 Schiffer 2007	Fixed Operation and Ma Auxiliary cooling, BMS
<	Jerrip. J 18 F 18 M 20 M Bat. J 22 A 22 S 22 O 20 N Cecept Schiffer model, consider Impo Impo Impo Impo Float life reduces 50% for every 10 °C ir Ocycle life depends on T Data Capacity depends on T Data Data Data Data	0 J 22 Mean (*C) 20 8 D 18 ● Mon. rt hourly file ● Hour horease 臣 T Graph
	Lead-acid Aging battery model Li-ion Agi Rainflow (cycle counting)	ing battery model

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:

Lead-acid Aging battery model	Li-ion Aging battery model
Wang et al., 2011 (LIFePO4) Grot et al., 2015 (LIFePO4) Saxena et al., 2016 (LICO2) Full equivalent cycles Rainflow (cycle counting) Naumann (LIFePo4 cyc+cal)	Parameters

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 box unchecked, as it is not allowed in EDU version.

Remaining capacity at battery end of life (%): 80
☐ If there is an AC Gen., every 14 days or 8 equivalent full cycles
charge battery bank at least up to 95 $\%$

To consider the update in the costs (for replacing when its lifetime ends and to account for the residual cost when the system lifetime ends), the default battery cost inflation considered is - 2%, with a reduction limit of 60% (achieved in 45.5 years). We leave these default values.

Annual Inflation Rate expected for -2	Max. Variation of Wind Batteries expected (e.g., for an expected 60% [reduction on current Batteries cost, introduce "-60%"):	-60 %
	Limit is reached in 45.4 years	

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**" (upper left area) and we have selected the family STECA and "Rectifier without PV controller" (we want inverter-charger but the PV controller will be apart):

Add from Database	ZERO	~		Without Rectifier (charger)
Include only VDC suitable from far	nily: STECA		· +	Rectifier + MPPT PV controller

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

	GENERAL	DATA			\frown				EFFICIENC		PUT	POWER	%) ->	
Γ	Name	Power (VA)	Lifespan (yr)	Acq. Cost (€)	Batt. Charger	Imax_ch.DC (A)	Ef_charger(%)	VDCmin(V)	VDCmax(V)	PV batt. controller	Proax	(_ren(W)	0%	2%
D	STECA: XPC 1600-48	1600	10	1440	ок	20	98	48	48	N0	\supset	1E15	0	30
Г					\sim									

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 640 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:

Maximum power demanded by load is 637.48 VA . The inverter selected is the one of 1600 VA Average power is 10.6% of rated power of the selected inverter. Inverter average efficiency considered will be 92.9 %

Average power is 10.6% of the selected inverter power, with an efficiency of 92.9% for this value. However, you must take into account that there are hours in the night with very low load (22 W), which is 22/1600·100=1.37% of the inverter nominal power, therefore for these hours the efficiency will be around 20%, needing from the inverter 22/0.2= 110 W approximately to supply only 22 W. In a real case an inverter of lower power would be better, however in this case we will leave the default one.

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

12. AC generators (backup genesets) data.

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

🚽 AC GENERATOR

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".

Ù	AC GENERATORS												_		×
Add from Database															
	GENERATORS DATA:														
Π	Name	Power(kVA)	Cost(€)	C.0&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	
Þ	Gasoline 0.5kVA	0.5	250	0.2	1000	30	Gasoline	litre	1.4	5 /	3.1	0.5	0.2	6.5	
Γ									$\overline{}$	\nearrow					

In the table we see the fuel price for Diesel is $1.3 \notin /I$ and for Gasoline $1.4 \notin /I$, with an expected inflation of 5% annual. We could change these values, as well as all the values of the table, but we leave the default values. At the end of the table we have the columns A and B which represent the fuel consumption parameters (see user manual for more info).

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:
AC GENERATOR HO Monday-Friday:	URLY AVAILABILITY: Weekend:
□ 0.1h □ 1.2h □ 2.3h □ 3.4h □ 4.5h □ 5.5h □ 7.8h □ 9.9h □ 9.9h □ 9.9h □ 9.9h □ 9.9h □ 10h □ 11h □ 11.12h □ 12.13h □ 14h □ 15.16h □ 15.16h □ 16.17h □ 17.18h □ 19.20h □ 22.2h □ 22.24h	□ 0-1 h □ 1-2 h □ 2-3 h □ 3-4 h □ 4-5 h □ 6-7 h ♡ 8-9 h ♡ 9-10 h ♡ 10-11 h ♡ 110-11 h ♡ 112-13 h ♡ 12-13 h ♡ 14-15 h ♡ 15-16 h ♡ 15-20 h ♡ 21-22 h ♡
OK	

There is no required information about the generators cost annual inflation and its limit, as for these components (and for the rest, except for the hydrogen components) it is assumed that they are mature technologies and therefore their costs are increased with the general inflation (defined later in the financial data).

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 (also called 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.

Add from data base STECA: PR 1010 Include only VDC suitable and MPPT as selected from family. STECA Name Imax (A) VDCmin (V) VDCmax (V) Cost (€) MARK MARK STECA: TAROM 440 40 48 298 N0 STECA: P TAROM 4055 55 48 48 STECA: P TAROM 4140 149 48 2215 N0 If the controller is included in the bid invert the controller of this screen will not be considered 0) Lifespan: 10 years Control data	PV	BATTERY CHARGE CONT	ROLLE	ER 48 V-				
Include only VDC suitable-and MPPT as selected from family. Name Imax (A) VDCmin (V) VDCmax (V) Cost (€) MPPT STECA: TAROM 440 40 48 48 298 N0 STECA: TAROM 440 40 48 48 298 N0 STECA: P TAROM 4055 55 48 48 1500 N2 STECA: P TAROM 4140 149 48 48 2215 N0 If the controller is included in the bid invert the controller of this screen will not be considered 0) Lifespan: 10 years Control data V Control data V	[Add from data base STEC/	A: PR 1010	0		~]	ма нн+- _~%с
Name Imax (A) VDCmax (V) Cost (€) MPPT STECA: TAROM 440 40 48 48 298 N0 30 + 7 * Ireg.max (A) STECA: P TAROM 4055 55 48 48 1500 N2 10 + 7 * Ireg.max (A) STECA: P TAROM 4140 149 48 48 2215 N0 If the controller is included in the bid invert the controller of this screen will not be considered on authomatically the cost of the controller will be considered 0) Lifespan: 10 years PV charge controllets include MPPT Consider only first one of the table Control data Control data		Include only VDC suitable and MPPT	as selecte	ed from family:	STECA	~]	
STECA: TAROM 440 40 48 48 298 N0 STECA: P TAROM 4055 55 48 48 1500 N0 STECA: P TAROM 4140 149 48 48 2215 N0 If the controller is included in the bid invertically the cost of the considered 0) Lifespan: 10 years PV charge controllers include MPPI Consider only first one of the table Control data	\mathbf{F}	Name	Imax (A)	VDCmin (V)	VDCmax (V)	Cost (€) MPPT	11	Acquisition cost (€):
STECA: P TAROM 4055 55 48 48 1500 NP STECA: P TAROM 4140 149 48 48 2215 NO If the controller is included in the bid invert the controller of this screen will not be considered on the considered on Lifespan: 10 years PV charge controllers include MPPI Consider only first one of the table Control data.		STECA: TAROM 440	40	48	48	298 NO		30 + 7 × Ireg,max (A)
STECA: P TAROM 4140 149 48 48 2215 NO If the controller is included in the bid invert the controller of this screen will not be considered on a submatically the cost of the controller will be considered 0) Lifespan: 10 years If the controller is include MPPI Consider only first one of the table Control data		STECA: P TAROM 4055	55	48	48	1500 ND		
PV charge controllets include MPPT Consider only first one of the table		STECA: P TAROM 4140	149	48	48	2215 NO		(If the controller is included in the bird inverter,
PV charge controllers include MPPT Consider only first one of the table						-	*	Control data
All the PV charge controllers must be of the same family (same control data)	E F	PV charge controllers include MF he PV charge controllers muts be of the	PPT same fam	ily (same con	er only first trol data)	one 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 (only in PRO+ version), 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.

Regarding the **battery charger (rectifier or AC / DC converter)**, 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:

RECTIFIER (BATTERY	CHARGER) (CONV. AC/DC) 230 Vac / 48 Vdc
Acquisition cost (6)	+ 0 * Pnom (kW) (If battery charger is included in inverter, this cost will authomatically be 0; if the battery charger is included in the AC generator, you must indicate here 0 for costs)
Litespan: 10 years	Efficiency: 90 *

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 values 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.

HOGA	×
Max. numbers of components in parallel allowed h updated:	nave been
Max. no. of batteries (of type of HIGHEST capacity Max. no. of PV modules (of type of HIGHEST powe 4) in parallel: 3 r) in parallel:
Max. no. of Wind Turbines (of type of HIGHEST po parallel: 6	wer) in
Max. no. of AC. Generators (of type of HIGHEST po parallel: 1	ower) in
	ОК

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):

℟ Project: D:\PROYECTOS IHOGA Project Data Data Base Report	3.3\Pr1.hoga : Visual Help License Updates	- 🗆 X
V LOAD / AC GRID	GENERAL DATA OPTIMIZATION CONTROL	DESTRATEGIES FINANCIAL DATA RESULTS CHART
RESOURCES	COMPONENTS	MIN. AND MAX No COMPONENTS IN PARALLEL: OPTIMIZATION PARAMETERS SELECTED BY: Bateries in parallel: Min.
VIND	Wind Turbines	PV mod. in parallel: Min. 0 Max. 4 Maximum execution time:
HYDRO	🗌 Hydro T. 🔩 🗌 TEG	Wind T. in parallel: Min. 1 Max 6 0 h. 15 min. Parameters
COMPONENTS ✓ PV MODULES	Battery bank	AC Gen. in parallel: Min. 1 Max 1 Minimum time for the Genetic Algorithms

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.

Note that 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 load demand, will be discarded.

CONSTRAINTS: <u>Maximum Unmet Load allowed:</u> 0.3
Unmet load refers to:
More Constraints

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):

	_		×
If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (for that co assigned infinite cost):	ombinatio	n it is	
Maximum Unmet Load allowed: 0.3 % of annual load			
(Max. energy not supplied by the stand-alone system. This Energy can be purchased from the AC grid if such AC grid exists and als allowed on the LOAD/AC GRID screen)	so the pur	chase is	
Minimum number of days of autonomy (batteries+hydroge() 4.5 days			
(v) if there is AC generator or fuel cell using external fuel or putchasing unmet load from AC grid is allowed, number of days of auto	nomy = in	nfinitum)	
Nominal capacity of batteries bank (Wh) < 20 × (peak power of PV generator + max. power from Wind Turbines group) (W)			
(√ if there is AC generator or fuel cell being external fuel or purchasing unmet load from AC grid is allowed, do not take into account Minimum renewable fraction	t this cons	straint)	
Maximum Levelized Cost of Energy: 100 €/kWh			
Maximum annual capacity shortage: 100 %; Data -> AC bus: Load operating reserve (%); 0 Peak load operating r	eserve (%	s): 0	
PV power oper, reserve (%): 0 Wind power oper, re	eserve (%	5): 0	
DC bus: Load operating reserve (%): 0 Peak load operating r	eserve (%	s): 0	
PV power oper, reserve (%): 0 Wind power oper, re	eserve (%	j); 0	
ОК			

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

17. Maximum execution time allowed.

In the main screen, in the "**GENERAL DATA**" tab, in the upper right area, 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 optimal solution. If sufficient time were not left, genetic algorithms metaheuristic technique 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).

-OPTIM	IIZATI	ON PAI	RAMETERS	SELECTED BY:
● iHOGA OUSER				
Maximum execution time:				
0 h. 15 min. Parameters				
Minimum time for the Genetic Algorithms				

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 27 cases per second, so in 1'00'' it is expected that all combinations will be evaluated and the optimum will be found.

omputation s	speed: 27 cas	es/second			
			EVAL ALL	POP. (% ALL)	GEN. ALG. (% ALL)
MAIN AL	G. (COMB. CO	MPONENTS)	1620 (1×1620)	1666 (102.84%)	24290 (1499.38%)
SEC. ALC	G. (COMB. ST	RATEGIES):	1	3 (300%)	41 (4100%)
	MAIN ALG.	SEC. ALG.	NUMBER OF CASES	%	TIME EXPECTED
OPTION 1:	EVAL ALL	EVAL ALL	1620	100 % 🤇	<u>0h 1' 0''</u>
OPTION 2:	EVAL ALL	GEN. ALG.	66420	4100 %	8h 41' 0"
OPTION 3:	GEN. ALG.	EVAL ALL	24290	1499.4 %	0h 1 4' 59''
OPTION 4:	GEN. ALG.	GEN. ALG.	995890	61474.7 %	10h 14'

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).

	- 🗆 X
MAIN ALGORITHM (OPTIMIZATION OF COMPONENTS)	SECONDARY ALGORITHM (OPTIMIZATION OF STRATEGY)
OPTIMIZATION METHOD:	OPTIMIZATION METHOD:
◯ GENETIC ALGORITHMS	⊖ GENETIC ALGORITHMS
<u>GENETIC ALGORITHM:</u>	GENETIC ALGORITHM;
Generations: 15 Population: 1234	Generations: 15 Population: 3
Crossover rate 90 % Mutation rate: 1 % Mutation Uniform	Crossover rate: 90 % Mutation rate: 1 % 🗸 Mutation Uniform
STOPPING CRITERION:	STOPPING CRITERION:
Stop execution of main algorithm if after 15 generations	Stop execution of secondary algorithm if after 15 generations
it cannot improve 1 % in 5 consecutive generations	it cannot improve 1 % in 5 consecutive generations
EVALUATE ALL COMBINATIONS:	
Display best: 10	
NUMBER OF CASES	AND TIME EXPECTED
Computation speed: 20 cases/second	
MAIN ALG. (COMB. COMPONENTS): 11	<u>/AL_ALL POP. (% ALL) GEN. ALG. (% ALL)</u> 620 1234 (76.17%) 17992 (1110.62%)
(1 SEC. ALG. (COMB. STRATEGY): 1	×1620) 3 (300%) 41 (4100%)
MAIN ALG. SEC. ALG. NUMBER	R OF CASES % TIME EXPECTED
OPTION 1: EVAL. ALL EVAL. ALL 1620	100 % <u>Oh 1' 21''</u>
OPTION 2: EVAL. ALL GEN. ALG. 66420	4100 % 0h 55' 21"
OPTION 3: GEN. ALG. EVAL. ALL 17992	1110.6 % Oh 14' 59"
UK OPTION 4. GEN. ALG. VISTOR	2 43535.5 % TOT 14
Optimization by means of enumerative method (ev optimal solution	aluating all combinations). It is guaranteed to obtain the

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 energy arbitrage 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). Energy arbitrage can also be considered pumped hydro storage (PHS) or hydrogen production systems (using electrolyzer).

Let's leave everything by default.

Global strategy: Cuad Followin Cycle Chargin	ng ng 🔽 Continue up to) SOC stp	Batt. charged by the AC grid // discharged if:	(also for Elyzer> H2) Elyzer. full load
⊖ Try Both	-		Optimize strategy of grid-conneted batteries:	
Variables to opti	mize relative to the	global strategy:		
Pmin_gen	Pmin_FC	H2TANKstp		
P1_gen	P1_FC	P2		
SOCstp_gen	SOCstp_FC	SOCmin		
Deritical con	H2TANKstp	Plim charge		Batteries availability

20. Financial data.

In the main screen, in the tab "**FINANCIAL DATA**" we must set different economic variables (nominal interest rate or nominal discount rate, 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)

ENERAL DATA OPTIMIZATION CONTROL STRATEGIES FINANCIAL DATA RESULTS CHART	
Nominal interest rate (capital cost): Annual real discount ratel (%): (nominal discount rate) 1.96 % Annual inflation rate (0&M): 2 % In LCOE / LCOH include real disc. rate in Energy Study period (system lifetime): 25 years In maximize NPV systems use Inf. sell / H2 In max NPV, LCOE calculated with Esell+Eload At the end of the study period consider the residual cost of the components Currency Euro (6) Intellifies and to applie be initial part 300 C Even Currency Currency Currency Currency Currency Currency At the end of the study period consider the residual cost of the components Currency Currency	Loan (constant quota, French system): Amount of Ioan: 80 % of the initial cost of investment Loan Interest 7 % Duration of Ioan: 10 years
Corporate taxes (%)	Extra Cash Flow

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, by 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 converting 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.

GENERAL DATA OPTIMIZATION CONTROL STRATEGIES FINANCIAL DATA RESULTS CHART Mono-objective optimization. Total No. of cases evaluated: 1620. Time: 57 otal Cost (NPC) (6) 15,61 12 Show diagram Report REPORT REPORT SIMULATE 14778.5 99.54 99.54 SIMULATE... SIMULATE... SIMULATE... SIMULATE... SIMULATE... SIMULATE... SIMULATE... SIMULATE... REPORT. REPORT. REPORT. REPORT. REPORT. REPORT. REPORT. REPORT. 14778.9 15013.3 15013.3 15594.4 99.15 99.15 93.04 93.04 140.94 140.94 0.03 0.17 8.19 100 93.04 COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp_dc); 4sx 4p_ (100%; PV#1: slope 40%; azimuth 0%) // Batteries OP2S-Hewker TLS-3 (160 Ah); 24s. x 1p_ // 1 x AC Gen. Gasoline 0.5K/A 0.5 VA // 1 Wind Tutb. DC. Zero (0 W at 15 m/s) // Bat. Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 14778.5 (0.5 G/kVh) ATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %

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

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 quide, since the AC load and the resources will not be exactly the same for all the time steps (due to the random variability introduced).

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 CO_2 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,.....

After finishing the optimization, the number of solutions to be shown can 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.

	1
See best	10
	_

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

🗹 Show diagram

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_dc): 4s.x 4p. (100% PV#1: slope 40°, azimuth 0°) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 VA // 1 Wind Turb. DC Zero (0 W at 15 m/s) // Bat. Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 14778.5 \in (0.5 \notin /kWh)

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

In the table, for each solution, you can see: the total NPC (in red as all the costs columns), CO₂ lifetime cycle emissions per year (in green), and several columns in blue: unmet load (kWh/yr), unmet load in %, autonomy days (in this case, INF means that there is AC backup generator and therefore it is supposed it can supply the load during any number of days), ratio between battery energy capacity and renewable nominal power, renewable fraction (%) and LCOE.

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
1	14778.5	99.54	0.7	0.05	INF	6.6	99.85	0.5033	SIMULATE	REPORT	(
	14770 E	00 5 4	0.7	0.05	INTE	e e	00.00	0 0000	CILILII ATE	DEDODT	1

Next three columns are buttons (SIMULATE, REPORT AND COSTS) which will be explained later.

If we move through the table with the bottom bar, and focus on the first row, we can see many other results. HDI and Jobs are results related to human development index and jobs created (not considered in this project, so do not consider them). Then there are several columns which

show the components of this combination: PV modules (serial x parallel x power), slope of the PV modules, nominal capacity of the battery bank, AC generator rated power, inverter rated power, wind turbines rated power (in this case for the optimal solution, 1st row, 1x0, that is, 1 turbine of 0 W, that is, no wind turbines in the optimal solution), etc.

0.525741 0.0048 4x4x100 40 24x1x180 1x500 1600 1x0 0 0 0 0.525741 0.0048 4x4x100 40 24x1x180 1x500 1600 2x0 0	HDI	Jobs	P. PV mod. (Wp_dc)	Slope#1(º)	Cn Bat. (Ah)	P. Gen (W)	P. Inv (W)	P. Wind T. (W)	F. Turb (l/s)	P. FC (W)	P. Elyz. (W)	H2 t	^
0.525741 0.0048 4x4x100 40 24x1x180 1x500 1600 2x0 0	0.525741	0.0048	4x4x100	40	24x1x180	1×500	1600	1×0	0	0	0		
0.525762 0.0048 4x4x100 40 24x1x180 1x1900 1600 1x0 0 0 0 0.525762 0.0048 4x4x100 40 24x1x180 1x1900 1600 2x0 0	0.525741	0.0048	4x4x100	40	24x1x180	1×500	1600	2×0	0	0	0		
0.525762 0.0048 4x4x100 40 24x1x180 1x1900 1600 2x0 0 0 0 0.525767 0.0048 4x4x100 40 24x1x270 1x500 1600 1x0 0 0 0 0.525787 0.0048 4x4x100 40 24x1x270 1x500 1600 2x0 0 <t< td=""><td>0.525762</td><td>0.0048</td><td>4x4x100</td><td>40</td><td>24x1x180</td><td>1×1900</td><td>1600</td><td>1×0</td><td>0</td><td>0</td><td>0</td><td></td><td></td></t<>	0.525762	0.0048	4x4x100	40	24x1x180	1×1900	1600	1×0	0	0	0		
0.525787 0.0048 4x4x100 40 24x1x270 1x500 1600 1x0 0 0 0 0.525787 0.0048 4x4x100 40 24x1x270 1x500 1600 2x0 0	0.525762	0.0048	4x4x100	40	24x1x180	1×1900	1600	2×0	0	0	0		
0.525787 0.00486 4x4x100 40 24x1x270 1x500 1600 2x0 0 0 0 0.525787 0.00486 4x3x135 40 24x1x180 1x1900 1600 1x0 0 0 0 0.525619 0.004863 4x3x135 40 24x1x180 1x1900 1600 2x0 0	0.525787	0.0048	4x4x100	40	24x1x270	1×500	1600	1×0	0	0	0		
0.525619 0.004863 4x3x135 40 24x1x180 1x1900 1600 1x0 0 0 0 0.525619 0.004863 4x3x135 40 24x1x180 1x1900 1600 2x0 0	0.525787	0.0048	4x4x100	40	24x1x270	1×500	1600	2×0	0	0	0		
0.525619 0.004863 4x3x135 40 24x1x180 1x1900 1600 2x0 0	0.525619	0.004863	4x3x135	40	24x1x180	1×1900	1600	1×0	0	0	0		
0.525787 0.0048 4x4x100 40 24x1x270 1x1900 1600 1x0 0 0 0	0.525619	0.004863	4x3x135	40	24x1x180	1×1900	1600	2×0	0	0	0		
	0.525787	0.0048	4x4x100	40	24x1x270	1×1900	1600	1×0	0	0	0		

If you continue moving right in the table with the bottom bar, you can see several columns which show the variables of the control strategy (not considered in this project as we did not optimized the control strategy). Then you can see several columns in blue, which are annual energy columns: total annual load (Etotal), renewable total annual generation (Eren), PV annual generation (Epv), wind turbines annual generation (Ew), Hydro turbines annual generation (Et), energy which could be exported to the AC grid if there was AC grid (E export), sold energy to the AC grid (Esell), bought energy to the AC grid (E buy)....

Etotal(kWh)	Eren(kWh)	Epv(kWh)	Ew(kWh)	Et(kWh)	E export(kWh)	E Sell(kWh)	E Buy(kWh)	E ch. bat(kWh)	^
1497.8	2091.1	2091.1	0	0	1	18.9	0	0	10

Also, we can see the annual energy charged by the battery (E ch. bat), which is the 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 (E disch. bat) is the energy that effectively supplies the battery, considering efficiency. The energy supplied by the AC gasoline generator (E gen) is in this case just 1.5 kWh per year. In black, we can see the hours the AC generator runs in the year (just 10.05 hours) and the battery lifetime (11.19 years).



Further to the right you can see in red columns related to costs: cost of the fuel of the AC generator (per year), other costs which are no meaning in this project, and the NPC of the different components.

C. Fuel Gen.(€/yr)	C. Fuel FC(€/yr)	E Buy (€/yr)	E Sell (€/yr)	Sell H2 (€/yr)	C. PV (NPC) (€)	C. Bat. (NPC) (€)	C. Aux. (NPC) (€)	C. Inv.	~
2.2	0	0	0	0	2889.7	6508.5	653.8		

We can see the simulation of the operation of the optimal solution by clicking on the first row of the table, in "**SIMULATE**" (*we could also see the simulation of the different solutions by clicking in the SIMULATE button of their row*):

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
	1 14778.5	99.54	0.7	0.05	INF	6.6	99.85	0.5033	SIMULATE.	REPORT	(
	a	00 5 4		0.05			00.05	0.0000	· · · · · · · · · · · · · · · · · · ·	DEDODT	

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 November 14th, from 6 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 another one*), shown in orange, during this hour the battery is at the minimum SOC (so it cannot supply load) and the gasoline generator cannot work because we did not allow it during the night until 7 a.m. in the AC generator screen (see section 12).



We can see the grid by clicking in the checkboxes of the right area: H.L.Gr. (horizontal left axis grid), H.R.Gr. (horizontal right axis grid) and V.R.Gr. (vertical axis grid). Also options for the scroll are below these checkboxes.

In the simulation screen, the different variables are shown as a specific point value for each time step. In our case, we are using time steps, therefore for each hour each variable is shown as a point. For example, the values of each variable shown at 6 a.m. are values for the hour from 6:00 to 7:00, there is around 110 W of AC load (grey curve), which cannot be covered by the battery (SOC is at the minimum) neither by the AC generator (not allowed to run until 7:00), therefore we have 110 W of unmet load (orange curve) from 6:00 to 7:00, which is represented as a point value of the orange curve at 6 a.m.. Before, from 5:00 to 6:00 (shown in the graph at

5 a.m.), there was no unmet load because the load was covered by the battery, blue curve (due to the low efficiency of the inverter at low power, it needs around 100 W to supply 22 W AC). Later, from 7:00 to 8:00 (represented in the graph at 7 a.m.), there is no unmet load because the gasoline generator can run from 7:00, therefore it runs (back curve) supplying the net load (load not covered by the PV generator, in yellow).



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. Also, you can zoom in the graph as previously explained for the other graphs.

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



In the third tab, we can see the probability density functions of the same variables we have seen in the second tab. Before, in **Project->Options**, check **"In the simulation window, show the probability density function (PDF) of the main results**".

In the simulation window, show the probability density function (PDF) of the main results

Then, in the third tab of the simulation screen, we can see the PDF of the different output variables. Each PDF graphs shows the probability density for each interval between the minimum and the maximum of the power / energy of that variable. For example, for the total load power, we can see the minimum column is for the interval between the minimum power and the minimum power – minimum power) / Number of columns. As min.

power is around 22 W and max. is around 600 W, the first column is for the interval between 22 W and 22 + (66-22)/20 = 51 W, that is, interval 22 W - 51 W. We can see the most of the time the total load power is in this interval (probability density of around 8 for that interval). For each PDF, the area (integral of the PDF graph) is 1. Below the graphs we can see the mean power / energy and the standard deviation (for the total load, mean 0.2 kW, standard deviation 0.1 kW; we could see in these values more decimal places if we change it in **Project->Options -> Number of decimal places in results of energy**).



Also, we can see the most of the time the PV output power is 0 (during night time), the most of the time AC generator power is 0 (it runs only few hours in the year). We can see the battery SOC is the most of the time at around 6 kWh.

We can change the number of columns for the PDF graphs (upper right area), and also we can select not to see the first and/or the last column. For example, if we unselect the PDF first column, we can see the PV power PDF curve only for hours when irradiation is different from 0 (not night time). Also, we see that, when the diesel generator runs, it runs most of the time at around 0.2 kW. And that unmet load most of the time (apart from 0) is around 0.02 kW = 20 W and around 0.11 kW = 110 W.



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

🕼 REPORT

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):

Printer Name: Properties Where: Properties Print to file Pages Option Number of copies Number of copies	Print			×
Pages Copies I	Printer Name:	Properties	~	erties
O Pages: Chter page numbers and/or page ranges, separated by commas. For example, 1,3,5-12	Pages Al Current pages: Enter page nu separated by	□ Thirt of ite	Copies Number of copies	Ţ
Other Print All pages Print mode Order Direct (1-9) `` Duplex Default Print on sheet	Other Print Order Duplex	Default	Print mode Default Print on sheet	Cancel

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 .doc or .rtf format (which can be open by Microsft Word) or in .txt format. 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:

Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	Costs	HDI	Jobs	P. PV mod. (Wp_d 🔺
0.7	0.05	INF	6.6	99.85	0.5033	SIMULATE	REPORT.	COSTS	0,525741	0.0048	4x4x100
								\sim			

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.

Save Data	×
Do you want to save cash flow?	
Sí No	

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

Microsoft	Excel				×
	El formato y la extensión de archiv menos que confíe en su origen. ¿E	o de 'prueba1tabla Jesea abrirlo de to	a.xls' no coinciden. Po dos modos?	uede que el archiv	o esté dañado o no sea seguro. No lo abra a
		Sí	No	Ayuda	

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.

A	A	В	С	D	E	F	G	Н	1	J	K	L	M	N	0	Р	Q	R	S
Project	t: Pr1.hoga.	Solution #1																	
2																			
B Inversio	on cost: 723	31.9 €(included	installati	ion and initial v	ariable costs	of 435.9 €). L	oan: 80 %, int	. 7% in 10 years											
4 CASH F	LOW THRO	UGHOUT SYSTE	M LIFET	IME.															
5 CASH F	LOW OF CO	STS (+) AND IN	COMES (-):															
5 All valu	ues in €. Cos	ts +, Incomes	For eacl	h component,	cash flows co	rrespond to a	cquisition cos	t (year 0), repla	cement costs	(years in which	the componen	t is replaced),	and return rev	enue at the end	of the system	n's life, if it ha	s a useful life (r	egative value), th	he three sums
YEAR	Cost	ts PV Gen.		O&M PV Gen		Costs Wind	т.	O&M Wind	г.	Costs Hydro	T.(+Pump+W.1	O&M Hydro	T.(+Pump)	Costs AC Gen		O&M AC Ge	n.	Costs Inverter	0
3	cash	n 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 🛛 🕅	NPC c
9	0	1760	1760	0)	0	0	0	0	0 0) ()	0 250	25	0	0 0	1440	1440
0	1	0	0	58.8	56.	5	0	0	0	0	0 () (0	0 0		0 2.	1 3	0	0
1	2	0	0	59.9	55.4	1	0	0	0	0	0 0) ()	0 0	(0 2.	1 1.9	0	0
2	3	0	0	61.1	54.3	3	0	0	0	0	0 0) ()	0 0		0 2.	1 1.9	0	0
3	4	0	0	62.3	53.	5	0	0	0	0	0 () (0	0 0		0 2.	2 1.9	0	0
4	5	0	0	63.6	52.	5	0	0	0	0	0 () ()	0 0		0 2.	2 1.8	0 1	0
5	6	0	0	64.9	51.3	8	0	0	0	0	0 0) (0	0 0		0 2.	3 1.8	6 O	0
6	7	0	0	66.2	50.	5	0	0	0	0	0 () (0	0 0		0 2.	3 1.8	0	0
7	8	0	0	67.5	49.3	5	0	0	0	0	0 0) ()	0 0	(0 2.	4 1.3	0	0
8	9	0	0	68.8	48.4	1	0	0	0	0	0 0) ()	0 0		0 2.	4 1.3	. 0	0
9	10	0	0	70.2	47.4	1	0	0	0	0	0 () ()	0 0		0 2.	5 1.3	1755.4	1185.9
0	11	0	0	71.6	46.5	5	0	0	0	0	0 0) ()	0 0		0 2.	5 1.0	i 0	0
1	12	0	0	73.1	45.0	5	0	0	0	0	0 0) ()	0 0		0 2.	6 1.0	i 0	0
2	13	0	0	74.5	44.	1	0	0	0	0	0 () ()	0 0		0 2.	6 1.0	i 0	0
3	14	0	0	76	43.9		0	0	0	0	0 0) ()	0 0		0 2.	7 1.9	i 0	0
4	15	0	0	77.5	4	8	0	0	0	0	0 0	0 0	0	0 0		0 2.	7 1.5	i 0	0
5	16	0	0	79.1	42.3	2	0	0	0	0	0 () (0	0 0		0 2.	8 1.5	i 0	0
6	17	0	0	80.7	41.4	1	0	0	0	0	0 0) ()	0 0		0 2.	8 1.4	0	0
7	18	0	0	82.3	40.0	5	0	0	0	0	0 0) (0	0 0		0 2.	9 1.4	0	0
8	19	0	0	83.9	39.4	3	0	0	0	0	0 0) ()	0 0		0 2.	9 1.4	0	0
9	20	0	0	85.6	39.3	1	0	0	0	0	0 0) ()	0 0	(0	3 1.4	2139.8	976.6
0	21	0	0	87.3	38.3	3	0	0	0	0	0 0) ()	0 0		0	3 1.3	0	0
1	22	0	0	89	37.0	j	0	0	0	0	0 0) ()	0 0		0 3.	1 1.3	0	0
2	23	0	0	90.8	36.9		0	0	0	0	0 0) (2	0 0		0 3.	2 1.3	0	0

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	(^			
1	14778.5	99.54	0.7	0.05	INF	6.6	99.85	0.5033	SIMULATE	REPORT	C			
2	14778.5	99.54	0.7	0.05	INF	6.6	99.85	0.5033	SIMULATE	REPORT	(
3	15013.7	99.15	0.4	0.03	INF	6.6	99.78	0.5112	SIMULATE	REPORT	(
4	15013.7	99.15	0.4	0.03	INF	6.6	99.78	0.5112	SIMULATE	REPORT	(
5	5 15594.6 93.04 0 0 INF 9.9 100 0.5308 SIMULATE REPORT (
6	15594.6	93.04	0	0	INF	9.9	100	0.5308	SIMULATE	REPORT	(
7	15840	140.94	2.6	0.17	INF	6.9	98.19	0.5401	SIMULATE	REPORT	C			
8	15840	140.94	2.6	0.17	INF	6.9	98.19	0.5401	SIMULATE	REPORT	C			
9	16225.1	93.04	0	0	INF	9.9	100	0.5523	SIMULATE	REPORT	٢.,			
< COME														
AC Ge 440 of	n. Gasoline 0.5kVA 0.5 VA 40 A // Unmet load = 0 %	// 1 Wind Turb. DC Zi // Total Cost (NPC) = 1	ero (0 W at 15 m/s) 4778.5€ (0.5€/kW	. (100% PV) i // Bat. Inve h)	rter ST	ECA: XPC 1600-48 of	1600 V	'A // PV batt. chan	ge controller. ST	ECA: TAROM				
STRA	STRATEGY: LOAD FOLLOWING. P1gen: INF. Pmin_gen: 150 W. Pcritical_gen: 0 W. SOC setpoint_gen: 20 %. SOC min.: 20 %.													
Se	See best 10 Save Excel table													

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

	А	В	C	DE	F	G	н	1	J	К	L	м	N	0	Р	Q	R	S	
1 Pro	oject: D:\PFOYE	CTOS IHO	GA 3.4-10-12-202	2\Pr1.hoga															
2 No	N		NPC(€)	Em.CO2(k	g/yr)	Unmet(kWh/y	r)	Unmet(%)	Da	ays auton.		Cn(Wh)/(Ppv+I	Pw)(W)	Renewable fra	iction (%)	LCOE (€/kWh)		HDI	
3																			
4	1		14778.5	99.	544	0.708		0.05		1E+10		6.63		99.85		0.5033		0.5257	1
5	2		14778.5	99.	544	0.708		0.05		1E+10		6.63		99.85		0.5033		0.5257	1
6	3		15013.7	99.	153	0.377		0.03		1E+10		6.63		99.78		0.5112		0.5258	1
7	4		15013.7	99.	153	0.377		0.03		1E+10		6.63		99.78		0.5112		0.5258	÷
8	5		15594.6	93.	037	0		0		1E+10		9.94		100		0.5308		0.5258)
9	6		15594.6	93.	037	0		0		1E+10		9.94		100		0.5308		0.5258	1
10	7		15840	140.	941	2.57		0.17		1E+10		6.87		98.19		0.5401		0.5256	i.
11	8		15840	140.	941	2.57		0.17		1E+10		6.87		98.19		0.5401		0.5256	i .
12	9		16225.1	93.	037	0		0		1E+10		9.94		100		0.5523		0.5258	1
13	10		16225.1	93.	037	0		0		1E+10		9.94		100		0.5523		0.5258	÷
14	11		16591.699	129.	928	1.998		0.13		1E+10		10.31		98.61		0.5655		0.5257	1
15	12		16591.699	129.	928	1.998		0.13		1E+10		10.31		98.61		0.5655		0.5257	1
16	13		16805.9	139.	529	3.985		0.27		1E+10		10.31		98.99		0.5736		0.5255	÷
17	14		16805.9	139.	529	3.985		0.27		1E+10		10.31		98.99		0.5736		0.5255	i .
18	15		16833.801	122.	096	0		0		1E+10		4.67		100		0.573		0.5258	1
19	16		17055.4	122.	923	0		0		1E+10		4.79		100		0.5806		0.5258	:
20	17		17464.301	122.	096	0		0		1E+10		4.67		100		0.5945		0.5258)
21	18		17685.9	122.	923	0		0		1E+10		4.79		100		0.602		0.5258	2
22	19		18021.1	12	5.8	0		0		1E+10		7		100		0.6134		0.5258	2
23	20		18235.9	126	.44	0		0		1E+10		7.18		100		0.6207		0.5258	1
24	21		18251.199		104	0		0		1E+10		13.25		100		0.6213		0.5258	2
25	22		18251.199		104	0		0		1E+10		13.25		100		0.6213		0.5258	2
26	23		18643.1	110.	582	0		0		1E+10		5.15		100		0.6346		0.5258	2 I.
27	24		18643.1	110.	582	0		0		1E+10		5.15		100		0.6346		0.5258	1
28	25		18651.6	12	5.8	0		0		1E+10		7		100		0.6349		0.5258	
29	26		18866.4	126	.44	0		0		1E+10		7.18		100		0.6422		0.5258	
30	27		18881.699		104	0		0		1E+10		13.25		100		0.6427		0.5258	
31	28		18881.699		104	0		0		1E+10		13.25		100		0.6427		0.5258	
32	29	~	18978 301	179	558	1 438		0.1		1E+10		13.75		99.03		0.6466		0.5257	• •

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.

<u>We won't do it</u>, 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**". You can see the name of the project in the main screen, in the upper left corner: Project:...

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

The water consumption data are indicated in the tab "WATER (m3/day) FROM WATER TANK". Suppose the house has a well so that we pump water to a 20 m³ tank, assuming it is full (100%) at the beginning of the year. The pumping height is 12 m. Consumption, mainly for irrigation, is 10 m³/day in summer (June-September) and 5 m³/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.

👔 Load and opti	ons of Selling / Purcl	hasing Energy from the	AC grid — I	⊐ ×
Data source:	erage 🔿 Load Profile	e 🔿 Import File (W, kgH2,	Hours AC DC H2 Water (h, m3/h) 1 Minutes- each hour in 1 row Import Ex	port
AC LOAD (W)	DC LOAD (W)	H2 LOAD (kgH2/h)	WATER (m3/day) FROM WATER TANK PURCHASE / SELL E	
DAILY WATER January 5 Februar 5 April 5 March 5 June 10 Scale fater for WATER TANK Water tank capit Capacity at the 1 PUMPING DAT Elevation head	CONSUMPTION (m3/c 0.5995 KWh/day) 0.5995 KWH/day) 0.59	July 10 July 10 August 10 September 10 October 5 November 5 December 5 For the Weekend: 11 min. (%): 0 on (%): 100 m Ext	$\begin{array}{c} \begin{array}{c} \mbox{HOUPLY WATER CONSUMPTION (IN % OF DAILY CONSUMPTION);} \\ \mbox{1.199 kWh/dey)} & \begin{tabular}{lllllllllllllllllllllllllllllllllll$	0

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 1^{st} 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 m³), 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·density·g·height·(1+friction_losses)/Efficiency =

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

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:

-MIN. AND MAX. No COMPONENTS IN PARALLEL:								
Bateries in parallel: Min.	1	Max.	4					
PV mod. in parallel: Min.	0	Max.	4					
Wind T. in parallel: Min.	1	Max.	2					
AC Gen. in parallel: Min.	1	Max.	1					

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

GENER		ON CONTROL ST	RATEGIES FINA	NCIAL DA	TA R	ESULTS CHART						
	Mono-objective optimization. Total No. of cases evaluated: 2160. Time: 1' 15"											
	18,944									-	160	
	18,688	\wedge					-			-	152	
() ()	18,432				/						144	
NPC	18,176										144 10 00 00	
ost (17 920										136	
tal C	17,020				\mathbf{i}						128 u	
f	17,664				``						: E	
	17,408					\mathbf{X}	1					
	17,152	· · · · ·					4				- 112	
	1	2 3	4	כ # Solution	(sorted	from best to worst)	1	ŏ	9	10		
									Shov	v diagram		
#	Total Cost (NPC)(£)	Emission (kgCO2Art)	Unmet(k\\/h\/r)	Unmet(%)	Daut	Cn(Wh)/(Pny+Pw)()/	Ben(%	LCOE(€/k\\/h)	Simulate	Benort	(^	
- 1	17173.2	136.59	2	0.11	INF	4.7	99.44	0.4919	SIMULATE	REPORT	(
2	17201.2	143.46	3	0.17	INF	4.7	99.55	0.4929	SIMULATE	REPORT	C	
3	17670.9	i 156.53	4.5	0.25	INF	4.8	98.72	0.5068	SIMULATE	REPORT	C	
4	18243.4	141.05	2.2	0.12	INF	7	99.68	0.5226	SIMULATE	REPORT	C	
5	18322	136.68	1.5	0.08	INF	7	99.6	0.5246	SIMULATE	REPORT	(
6	18643.4	110.59	0	0	INF	5.2	100	0.5334	SIMULATE	REPORT	(
7	18643.4	110.59	0	0	INF	5.2	100	0.5334	SIMULATE	REPORT	(
8	18732	150.37	3.2	0.18	INF	7.2	99.12	0.5368	SIMULATE	REPORT	C	
9	18943.9	153.03	0	0	INF	3.6	99.97	0.5419	SIMULATE	REPORT	¢	
<											>	
COME	- PONENTS: PV modules a	Si12-Schott ASI100 (1)	00 Wn. dc): 4s x 4n	(100% PV)	#1: slor	ne 40° azimuth 0°)// F	atteries	s OPZS-Hawker T	1 S-3 (180 Ah): 2	4s x1n //1x		
AC Ge	n. Diesel 1.9kVA 1.9 VA /	/1 Wind Turb. DC Sou	thwest:AIR X (547 V	Vat15m/s) // Bat.	Inverter STECA: XP0	1600-	48 of 1600 VA // R	ectif. included i	n bi-di in∨erter	//	
PV ba	tt. charge controller. STE	CA: TAROM 440 of 40 A	A // Unmet load = 0	.1 % // Tota	al Cost ((NPC) = 17173.2 € (0.4	9€/kW	'h)				
STRA												
	TEGT. LOAD FOLLOWIN	IG. P1gen: INF. Pmin. d	gen: 570 W. Poritica	l gen:UW.	. SOC s	etpoint gen: 20 %. Si	DC min.	.: 20 %.				
	TEGT. LOADT OLLOWIN	IG. P1gen: INF. Pmin_g	gen: 570 W. Poritica	I_gen: U W.	SOCs	etpoint_gen: 20 %. SI	DC min.	: 20 %.				
		IG. P1gen: INF. Pmin_g	gen: 570 W. Pontica	l_gen: U VV.	SOCs	etpoint_gen: 20 %. SI	DC min.	.: 20 %.			~	

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

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/PHS", the following is shown:



Version 2: water consumption by direct pumping (without water tank):

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):

${\it (}$ Load and options of Selling / Purchasing Energy from the AC grid	- 🗆 X
Data source: Monthly Average Load Profile Import File (W, kgH2/h, m3/h)	Hours AC DC H2 Water Minutes-each hour in 1 row Import I v Minutes-1 per row Import
AC LOAD (W) DC LOAD (W) H2 LOAD (kgH2/h) WATER (m3/day) FROM WATER TANK	PURCHASE / SELL E
DAILYWATER CONSUMPTION (m3/day): HOUPLYWATER CONSUMPTION January 5 0.5995 kWh/day) July 10 (1.199 kWh/day) February 5 0.5995 kWh/day) August 10 (1.199 kWh/day) 0 0 0 0 March 5 0.5995 kWh/day) September 10 (1.199 kWh/day) 12 h 13 h 14 h 15 h 16 h April 5 (0.5995 kWh/day) October 5 (0.5995 kWh/day) 12 h 13 h 14 h 15 h 16 h June 10 (1.193 kWh/day) December 5 (0.5995 kWh/day) June 40 - 40 - 40 - 40 - 40 - 40 - 40 - 40	TON (IN % OF DAILY CONSUMPTION); 5h 6h 7h 8h 9h 10h 11h 0 40 2 2 0 0 DEFINE • n 17h 18h 19h 20h 21h 22h 23h Total = 2 2 2 2 40 0 100% Generalized and the second and the

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)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	٢ ٨
1	19875.8	133.07	1.4	0.08	INF	5.2	99.82	0.5717	SIMULATE	REPORT	C
2	19875.8	133.07	1.4	0.08	INF	5.2	99.82	0.5717	SIMULATE	REPORT	C
3	20078.5	131.9	0.5	0.03	INF	5.2	99.78	0.5772	SIMULATE	REPORT	C
4	20078.5	131.9	0.5	0.03	INF	5.2	99.78	0.5772	SIMULATE	REPORT	C
5	20400.3	127.06	0	0	INF	7.7	99.98	0.5863	SIMULATE	REPORT	C
6	20400.3	127.06	0	0	INF	7.7	99.98	0.5863	SIMULATE	REPORT	C
7	20401.7	180.31	3.6	0.2	INF	3.6	99.6	0.5875	SIMULATE	REPORT	C
8	20506.1	176.78	2.2	0.12	INF	3.6	99.55	0.5901	SIMULATE	REPORT	C
9	20673.8	126.77	0	0	INF	7.7	99.97	0.5942	SIMULATE	REPORT	C
											× *
<											2
COMP AC Ge TARO	COMPONENTS: PV modules SiP12-TAB:PV-135-mod (135 Wp_dc): 4s x 4p. (100% PV#1: slope 40%, azimuth 0%) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 VA // 1 Wind Turb. DC Zero (0 W at 15 m/s) // Bat. Inverter STECA: XPC1600-48 of 1600 VA // PV batt. charge controller. STECA: P TAROM 4055 of 55 A // Unmet load = 0.1 % // Total Cost (NPC) = 19875.8 € (0.57 €/kWh)										
STRA	n PALEGIT, LUAD FULLUWING, Pilgen, INF, Priningen, Ibu W. Poniucalgen, u W. SUC setpointgen; 20%, SUC min.; 20%.										

In the simulation of the optimal system (first row of the table) we can see that the batteries supply the load 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 higher than the AC consumption, due to the losses in the inverter. At the end of the year the discel generator supplies the demand during a few hours.



Version 3: AC grid available (not allowed in version EDU).

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 65% 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 35% 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 35%.

CONSTRAINTS: <u>Maximum Unmet Load allowed:</u> 35 % annual
Unmet load refers to:
More Constraints

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 CO₂ per kWh.

Load and options of setting / Farchasing Line gy from the A Data source: Monthly Average O Load Profile O Import File (W, kgH2/n,	m3/h)	AC DC H2 Water inutes-each hour in 1 row Import Export
AC LOAD (W) DC LOAD (W) H2 LOAD (kgH2/h)	WATER (m3/day) FROM WATER TANK PURCHASE /	SELL E
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Fixed Buy Price (¢/kWh) 0.15 Hourly Price Annual Inflation (%): Emission (kgCO2/kWh): 3 0.4 Emission (kgCO2/kWh): 3 0.4 Emission (kgCO2/kWh): 40 Fixed Price (t/kWYn) Fixed Price (t/kWYn) Fixed Access price (t/kWh) Fixed Back-up price (t/kWh)	Sell Excess Energy to AC grid Fixed Sell Price (£/kWh) O.12 Hourly Price Pr. sell = pr. buy x Annual Inflation (%): 3 Max. Power(kW) 3.45 Fixed Transfer Charge) Price (£/kWh) Fixed Transfer price (£/kWh) Fixed Transfe	AC GRID AVAILABILITY Priority to supply E not covered by renewables: ● Storage/Generator
Total tax for electricity costs (buy + charges) (%):	Total tax for electricity sold (%): 0	O&M annual cost of grid: 100 € osses in wire and transformer (%): 0

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)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	С ^
1	15066.8	324.69	600	33.72	INF	0	66.28	0.4251	SIMULATE	REPORT	С
2	15066.8	324.69	600	33.72	INF	0	66.28	0.4251	SIMULATE	REPORT	С
3	15066.8	324.69	600	33.72	INF	0	66.28	0.4251	SIMULATE	REPORT	С
4	15066.8	324.69	600	33.72	INF	0	66.28	0.4251	SIMULATE	REPORT	С
5	15106.9	330.2	622.3	34.98	INF	0	65.02	0.4258	SIMULATE	REPORT	С
6	15106.9	330.2	622.3	34.98	INF	0	65.02	0.4258	SIMULATE	REPORT	С
7	15106.9	330.2	622.3	34.98	INF	0	65.02	0.4258	SIMULATE	REPORT	С
8	15106.9	330.2	622.3	34.98	INF	0	65.02	0.4258	SIMULATE	REPORT	С
9	15546.2	326.39	573.7	32.25	INF	0	67.75	0.439	SIMULATE	REPORT	С
											~
<											>
COMF Inverte	COMPONENTS: PV modules aSi12-Schott: ASI100 (100 Wp_dc): 4s x 3p. (100% PV#1: slope 40%, azimuth 0%) // 1 Wind Turb. DC SouthwestAIR X (547 W at 15 m/s) // Bat. A Inverter STECA: XPC 1600-48 of 1600 VA // Unmet load = 33.7 % // Total Cost (NPC) = 15066.8 € (0.43 €/kWh)										
STRA	TRATEGY: 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.



Regarding operating reserve, in power systems we must ensure that any sudden increase of load or fall of the renewable generation must be covered by the system. During each time step, there will be a required reserve capacity (one for each bus, AC and DC) that must be covered by the real reserve capacity (one for each bus, AC and DC). If not, a capacity shortage happens during this time step. The total capacity shortage during the year must not be higher than he maximum capacity shortage constraint (in the constraints section), in percentage of the total load (more info in the user manual).

In the main screen, GENERAL DATA tab, click in the button "**More constraints**". By default, there is no need for operational reserve. In our case, suppose we want the reserve requirements for AC and DC bus shown below, with a maximum annual capacity shortage allowed of 5%:

₩ CONSTRAINTS	_		×
If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (for the assigned infinite cost):	at combinatio	n it is	
Maximum Unmet Load allowed: 35 % of annual load			
(Max, energy not supplied by the stand-alone system. This Energy can be purchased from the AC grid if such AC grid exists and allowed on the LOAD/AC GRID screen)	d also the pur	chase is	
Minimum number of days of autonomy (batteries+hydrogen) 4.5 days			
(🗹 if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, number of days of a	utonomy = in	nfinitum)	
Nominal capacity of batteries bank (Wh) < 20 x (peak power of PV generator + max. power from Wind Turbines group)	(^)		
(🗹 if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, do not take into acc	ount this cons	straint)	
Minimum renewable fraction: 50 %			
Maximum Levelized Cost of Energy: 100 €/KWh			_
Maximum annual capacity shortage: 5 %; Data -> AC bus: Load operating reserve (%); 20 Peak load operati	ng reserve (%	s): 10	
PV power oper, reserve (%). 20 Wind power ope	er, reserve (%	.): 20]
DC bus: Load operating reserve (%): 20 Peak load operati	ng reserve (%	ه): 10	
PV power oper, reserve (%): 20 Wind power ope	er, reserve (%	.): <mark>20</mark>]
During each time step, battery provides reserve capacity considering SOC disc	harged in (mir	n): 15	
OK			

We accept. If we click in the first row of the results table, nothing happens, as in this case the capacity shortage is lower than the maximum allowed (5%).



If we click in the REPORT of the first row, we can see the reserve capacity shortage during the year for AC and for DC, which is 0 kWh/yr for both and total capacity shortage is 0%.

ENERGY BALANCE DURING 1 YEAR (kWh/year):

Overall Load Energy: 1779.2 kWh/yr. From Renewable: 66.28%. Reserve Capacity Shortage: AC 0 kWh/yr; DC 0 kWh/yr; Total capacity shortage: 0 % of total load.

We can see the simulation of the first row. If we check the box "**Cap. Short**" (capacity shortage for each time step), it is 0 all the year. The red checkboxes "AC" and "DC" show the required reserve for each time step (considering the data set in the constraints window), while the green checkboxes "AC" and "DC" show the real reserve for each time step (real reserve can be obtained from the grid, from the batteries, from the fuel cell or from the backup generator if it is running during the time step). In our case, we can see AC and DC required reserve is much lower than AC and DC real reserve for all the time steps. In this case we only have for reserve the grid. AC real reserve is it 3.45 kW of the maximum power from the grid minus the power purchased from the grid during each time step. DC real reserve is limited by the charger maximum power (the inverter/charger has a maximum DC charge current of 20 A -> 20 A x 48 V = 960 W).



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-RNinja.hoga**".

In the SOLAR or WIND resource windows, click in "Download hourly data".

👔 SOLAR RESOURCE	
Latitude (º) (+N, -S) : 28.06	Get data from local DB
Longitude (º) (+E, -W) : -15.51	Download hourly data
Locate on map Update coord.	Download NASA monthly 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

<u>https://www.tunnelbear.com/</u>) 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 2279 kWh/m², compared to 2005 kWh/m² 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 7.38 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 monthly average data.



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PVGIS data:

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.

				- 🗆	×
Latitude (*) (+N, -S): 28.06 Get Longitude (*) (+E, -W): -15.51 Dow Locate on map Update coord. Downlo Data source for Global irradiation Monthly Average Import from File FROM Generation of PV gen. ((equivalent to irradian	e data from local DB wnload hourly data aad NASA monthly data PVGIS year 2007 (kW) normalized to 1 kWp cc kW/m2 × PR)	#1: PV panels slope (*): #2: PV panels slope (*): 60 PV gen. #1: 100 % Optimal Slope#1 Optim Steps Hour (kWh/m2) 1 Minutes- a Minutes- 1	; PV panels Azimuth (*): 0 PV panels Azimuth (*): 0 Ground Reflectance: 0. ∏Fixed albedo mize PV#1 panels slope during 1 ach hour in 1 row (tilt, in kW/m2)	2 Import Alb. Gr. the optimization of the s O Horiz Import Import	:ystem
Data Source for Monthly Average Daily Irradiation av. tilt s. January 4.45 kWh/m2 Februray 4.93 kWh/m2 March 5.19 kWh/m2 April 4.96 kWh/m2 June 5.12 kWh/m2 July 5.93 kWh/m2 July 5.93 kWh/m2 July 5.93 kWh/m2 October 5.15 kWh/m2 November 4.61 kWh/m2 December 3.59 kWh/m2 Scale factor (x by) 1 Variability minutes: correlation factor. 1.9	On: Radiation Horizontal Surfa PV Tracking System: No T Factor F(I) for the back albe (bifacial modules) (Durusov MONTHLY AVER 6 - - - - - - - - - - - - -	ace (kWh/m2) Calculation Tracking Calculation acdo 2020): 0.33 Collares AGE DAILY IRRADIATION, TILT AGE DAILY IRRADIATION, TILT Horizontal Calculation Horizontal Calculation in m Daily Aver Total Ar Annual Irr. Back	Method for Hourly Iradiation: rdan Erbs et al Pereira & Rabl Graham ED SURFACE 0 N D win onth January rage Irradiation (Tilt Surf.): 4.9; nnual Irradiation (Tilt Surf.): 1817 < surface / Direct for CPV: 1817 (Surf. Surf. Surf.): 1817 (Surf. Surf. Surf. Surf.): 1817 (Surf. Surf. Surf. Surf.): 1817 (Surf. Surf. Sur	nmer: ficial hour advances: h to solar hour From day 30 of month 3 To day 26 of month 10 ter: ficial hour advances: h to solar hour Import from hourly file Official hour 7 kWh/m2 5.88 kWh/m2 4.1 kWh/m2 4.1 kWh/m2 105.72 k who hell	∷ Wh/m2
	Calculate	Graph in steps of 60	min. Export G. tilted	Export G. horiz.	

We can see that annual irradiation over the inclined surface is 1815 kWh/m2. Average daily irradiation in December is 3.59 kWh/m2. We accept clicking "**OK**".

In the Wind resource window, we can see the average wind speed is 3.45 m/s, with a Weibull form factor of 2.8. We accept clicking "**OK**".

	— П X
Latitude (*) (+N -S) : 28.06 Get data from local DB Longitude (*) (+E -W) : 15.51 Download hourly data Locate on map Update coord Download NASA Monthly data	Monthly Average Data: Monthly Average Speed Night speed. Amplitude, F Factor and Hour max speed Surface Roughness
Monthly Average Import data file (in m/s) FROM PVGIS year 2007 Generation of wind turb. (kW) normalized to 1 kW rated p.	Steps Class 2 Length 0.1 m Mours 1 Minutes- each hour in 1 row Import Agricultural area with some buildings and preserving hedges 8 meters high with an approximate distance of 500 m. (m/s) 316
Correlation of wind speed for each minute: std. dev. 1m/s Update min.	Image: Non-State interview Image: Non-State interview 3.04 Image: Non-State interview 3.05 Image: Non-State interview 64 Image: Non-State interview 424 Image: Non-State interview 3.06 Image: Non-State interview 10 Image: Non-State interview 10 Image: Non-State interview 10 Image: Non-State interview<
Calculate Graph in steps of 60 min. Export Av. yea 3.45 Scale by (x by): 1 Scaled Average Speed (m/s) OK	r (m/s) Info time of calm wind Calm is considered Form factor of the wind speed serial: 2.8

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)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
1	24996.3	202.65	3.2	0.21	INF	4.7	98.95	0.8527	SIMULATE	REPORT	(
2	25176.4	212.89	4.3	0.29	INF	4.7	99.13	0.8595	SIMULATE	REPORT	(
3	25241.8	181.93	3.2	0.22	INF	7.8	98.91	0.8611	SIMULATE	REPORT	(
4	25627.6	174.9	2.8	0.19	INF	5	99.01	0.874	SIMULATE	REPORT	(
5	25752.5	183.2	4	0.27	INF	5	99.21	0.8789	SIMULATE	REPORT	(
6	26405.7	171.16	3.1	0.2	INF	15.5	99	0.9007	SIMULATE	REPORT	(
7	26405.7	171.16	3.1	0.2	INF	15.5	- 99	0.9007	SIMULATE	REPORT	(
8	26552.5	181.16	4.2	0.28	INF	15.5	99.14	0.9064	SIMULATE	REPORT	(
9	26552.5	181.16	4.2	0.28	INF	15.5	99.14	0.9064	SIMULATE	REPORT	٢.,
1											> ×
COMPORENTS: PV modules SiP12-TAB:PV-135-mod (135 Wp_dc): 4s x 4p. (100% PV#1: slope 40%, azimuth 0%) // Batteries OPZS-Hawker:TLS-5 (270 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 VA // 2 Wind Turb. DC SouthwestAIR X (547 W at 15 m/s) // Bat. 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) = 24996.3 € (0.85 €/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).

If you are not interested in TEG, you can skip to the next section.

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 or another process 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 16 to 19 h, during all the days, and the temperature of the hot exchanger of the TEG is around 700°C during that hours. We change the hot temperature from 6 to 9 a.m. and from 16 to 19 h to 700 °C (change the first line, then click on the right or left cell to change all the cells of the column):

Te	mperature o	of HOT sou	rce (ºC)	Temperatur	e of COLD	source (ºC)	1											
_																		
	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	1
	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	
Þ	20	700	700	700	20	20	20	20	20	20	20	700	700	700	20	20	20	-
	5																>	

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).



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, $0 \in$). 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 60.33^o and 8.77^o, respectively.



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

Data to download: Year 2019 💌
 Monthly Average Irradiation Monthly Average Temperature For Bat. Monthly Average Wind Speed At 10 m height Consider roughness At 50 m height Wind Speed Weibull Shape Factor Altitude above sea level
OK Cancel

After downloading the NASA data, we change the PV panels slope to 70^o (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:

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	23-24
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	30
APRIL	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
MAY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
JUNE	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
IULY	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	31
AUGUST	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
EPTEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
DCTOBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	30
IOVEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	3
DECEMBER	20	20	20	20	20	600	600	400	400	300	300	600	400	400	400	300	300	600	600	400	400	300	300	3

Cold source:

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.

Ň	CONSTRAINTS -		×				
	If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (for that assigned infinite cost):	ombination i	is				
Maximum Unnet Load allowed: 0.3 % of annual load [Max, energy not supplied by the stand-alone system. This Energy can be purchased from the AC grid if such AC grid exists and also the purch allowed on the LOAD/AC GRID screen) Minimum number of days of autonomy. (batteries+hidrog-ml): 4.9 d yze [[\screen]' if there is AC generator or fuel cell using external uel or purchasin runnet load from AC grid is allowed, number of days of autonomy = in Nominal capacity of batteries bank (Ah) < [20] x (shortcut current of FV generator + current from Wind Turbines grupp at 14m/s) (A) [\screen]' if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, do not take into account this con							
	Minimum renewable fraction: 50 %						
	Maxmum Levelized Cost of Energy: 000 C/KWh						

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.

-MIN. AND MAX. No COM	PONENT	'S IN PA	ARALLEL:
Bateries in parallel: Min.	1	Max.	3
PV mod. in parallel: Min.	0	Max.	21
Wind T. in parallel: Min.	1	Max.	62
AC Gen. in parallel: Min.	1	Max.	1

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:

MIN. AND MAX. No COM	PONENT	'S IN PA	ARALLEL:
Bateries in parallel: Min.	1	Max.	3
PV mod. in parallel: Min.	0	Max.	21
Wind T. in parallel: Min.	1	Max.	5
AC Gen. in parallel: Min.	1	Max.	1

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:

OPTIMIZATION PARAMETERS SELECTED BY:										
	R									
Maximum execution time:										
0 h. 5 min. Parameters										
Minimum time for the Genetic Algorithms										

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 4th to last generation the optimal is the same):

Mone-objective optimization. Totel No. of cases evaluated: 5737. Time: 5' 49" 0 <								HART	SULTS CI	ATA R		S FINA	RATEGIES	ONTROL ST	IZATIOI	A OPTIMIZA	NERAL D
26,624 26,368 26,368 26,368 26,368 26,368 26,368 26,368 26,368 25,366 25,386 25,386 25,386 25,386 25,386 25,386 25,386 25,386 25,276 25,276 25,276 25,276 25,276 28,952 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 3en 7 25237,6 289,52 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 8 25237,6 289,52 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 9 25237,6 289,52 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 10 25237,6 289,52 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 11 25237,6 289,52 3,9 0,26 1NF 1,6 98,37 0,8613 SIMULATE REPOR 12 25237,6	_				' 49''	Fime: 5'	5737. 1	luated:	cases eva	l No. of	on. Tota	imizati	ective optir	Mono-obj			
F 25,600 25,472 25,344 25,216 2 3 4 5 6 7 8 9 10 11 12 13 14 Show diagram Show diagram <td< th=""><th>3 3 3 3 3 3 3 3 2</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>26,62 26,49 26,36 26,24 () 26,24 26,11 25,96 25,85 25,85 18 25,72</th></td<>	3 3 3 3 3 3 3 3 2																26,62 26,49 26,36 26,24 () 26,24 26,11 25,96 25,85 25,85 18 25,72
Total Cost (NPC)(£) Emission (kgC02/yr) Unmet(kWh/yr) Unmet(%) D.aut Cn(Wh)/(Ppv+Pw)(V) Ren(%) LCOE(6/kWh) Simulate Report ien Total Cost (NPC)(£) Emission (kgC02/yr) Unmet(kWh/yr) Unmet(%) D.aut Cn(Wh)/(Ppv+Pw)(V) Ren(%) LCOE(6/kWh) Simulate Report 7 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPOR 9 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPOR 10 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPOR 11 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPOR 12 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPOR 12 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 </th <th>15</th> <th>14 1</th> <th></th> <th></th> <th>12</th> <th>11</th> <th></th> <th></th> <th>9</th> <th></th> <th></th> <th>6</th> <th></th> <th></th> <th>2</th> <th></th> <th>25,60 25,47 25,34 25,21</th>	15	14 1			12	11			9			6			2		25,60 25,47 25,34 25,21
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	· (REPORT	ATE	SIMUL	0.8613		98.37	1.6		6 INF	0.2	3.9		289.52	237.6	25237	12
13 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPORT	· (REPORT	ATE	SIMUL	0.8613		98.37	1.6		6 INF	0.2	3.9		289.52	237.6	25237	13
14 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE BEDOR	· (REPORT	ATE	SIMUI	0.8613		98 37	1.6		6 INE	0.0	3 9		289 52	237.6	25237	14
15 25237.6 289.52 3.9 0.26 INF 1.6 98.37 0.8613 SIMULATE REPORT	· (REPORT	ATE.	SIMUL	0.8613		98.37	1.6		6 INF	0.2	3.9		289.52	237.6	25237	15
	>					0.5.7.0											

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.

If you are not interested in multi-objective optimization, you can skip to the next section.

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:

Project: D:\Pr1-MO-Emis.hoga
Project Data Calculate Data Base Report Help

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 - CO₂ 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):

CONSTRAINTS: <u>Maximum Unmet Load allowed:</u> 30 % annual										
Unmet load refers to:										
More Constraints										

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 kgCO₂/kWh:

AC LOAD (W)	DC LOAD (W)	H2 LOAD (kgH2/h)	WATER (m3/day) FROM WATER TANK	PURCHASE / SE
Purchase fr Energy by S Fixed Buy Pu Annual Inflation 3 Fixed Pmax 3.45 C Access Charge Fixed Access Back-up Charge Fixed Back-u (Will be added to	om AC grid Unmet L Stand-alone system rice (€/kWh) 0.18 0 (%): Emission (0 (%): Emission (0 (%): Fixed Cost 0 (%): 0 Price (€/kWh) 0 Price (€/kWh) 0 Price (€/kWh) 0 o the E purchased) 0	.oad (Non Served Hourly Price kgC02/kWh): Emissions data P (€/kW/yr) Hourly Values Hourly Price Add negative gen. charge	Sell Excess Energy to AC grid ✓ Fixed Sell Price (€/kWh) ○ Pr. sell = pr. buy x Annual Inflation (%): 3 Max. Power(kW) 3.45 ✓ =Pmax buy Energy Generation Charge (Transfer Charge ✓ Fixed Transfer price (€/kWh) 0 Self-consumption and Net Mettering: No net mettering Cost of net metering service (€/kWh) 0 Buy-back: Export E is paid at (€/kWh) 0 0 0	Hourly Price
Total tax for electr	icity costs (buy + charg	es) (%): 0	Total tax for electricity sold (%):	Los

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

-Priority to supply E not covered by renewables:---

● Storage/Generator ○ AC Grid

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

GENERAL DATA OPTIMIZATION CO	NTROL STRATEGIES F	FINANCIAL DATA	RESULTS CHART
OPTIMIZATION TYPE:			
TEMPORARY INTERVAL: ALL USEFUL LIF	E OF THE SYSTEM (FIXED INS	TALLATIONS)	
O MONO-OBJECTIVE (Cost)	TI-OBJECTIVE	Parameters	
NPC - CO2 Emis. O Triple NPC - Unmet Load Another	Display only non-domin % sobre coste mín. 300 Nº máx. No dom.: 50	. Save Pareto every: 5 gen. Export Paretos	
O TEMPORARY INTERVAL: LESS THAN ONE	YEAR (TRANSPORTABLE FAC	LITIES, ONLY FOR PV-0	DIESEL-BATTERIES)

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

PV inverter or battery charge regulator includes Maximum Power Point Tracking (MPPT)

and PV generator is connected to AC bus (it has its own inverter) ->

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.

V MODULES									-		×
Add PV module	Zero	~				_					
Add PV modules family	SiM12-Atersa	~		+ -	▲ ✓ × (°	•					
PHOTOVOLTAIC MODU	LES DATA:										
Name	Nom Volt (V)	lsc(A)) Power(Wp)	Cost(£)	C.O&M(6A/r)	Life(vears)	NOCT(#C)	Power T. coef (%/*C)	BIFACIALIT	Y(0-1) 🔥	
aSi12-Schott: ASI100	12	6.79	100	110	1.1	25	49	-0.2		0	
SiP12-TAB:PV-135-mod	12	8.73	135	160	1.6	25	45	-0.47		0	
C Efficiency due to degradation of Standard conditions	of the modules, losses in wire e regulator includes Meximu	s, dirt in p n Power F	anels, etc. 0.8 Point Tracking (MPF	21)					Fixe Mai 40	> d Operatio	on and Cost €/yr
Calculate number of f Consider effect of Ter Data of ambient tempe Monthly average From file (8760 hour	™ modules in serieal as: Vb mperature prature (*C) ✓ Erbs model fy values)	us_dc/Vr 17.6 F Impo	mex_p_module (gr 17.9 M 17.8 A 16 ort FROM PV	rid-connecter 8.5 M 19.4 GIS year 2007	d systems). Dat	a: Vmax_p_m A 22.4 S 22	odule / Vnom	inal_module = 1.475	d for CPV		
PV generator is connected	d to AC bus (it has its own inv	erter) ->	Number of PV mo	odules in seri	ial: 4	PV inverter	data				
Annual Inflation Generator Cost	Rate for PV -2 %		Limit is reached	Max. Vi reductii in 59.6 year:	ariation of PV gen on on current PV g s	. Cost (e.g., for jen. cost, intro	an expected duce "-70%"):	70% -70 %			
				ОК							

Save the project. We click on "**CALCULATE**" and we obtain the following results, where we have obtained 3 non-dominated solutions (called the "*pareto front*"), that is, if you choose any of these 3 solutions, none of the remaining 2 is better than the selected 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 CO₂ emissions.



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".

TEMPORARY INTERVAL: ALL USEFUL LIFE OF	F THE SYSTEM (FIXED INST	(ALLATIONS)	
O MONO-OBJECTIVE (Cost) O MULTI-O	BJECTIVE	Parameters	
NPC - CO2 Emis. O Triple O NPC - Unmet Load Another	 ✓ Display only non-domin. % sobre coste mín. 300 № máx. No dom.: 50 	Save Pareto every: 5 gen. Export Paretos	
O TEMPORARY INTERVAL: LESS THAN ONE YEA	AR (TRANSPORTABLE FAC	ILITIES, ONLY FOR PV	DIESEL-BATTERIES)

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%).

iHOGA	×
Adapt the value of the Maximum Unmet Load allo	wed
ОК	

Save the project. We recalculate and obtain the following results screen, in which 2 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.



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:

OPTIMIZATION TYPE:	
TEMPORARY INTERVAL: ALL USER	FUL LIFE OF
O MONO-OBJECTIVE (Cost)	● MULTI-OB
ONPC - CO2 Emis. Triple NPC - Unmet Load O Another)

We obtain 3 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.



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.

A	В	С	D	E	F	G	н	1	J	K	L	M	N	0	P	Q	R	S	
1 Project: D:\PI	OYECTOS INC	GA 3.4-10-12-	2022\Pr1.hoga	a. Solution # 1															
2																			
3 COMPONENT	S: PV generation	or of 1600 Wp.	dc (100% PV#	1: slope 40º, a:	timuth 0º). 1 x A	AC Generator o	f 500 W. Batt	ery bank of 8	640 Wh. Bat.	Inverter of 160	00 VA.								
STRATEGY: LO	DAD FOLLOWI	NG. P1gen: INF	W. Pmin_gen	: 150 W. Pcritic	al_gen: 0 W. SC	DC stp_gen: 20	%. SOC min.:	20 %.											
5																			
5 HOURLY VAL	UES. All power	values are exp	pressed in W (H	12.load is in W	referring to the	HHV of H2). Th	he SOC data o	f the batterie	s in energy (V	/h).									
7 Water tank ()	Nater tank) is	energy needed	to pump the	water (Wh) wh	ile (Water tank	volume) is the	e volume store	ed (m3).											
No.Gen on is	the number o	f AC generator	s that are runn	ning during this	time step. Hour	rs eg Gen is th	ne number of a	equivalent ho	urs (including	out-of-range p	enalty and sta	t-up penalty)	of AC generate	ors. The fuel co	nsumption of th	e Gen. AC (Fu	el.Gen) is e	xpressed in litr	e. Th
Ocsts of purc	hasing energy	to the grid, the	fuel cost of th	ne AC Gen. (Fue	l.Cost), the cos	t of the extern	al fuel used by	the fuel cell	(C.fuel.ext Fi	C) and incomes	of selling E an	d costs of buyi	ng E to the AC	grid (Inc.Sell a	d Cost.Buy) are	expressed in	€. They are	cash flow val	ues c
0 Load of Hydr	ogen (H2 load	mass) is expr	essed in kg/h o	f H2. H2 in tan	k (H2 Tank ma	ss), H2 used by	fuel cell, fron	hH2 tank (Fu	el.FC) or exter	mally purchase	d (Fuel.ext FC)	and hydrogen	generated by	the electrolyze	r (Prod H2) are	expressed in	kg of H2.		
1 Hydrogen sto	red in H2 Tank	(H2 Tank HH	V) is expressed	in Wh HHV of	H2														
2 Date	Hour	Load(W)	AC_load(W)	DC_load(W)	H2_load(HHV)	H2_load_mas \	Water_load(V	PV(W)	Wind(W)	Hydro(W)	Ef_turb(perce	AC.Gen.(W)	No.Gen_on	Hours_eq_Ge	Cons.Fuel(litre	Fuel.Cost(€)	F.C.(W)	Fuel.FC(kg	F
3 01-January	0:00	25.34	25.34	0	0	0	0	C		0	D 1	(0 0	0	0		0	0
4 01-January	1:00	25.08	25.08	0	0	0	0	0		0	D 1			0 0	0	0		0	0
5 01-January	2:00	24.82	24.82	0	0	0	0	0	1	0	0 1			0 0	0	0		0	0
6 01-January	3:00	25.34	25.34	0	0	0	0	C		0	0 1			0 0	0	0		0	0
7 01-January	4:00	25.08	25.08	0	0	0	0	0		0	D 1			0 0	0	0		0	0
8 01-January	5:00	25.87	25.87	0	0	0	0	0	1	0	0 1			0 0	0	0		0	0
9 01-January	6:00	125.4	125.4	0	0	0	0	C		0	D 1			0 0	0	0		0	0
0 01-January	7:00	244.53	244.53	0	0	0	0	9.7		0	D 1			0 0	0	0		0	0
1 01-January	8:00	152.06	152.06	0	0	0	0	232.18		0	0 1			0 0	0	0		0	0
2 01-January	9:00	130.68	130.68	0	0	0	0	488.65		0	D 1) (0	0		0	0
3 01-January	10:00	124.08	124.08	0	0	0	0	622.81		0	D 1) ()	0	0		0	0
4 01-January	11:00	358.51	358.51	. 0	0	0	0	705.82		0	t 0			0 0	0	0		0	0
5 01-January	12:00	540	540	0	0	0	0	761.32		0	0 1	. () (0	0		0	0
6 01-January	13:00	261.36	261.36	0	0	0	0	949.34	1	0	t d) (0	0		0	0
7 01-January	14:00	204.86	204.86	0	0	0	0	602.99		0	t 0			0 0	0	0		0	0
8 01-January	15:00	175.56	175.56	0	0	0	0	617.11		0	0 1	. () (0	0		0	0
9 01-January	16:00	158.4	158.4	0	0	0	0	365.62		0	D 1			0 0	0	0		0	0
0 01-January	17:00	206.98	206.98	0	0	0	0	219.48		0	0 1			0 0	0	0		0	0
1 01-January	18:00	287.5	287.5	0	0	0	0	6.79		0	0 1			0 0	0	0		0	0
2 01-January	19.00	797 79	797 79		0	0	0			0	n 1			n n	0	0		0	0

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 1 minute time steps:



Although previously we have used 1 h as time step in the optimization, the software already has data in 1-minute time steps of load consumption, irradiation, temperature and wind speed, obtained when they were defined in their respective screens.

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 recalculated with time 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 (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.



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. If we change to 60 min., the simulation updates automatically to 1 h time steps.



Obtaining the same result as previously with 60 minutes time step. We go back with the button "**Back**" to the main screen, and we see that the results are updated in the first row of the table:



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:

Batteries Model		Fixed Operation and Ma
C Ah 🔽 Li	i model Ah	·
🔿 KiBaM (Manwell-N	dcGowan 1993)	
C Copetti 1994	Control Data	
Schiffer 2007	Schiffer bat. data	
Temp. J 18 F 18 Bat. (ªC) J 22 A 22 ▼ Except Schiffer m Tmean>=Tfloat life Float life reduces 50% □ Cycle life depends □ Capacity depends	M 20 A 20 M 20 S 22 0 20 N 18 odel, consider e Impor e Impor e Impor e Impor e s on T Data PC inc Impor e Imp	J 22 Mean (°C) 20 3 D 18 6 Mon. C Hour rease T Graph
Lead-acid battery mod	lel Li-ion battery mo	del
C Rainflow (cycle C Equivalent full c	counting) ycles	
Schiffer ageing	model	

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

🖟 Battery Charge Controller Data	-		×
TO BE APPLIED ONLY IN COPETTY OR SCHIFFER MODELS			
CONTROL PWM			
0.111111			
OVER-CHARGE PROTECTION (PWM):			
Float Charging voltage: 2.3			
Boost Charging voltage: 24			_
Boost duration: 2 h	onnect (I VD): 1.85	v	
Boost activated if SDC< 70 %	connect (LVD), 1.00	× N	
Low Yorkage Rec	C Disconnect: 30	*	
Equalization Charging voltage: 2.45 V	C Beconnect: 50	*	
Equalization duration: 2 h	C Heconnect.		
Equalization activated if SOC< 40 🕺 🗌 Use as Low SOC for Disc	onnect the value of SOC	min. use	
Equalization activated if no equalization in the optimization and us	e as Low SOC for Recor	inect same	
nor boost charge during 30 days SUC min plus a 10 %			
Temperature compensation (only for Copetti model): -5 mV/*C			
If there is an AC Generator, every 14 days or 8 equivalent full cycles, generato	r charges batteries at lea:	st up to 95	5 %
ОК			

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). Let's suppose that the controllers selected do not have this characteristic so we leave unchecked the option on the bottom:

If there is an AC Generator, every	14	days or	8	equivalent full cycles, generator charges batteries at least up to	95	2
------------------------------------	----	---------	---	--	----	---

We click **OK** to return to the battery window.

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

🕅 Aging batteries model data	- D X
Aging batteries model shown in (Schiffer et al., 2007) Batteries tata: DP2S In the batteries must be from the same family, voltage data refered to 2 V cells: Open-circuit voltage at full charge, U0: 2.1 V Gradient of change in DCV with state-of-charge, g: 0.1 V Initial effective internal resistance (charge), ro.c. 0. 0.43 ohm Ah Initial effective internal resistance (charge), ro.c. 0. 0.43 ohm Ah Initial effective internal resistance (discharge), ro.c. 0. 0.38 ohm Ah Resistance representing charge-transfer process which depends on SOCC, Mc: 0.36 Resistance representing discharge, Cc: 1.001 Normalized capacity of battery, charge, Cc: 1.001 Normalized capacity of battery, discharge, Cd: 1.642 Normalized reference current for current factor, Iref: 0.1 A/Ah Height of battery, z: 20 cm Corrosion voltage of fully-charge dbattery without current flow, Ucor0 1.75 V Normalized reference for Sassing Linastic 1.273 V	Potential of reference electrode Hg/Hg2S04: 0.616 V Curve of Corrosion speed vs. potential of positive electrode [vs. Hg/Hg2S04 ref.]: Ucorr (M) vs ref. Hg. Corrosion speed ks 0.6 4 0.8 45 0.95 5 1 6 1.1 8.5 1.1 9 1.1 12 5 1.1 8.5 1.1 8.5 1.1 8.5 1.1 9 1.1 12 5 1.1 4 1.2 5 1.35 7 1.4 15
Contrast rotage of classing, Ugas0: 2.23 V Normalized Gassing Current, Igas0: 2.0 mA/100A SOC for considering full charge in order to set fsoc=1 and obtain current for factor fl: 0.99 SOC to reset Number of Bad Recharges: 0.9 End of batteries lifetime will be considered when Max. Capacity is 80 % of nominal capacity Corrosin speed during floating life (Catculate Calculate	1.4 15 Potential of positive electrode (V) vs ref. Hg/Hg2SO4 When Max. Capacity < Nominal Capacity, use this SOC in terms of Max. Capacity
E BACK	

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:

omputations	speed. 0.5 Cut	especona			CEN ALC (% ALL)
MAIN AL	.G. (COMB. CO)MPONENTS):	1620 (1×1620)	55 (3.4%)	802 (49.51%)
SEC. AL	G. (COMB. ST	RATEGIES):	1	3 (300%)	41 (4100%)
	MAIN ALG.	SEC. ALG.	NUMBER OF CASES	%	TIME EXPECTED
OPTION 1:	EVAL. ALL	EVAL ALL	1620	100 %	0h 30' 0''
OPTION 2:	EVAL. ALL	GEN. ALG.	66420	4100 %	20h 30'
OPTION 3:	GEN. ALG.	EVAL ALL	802	49.5 %	<u>0h 14' 51"</u>
OPTION 4:	GEN. ALG.	GEN. ALG.	32882	2029.8 %	10h 7'

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 0.9 cases per second is estimated, and the estimated optimization time using the enumerative method (all possible combinations) is 30'00". As we are only allowing 15 minutes of calculation, it chooses the method of **genetic algorithms** (metaheuristic optimization technique), 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 8th 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 - 9th 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_dc): 4s.x 4p. (100% PV#1: slope 40°, azimuth 0°) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Gasoline 0.5kVA 0.5 VA // Bat. Inverter STECA: XPC 1600-48 of 1600 VA // PV batt. charge controller. STECA: TAROM 440 of 40 A // Unmet load = 0 % // Total Cost (NPC) = 16046.9 \in (0.55 \in /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: 8.25 years (compared to the 11.19 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	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		0
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		D
	0	0	0	8.25	3313	5378	0	0		0

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 9 years (3285 days display), the batteries end their life when 8.25 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"

M BATTERIES	
Add Battery	LG Chem: RESU3.3
Add Batteries family	OPZS-Hawker 🗸 🗸

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	ι
OPZS-Hawker:TLS-5	270	2	178	1.78	20	3	54	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	1000	L
Zero	0	2	0	0	20	0	0	100	100	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	ι
LG Chem: RESU3.3	63	48	3400	30	10	2	62.5	95	15	28800	14400	9600	7200	5760	4800	4114	3600	3200	2500	L
2001011.112000.0	00	10	0.00		10	-	02.0		10	20000	11100	0000	1200	0100	1000		0000	0200	2000	
																				>

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 model and adapts correctly to lithium-ion batteries.

-Batteries Mod	el						
O Ah	🔽 Li model Ah						
C KiBaM (Manwell-McGowan 1993)							
O Copetti 19	94	Control Data					
Schiffer 2	007	Schiffer bat, data					

For the ageing model, you can select several models: Wang, Grot or Naumann for LiFePO4, Saxena for LiCoO2 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).

Lead-acid Aging battery model	Li-ion Aging battery model
 ○ Wang et al., 2011 (LiFePO4) ○ Grot et al., 2015 (LiFePO4) ○ Saxena et al., 2016 (LiCoO2) 	
Rainflow (cycle counting) Naumann (LiFaPot cycles)	Parameters

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.

Wang Grot Saxena Calendar ageing Naumann	
✓ Include calendar ageing in Wang and Saxena models ○ Swierczynski et al., 2016	I limit (cycle / calendar): C· 0.05
✓ Include Calendar in Full eq. cycles and Rainflow models	
<u>Data (Petit et al., 2016):</u>	<u>Data (Swie<mark>r</mark>czynski et al., 2015):</u>
Cfade(%)=B·exp[-A/(RT)]·t^z	Cfade(%)=(a·SOC^b+c)·(d·T^e+f)·t^g
SOC 30% 65% 100%	a 0.019 b 0.823
B 734E3 675E3 218E3	c 0.5195 d 3.258 ·10^-9
A 73369 69804 56937	e 5.087 f 0.295
z 0.943 0.9 0.683	g 0.8
graph T(°C): 20	graph: T(°C): 20 SOC(%): 80
24 16 10 15 20 25 Time (years) - SOC 30% - SOC 65% - SOC 100% - EOL	32 40 32 24 5 5 5 24 16 8 0 0 10 20 Time (years)

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.

Temp. J 18 Bat. (⁰C) J 22	F 18 A 22	M 20 S 22	A 20	M 20 N 18	J 22 D 18	Mean (ºC) 20	
Except S Triean>:	chiffer mo =Tfloat life	odel, cor e	nsider	Import h	ourly file	Mon. O Hour	
Float life red	uces 50%	for eve	ry 10	₽C increa	ase 📑	👝 T Graph	
🔽 Cycle life	Cycle life depends on T Data						
🔽 Capacity	depends	on T	Data				

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.

omputations	speed: 2.534 c	ases/second	EVAL ALL	<u>POP. (% ALL)</u>	GEN. ALG. (% ALL)
MAIN AL	G. (COMB. CO	MPONENTS)	: 360 (1×360)	159 (44.17%)	2274 (631.67%)
SEC. AL	G. (COMB. ST	RATEGIES):	ì	3 (300%)	41 (4100%)
	MAIN ALG.	SEC. ALG.	NUMBER OF CASES	%	TIME EXPECTED
OPTION 1:	EVAL ALL	EVAL. ALL.	360	100 %	<u>Oh 2' 22''</u>
OPTION 2:	EVAL. ALL	GEN. ALG.	14760	4100 %	1h 37'
OPTION 3:	GEN. ALG.	EVAL. ALL.	2274	631.7 %	0h 14' 57''
OPTION 4	GEN. ALG.	GEN. ALG.	93234	25898.3 %	10h 12'

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:

OPTIMIZATION PAR	AMETERS	SELECTED BY:-				
● iHOGA ○ USER						
Maximum executio	n time:					
0 h. 15	min.	Parameters				
Minimum time for t	he Genetic	Algorithms				

The following screen appears:

PARAMETERS OF THE OPTIMIZA	TION	- 0					
AIN ALGORITHM (OPTIMIZATIO	ON OF COMPONENTS)	SECONDARY ALGORITHM (OPTIMIZATION OF STRATEGY)					
OPTIMIZATION METHOD:		OPTIMIZATION METHOD:					
	● EVALUATE ALL COMB	◯ GENETIC ALGORITHMS					
GENETIC ALGORITHM:		GENETIC ALGORITHM;					
Generations: 15 Pop	ulation: 159	Generations: 15 Population: 3					
Crosser roto: 90 av Mut	otion voto: 1	Craceover retain 99 % Mutation rate: 1 % Mutation Uniform					
CIUSSOVEITALE. 30 % INIU							
STOPPING CRITERION:		STOPPING CRITERION:					
Stop execution of main algorithm if	after 15 generations	Stop execution of secondary algorithm if after 15 generations					
it cannot improve 1 % in	5 consecutive generations	it cannot improve 1 % in 5 consecutive generations					
EVALUATE ALL COMBINATIONS:							
Display best 10							
	NUMBER OF CAS	ES AND TIME EXPECTED					
	Computation speed: 2 534 cases/second						
	Comparation speed. 2.55 reasely second						
	MAIN ALG. (COMB. COMPONENTS):	360 159 (44.17%) 2274 (631.67%)					
		(1x360) 1 2 (2009c) 41 (4100%)					
	SEC. ALG. (COMB. STRATEGT).						
	MAIN ALG. SEC. ALG. NUM	BER OF CASES % TIME EXPECTED					
	OPTION 1: EVAL. ALL EVAL. ALL 36	0 100 % <u>Oh 2' 22''</u>					
	OPTION 2: EVAL ALL GEN ALG. 14	760 4100 % 1h 37'					
OK	OPTION 3: GEN ALG. EVAL ALL 22 OPTION 4: GEN ALG. GEN ALG. 93	74 b31.7 % UN 14"57" 234 25898.3 % 10b.12'					
UK	GENERAL GENERAL GENERAL 33						
	Optimization by means of enumerative method optimal solution	(evaluating all combinations). It is guaranteed to obtain the					

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:

EVALUATE ALL	COMBIN	ATIONS:
Display best:	360	

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 the same as previously (without considering Li-ion batteries), and is shown in the next figure.



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 9th 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). Also, solution of 9th row includes 1.9 kVA diesel generator (comparing to optimal solution, which includes 0.5 kVA gasoline generator).

HDI	Jobs	P. PV mod. (Wp_dc)	Slope#1(º)	Cn Bat. (Ah)	P. Gen (W)	P. In∨ (W)	P. Wind T. (W)	F. Turb (I/s)	P. FC (W)	P. Elyz. (W)	H2 ti 🧄
0.525786	0.0048	4x4x100	40	24x1x180	1x500	1600	1x0	0	0	0	
0.525786	0.0048	4x4x100	40	24x1x180	1×1900	1600	1x0	0	0	0	
0.525785	0.00486	4x3x135	40	24x1x180	1x500	1600	1x0	0	0	0	
0.525785	0.00486	4x3x135	40	24x1x180	1×1900	1600	1x0	0	0	0	
0.525786	0.0048	4x4x100	40	24x1x270	1x500	1600	1x0	0	0	0	
0.525786	0.00648	4x4x135	40	24x1x180	1×500	1600	1x0	0	0	0	
0.525786	0.0048	4x4x100	40	24x1x270	1×1900	1600	1x0	0	0	0	
0.525786	0.00486	4x3x135	40	24×1×270	1x500	1600	1x0	0	0	0	
0.525551	0.00481	4x4x100	40	1x1x63	1×1900	1600	1x0	0	0	0	
	_		_		<u> </u>	_					

The 9th best solution NPC is 20246.4 €, considerably higher than the best one.

Gen	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(۸
1	16046.9	110.42	0	0	INF	6.6	100	0.5462	SIMULATE	REPORT	C
2	16677.4	110.42	0	0	INF	6.6	100	0.5677	SIMULATE	REPORT	C
3	18421.3	138.39	0	0	INF	6.9	100	0.6271	SIMULATE	REPORT	C
4	18753.3	139.55	0	0	INF	6.9	99.99	0.6384	SIMULATE	REPORT	C
5	19371.4	143.85	0	0	INF	9.9	100	0.6594	SIMULATE	REPORT	C
6	19925.6	128.11	0	0	INF	5.2	100	0.6783	SIMULATE	REPORT	C
7	20001.9	143.85	0	0	INF	9.9	100	0.6809	SIMULATE	REPORT	C
8	20211.3	155.79	0	0	INF	10.3	100	0.688	SIMULATE	REPORT	C
9	20246.4	211.9	3.6	0.24	INF	2.3	95	0.6908	SIMULATE	REPORT	C
1		_									, Ň
											·

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 and working conditions.

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 (9th best solutions), it has to operate 169.27 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).

FC (kWh)	Hours	eq. Gen	Bat. life (yr)	House Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours Elyzer.	C. Fuel Gen.(€/yr)	C. Fuel FC(€/yr) E Bu	ıy (€/ 🗸
	0	0	8.25	3313	5378	0	0	0	0	
	0	0	8.25	313	5378	0	0	0	0	
	0	0.21	5.67	329.83	5410	0	0	0	0	
	0	0.23	5.59	3291 33	5410	0	0	0.1	0	
	0	0	7.99	331 <mark>4.5</mark>	5378	0	0	0	0	
	0	0	8.28	425	5176	0	0	0	0	
\	0	0	7.99	314.5	5378	0	0	0	0	
	1	0	7.1	3286	5411	0	0	0	0	
	0	169.27	6.72	0	0	0	0	47.9	0	

Comparing the 1st row (lead acid battery 180 Ah) with the 9th 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 (9th row) the generator must run for 169.27 eq. hours during 1 year, while in the case of lead-acid (optimal solution, 1st row) it doesn't work.

Regarding battery lifetime, the optimal solution has a lead-acid battery which will last 8.25 years while the 9th solution has a Li-ion battery which will last 6.72 years.

If we see the simulation of both cases, in the first case we can see the first 10 days of January, year 1, in red the SOC of the battery, we can see each day only around a 40% of depth of discharge is reached (less than half a full cycle).



In the 2nd tab of the simulation screen we can see during a whole year (the last year of the simulation of the Schiffer model, year 9) the SOC:



Now, if we simulate the 9th combination (with Li-ion), we can see the difference:



In the case of Li-ion, the battery capacity is much lower, therefore many days of the year a full cycle is performed. This is why the lifetime of these batteries is lower than the lifetime of lead-acid, in this case, even considering that the Li-ion batteries can perform more than twice cycles.

Smaller capacity lead-acid batteries could be considered in the optimization, and probably the optimal solution would have more difference in NPC, being lead-acid batteries the optimal in this case.

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:

MIN. AND MAX. No COMPONENTS IN PARALLEL:								
Bateries in parallel: Min. 1	Max. 3							
PV mod. in parallel: Min. 0	Max. 2							
Wind T. in parallel: Min. 1	Max. 2							
AC Gen. in parallel: Min. 1	Max. 1							

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:

EVALUATE ALL	COMBIN	ATIONS:
Display best:	162	

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



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_dc): 4s.x 2p. (100% PV#1: slope 40^o, azimuth 0^o) // Batteries OPZS-Hawker:TLS-3 (180 Ah): 24s. x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 VA // Bat. 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) = 32104.8 € (1.09 €/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 (1356.35 equivalent hours, including start-up and operating outside the optimum range penalties). The cost of diesel fuel is high (384.6 \notin /year), and also the generator must be replaced every few years (the generator lasts 10,000 hours, so every 10000/1356.35= 7.37 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, F	uel FC 🔺
571.7		0 1356.35	8.47	0	0	0	0		384.6	
568.3		1348.02	11	Π	n	Π	Π		382.3	

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 10915.1 €. 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):

	PERFORM PROBABILITY ANALYSIS
umber of series to analyze each combination of components and	control strategy: 500 Stopping rule in Monte Carlo Simulation Image: Confidence level (%) 99 v for max. error of the mean (%) 5 Or Relative standard error lower Hean (%) 1
Analyze variability of the average value of load	Analyze variability of the average value of irradiation
DAILY LUAD AVERAGE VALLIE	IRRADIATION AVERAGE VALUE
Mean: 4.11 kWh/day Standard Deviation: 0.3 kWh/day Mean= 4.122, Std. Dev. = 0.299 kWh/day Maximum = 4.98, Min. = 3.2 kWh/day Hourly variability in the series: 0	Mear. 5.85 kWh/m2/day Standard Deviation: [0.2 Mear. 5.85 kWh/m2/day Mear. 5.868, Std. Dev. = 0.21 kWh/m2/day Maximum = 6.52, Min. = 4.97 kWh/m2/day Hourly variability in the series: [0] % Std. deviation for temperature: 1] ♥C
	Analyze variability of the average value of water flow
Analyze variability of the average value of wind speed	Analyze variability of the average value of fuel price inflation. Average (%): 5
	AVERAGE FUEL PHICE INFLISUP 52
	Mean: 5 % Standard Deviation: 0.5 % Mean= 5.007, Std. dev. = 0.507 % Mean= 5.007, Std. dev. = 3.55 %
	Hourly variability in the series: 0 % Average fuel price infl.(%)
	Correlation data
Consider correlation between the variables	
Consider correlation between the variables	
Consider correlation between the variables In the simulation, show the case obtained will load	h the following data; Wind speed Fuel inflation
Consider correlation between the variables In the simulation, show the case obtained with Load: Irradiation: Average	h the following data; Wind speed Fuel inflation Via Average Via Average Vi
Consider correlation between the variables In the simulation, show the case obtained with Load: Irradiation: Average In the case of the simulation, include hourly variable	h the following data; Wind speed Fuel inflation Vind speed Vind
Consider correlation between the variables In the simulation, show the case obtained with Load: Irradiation: Average In the case of the simulation, include hourly variable In the case of the simulation, include hourly variable In the prebability analysis report, in the last tw	h the following data; Wind speed Fuel inflation Vind speed Vind speed Vind speed Vind speed Vind speed Vind speed Vind speed Average Vind speed Vind s
Consider correlation between the variables In the simulation, show the case obtained with Load: Average Average In the case of the simulation, include hourly variable In the probability analysis report, in the last tw Hours running AC Generator (h/yr)	h the following data; Wind speed Fuel inflation Vind speed Average Vinderage Vindera
Consider correlation between the variables In the simulation, show the case obtained with Load Irradiation: Average Average In the case of the simulation, include hourly variable In the probability analysis report, in the last tw Hours running AC Generator (h/yr) When clicking at any cell of the results table, do.mc	h the following data; Wind speed Fuel inflation Vind speed Average Vinderage Vinderage ility o charts, show the probability distribution of; Vinderage

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:

	NUM	BER OF C	ASES AND TH		ED	
Computation sp	beed: 0.1 cases	:/second				
MAIN ALC	G. (COMB. CON	(PONENTS):	<u>EVAL. ALL</u> 162 (1x162)	<u>POP. (% ALL)</u> 10 (6.17%)	<u>GEN. ALG. (% ALL)</u> 143 (88.27%)	
SEC. ALG	. (COMB. STR	ATEGIES):	1	3 (300%)	41 (4100%)	
	MAIN ALG.	SEC. ALG.	NUMBER OF CASE	S %	TIME EXPECTED	
OPTION 1:	EVAL. ALL	EVAL. ALL.	162	100 %	0h 26' 59"	
OPTION 2:	EVAL. ALL	GEN. ALG.	6642	4100 %	18h 26'	
OPTION 3:	GEN, ALG,	EVAL, ALL.	143	88.3 %	<u>0h 23' 49"</u>	
OPTION 4:	GEN. ALG.	GEN. ALG.	5863	3619.1 %	16h 17'	
Waring!. M evaluate a With this m but this is j	MAIN ALG. SEC. ALG. NUMBER OF CASES % TIME EXPECTED OPTION 1: EVAL. ALL EVAL. ALL. 162 100 % 0h 26' 59" OPTION 2: EVAL. ALL GEN. ALG. 6642 4100 % 18h 26' OPTION 3: GEN. ALG. EVAL. ALL. 143 88.3 % <u>0h 23' 49"</u> OPTION 4: GEN. ALG. GEN. ALG. 5863 3619.1 % 16h 17' Waring!. Minimum computing time is 0h 23' 49" so that the Main Genetic Algorithm can evaluate a minimum number of combinations. With this minimum time it is not guaranteed to obtain the optimal combination of componer but this is probable to obtain the optimal or a solution near the optimal					

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 3 variables in the probability analysis (wind speed), $5^3 = 125$ 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:

I	n the simulation, show the case	obtained with the following dat	a;	
	Load:	Irradiation:	Wind speed	Fuel inflation
	Average 🗸 🗸	Average 🗸 🗸	Average ~	Average ~

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).

Save Simulation Data Save Prob. Data

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:

A B	C D	E	FG	H I	J K	L	M N	0	P Q	R S
Project: Pr1-Prob.hoga	a. Solution # 1									
COMPONENTS: PV ger	nerator of 1080 Wp_dc (100%	PV#1: slope 40º, azimuth	0º). 1 x AC Generator of 19	00 W. Battery bank of 8640	Wh. Bat. Inverter of 1600	VA.				
TRATEGY: LOAD FOLI	LOWING. P1gen: INF W. Pmin_	gen: 570 W. Pcritical_gen	: 0 W. SOC stp_gen: 20 %.	SOC min.: 20 %.						
RESULTS FOR THE DIF	FERENT COMBINATIONS OF T	HE PROBABILITY ANALYSIS	5:							
rst 500 rows are the	results corresponding to rando	om data series. Next 125 r	ows correspond to charac	teristical cases. Next row cor	respond to the case show	n in simulatio	n. Finally MINIMUM	MAXIMUM, AVERAGE an	d STD.DEV. of the results	of the 500 random seri
esults corresponding	to random data series:									
ase prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambW(°C)	Wind(m/s)	W.Flow(l/s) or i	nf. fuel(%)	oad(kWh/day)	Total NPC (€)	LCOE(€/kWh)	Emission
0	5.49	20.04	20.04	4.66	5	(4.1	32104.8	1.093	11
1	5.48	19.47	20.04	4.66	5.12		3.7	27342.7	1.033	
2	5.52	20.04	20.04	4.66	4.95		4.11	31943	1.085	11
3	5.73	18.89	20.04	4.66	4.91		4.08	30070.4	1.029	10
4	5.52	21.65	20.04	4.66	5.06		3.92	29807.2	1.063	1
5	5.63	19.34	20.04	4.66	5.41		4.23	33211.5	1.098	1
6	5.43	19.51	20.04	4.66	5.46		4.63	39756.8	1.2	15
7	5.19	19.31	20.04	4.66	4.12		4.48	37209	1.16	1
8	5.5	19.61	20.04	4.66	4.74		4.33	34628.1	1.116	134
9	5.41	17.58	20.04	4.66	5.81		3.89	31295.6	1.123	10
10	5.42	20.37	20.04	4.66	4.37		3.93	29725.5	1.057	10
11	5.54	19.61	20.04	4.66	4.58		3.82	27835.2	1.017	9
12	5.42	20.51	20.04	4.66	4.89		3.88	29735.8	1.072	10
13	5.21	18.54	20.04	4.66	5.37		3.87	31799.8	1.148	1
14	5.51	19.67	20.04	4.66	5.03		4.37	35396.6	1.131	13
15	5.67	20.13	20.04	4.66	4.2		4.31	32208.8	1.044	1
16	5.5	21.17	20.04	4.66	5.71		4.57	39171.4	1.197	15
17	5.5	19.55	20.04	4.66	5.07		3.97	30554.5	1.074	10
18	5.48	18.58	20.04	4.66	4.75		4.4	35532	1.128	14
19	5.57	21.21	20.04	4.66	5.25		3.85	28704	1.041	91
20	5.7	20.54	20.04	4.66	4.93		3.78	26594.7	0.983	8
21	5.51	19.74	20.04	4.66	5.24		4.26	34170.2	1.121	12
	5.66	20.39	20.04	4.66	4.11		4.26	31655.3	1.038	12

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 77 to 201), including the average case, the most optimistic (mean irradiation + 3DT, mean consumption - 3DT) and More pessimistic (mean irradiation-3DT, mean consumption + 3DT):

Cases of irradiation and temperature: average, av.+SD, av.+3SD, av.-SD, av.-3SD Cases of fuel price inflation:, average, av.+SD, av.+3SD, av.-SD, av.-3SD

Cases of load: average, av.+SD, av.+SSD, av.-SD, av.-SSD
	87 Res	sults corrosponding								
		suits corresponding	g to characteristic cases (combinations of data: X	/ERAGE, AVERAGE+StdDv	, AVERAGE+3StdDv, AVERAGE	-StdDv AVERAGE-3StdDv):			
	88 Cas	se prob. No.	Rad.(kWh/m2/day)	Tamb(ºC)	TambV(ºC)	Wind(m/s)	W.Flow(I/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	
	0.0	86	5.7	20.24	20.24	4.62	55	2 22	20428.1	
	00	07	5.7	20.24	20.24	4.62	5.5	4.12	20426.1	
	99	07	5.7	20.24	20.24	4.02	0.5	4.12	55455.1	
	100	88	5.7	20.24	20.24	4.62	6.5	4.42	3/429.8	
	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	2.5	3.02	26102.4	
	112	101	5.7	20.24	20.24	4.62	2.5	3.02	19/52 1	
	114	101	3.7	20.24	20.24	4.02	5.5	3.22	10400.1	
	114	102	5.9	21.24	20.24	4.62	5	4.12	29022.8	
	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	
	162 163 164	150 151 152	6.3 6.3 5.5	23.24 23.24 19.24	20.24 20.24 20.24	4.62 4.62 4.62	3.5 3.5 5	3.82 3.22 4.12	16150.9 32569.6	
timistic ext adiation av. ion av3SD,	162 163 164 reme .+3SD , load	150 151 152 case: , fuel av3SD	6.3 6.3 5.5	23.24 23.24 19.24	20.24	4.62 4.62 4.62	3.5 3.5 5	3.82 3.22 4.12	22208.5 16150.9 32569.6	
timistic ext adiation av. on av3SD	162 163 , 164 reme ,+3SD , load	150 151 152 case: o, fuel av3SD	6.3 6.3 5.5	23.24 23.24 19.24	20.24 20.24 20.24 20.24	4.62 4.62 4.62	3.5 3.5 5 6.5	3.82 3.22 4.12	222045 161510.9 92569.6	
timistic ext adiation av. ion av3SD,	162 163 , 164 reme ,+3SD , load	150 151 152 case: , fuel av3SD	6.3 6.3 5.5 5.5 5.5	23.24 23.24 19.24 19.24	20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62	3.5 3.5 5 6.5 6.5	3.82 3.72 4.12 4.42 5.02	42212.5 16150.9 32569.6 42212.5 49730.1	
timistic ext adiation av. on av3SD,	162 163 , 164 reme ,+3SD , load	150 151 152 case: p, fuel av3SD	5.1 5.1 5.1	23.24 23.24 19.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 6.5 6.5 6.5	3.82 3.22 4.12 4.12 4.12	22204.5 16151.50 32569.6 42212.5 42770.1 34017.3	
timistic ext adiation av. ion av3SD,	162 163 164 reme .+3SD , load	150 151 152 case: , fuel av3SD 188 189 190 191	6.3 6.3 5.5 5.5 5.5 5.1	23.24 23.24 19.24 19.24 19.24 19.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	6.5 6.5 6.5 6.5 6.5	3.82 3.22 4.12 4.12 5.02 3.82 3.22	42212.5 42212.5 42212.5 49730.1 340017.3 25948.1	
timistic ext adiation av. ion av3SD,	162 163 , 164 reme ,+3SD , load 201 201 201 203 204	150 151 152 case: , fuel av3SD 188 189 190 191 192	6.3 6.3 5.5 5.5 5.5 5.1 5.1 5.1	23.24 23.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	6.5 6.5 6.5 6.5 6.5 6.5 6.5	3.82 3.22 4.12 4.12 5.02 3.82 3.82 3.22 4.12	42218.5 32569.6 32569.6 42212.5 49730.1 34017.3 25948.1 34566.7	
timistic ext adiation av. fon av3SD	162 163 164 reme .+3SD , load	150 151 152 case: , fuel av3SD 188 189 190 191 191 192 193	6.3 6.3 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5	3.82 3.22 4.12 4.12 5.02 3.82 3.82 3.82 4.12 4.42	22204.5 161510.9 32569.6 42212.5 49730.1 490730.1 30117.3 25948.1 34566.7 5860.7	
timistic ext adiation av. ion av3SD,	162 163 164 reme .+3SD , load 200 201 202 203 204 205 206	150 151 152 case: , fuel av3SD 188 189 190 191 192 193 194	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 6.5 4.5 4.5	3.82 3.22 4.12 4.12 5.02 3.82 3.22 4.12 4.42 5.02	42212.5 42212.5 42212.5 49730.1 34017.3 25948.1 34566.7 38000	
timistic ext adiation av. on av3SD,	162 163 164 reme .+3SD , load 200 201 202 203 204 205 206 207	150 151 152 case: p, fuel av3SD 188 189 190 191 191 192 193 194 195	5.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 4.5 4.5 4.5 4.5	3.82 3.22 4.12 4.12 5.02 3.82 3.22 4.12 4.12 4.42 5.02 3.82	42212.5 42212.5 42212.5 42770.1 34007.3 25948.1 3456.7 28900 Pessim	nistic extreme cas
timistic ext adiation av. ion av3SD	162 163 164 reme .+3SD , load 200 201 202 203 204 205 206 205 206 207 208	150 151 152 case: , fuel av3SD 188 189 190 191 191 193 194 195 196	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5	3.82 3.22 4.12 4.12 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22	42212.5 42212.5 49730.1 34007.3 25948.1 34565.7 29902 Pessim	histic extreme cas
timistic ext adiation av. on av3SD,	162 163 164 reme .+3SD , load 201 202 203 204 205 206 207 208 209	150 151 152 Case: b, fuel av3SD 188 189 190 191 192 193 194 195 196 197	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 4.5 4.5 4.5 4.5 4.5 4.5 3.5	3.82 3.22 4.12 4.12 5.02 3.82 3.22 4.12 4.12 4.12 5.02 3.82 3.82 3.82 3.82 3.82 4.12	42212.5 42212.5 42730.1 34017.3 2548.1 3456.7 Pessim irradia	nistic extreme car ation av3SD, fu
timistic ext adiation av. on av3SD	162 163 164 reme .+3SD , load 200 201 202 203 204 205 206 207 208 209 210	150 151 152 Case: , fuel av3SD 188 189 191 191 192 193 194 195 196 197 198	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 4.5 4.5 4.5 4.5 4.5 4.5 4.5 4.5 3.5	3.82 3.22 4.42 4.42 5.02 3.82 3.82 4.42 5.02 3.82 4.42 5.02 3.82 3.22 4.42 4.42 5.02 3.82 3.22 4.42	42212.5 42212.5 49730.1 34017.3 25948.1 340607 Pessirr irradi	nistic extreme car ation av3SD, fu
timistic ext adiation av. on av3SD,	162 163 164 reme .+3SD , load 200 201 202 204 205 206 207 208 209 210 211	150 151 152 Case: b, fuel av3SD 188 189 190 191 192 193 194 195 196 197 198	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 4.5 4.5 4.5 4.5 4.5 4.5 3.5 3.5 3.5 3.5	3.82 3.22 4.12 4.12 4.12 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22 4.12 4.42 5.02	42212.5 42212.5 42212.5 49730.1 34017.3 25948.1 34566.7 38000 Pessim irradia inflation a	nistic extreme car ation av3SD, fu av.+3SD, load av.
timistic ext adiation av. on av3SD,	162 163 164 reme +3SD 201 202 203 204 205 206 207 208 207 208 207 208 207 208 207 207 208 207 207 207 208 207 207 207 207 207 207 207 207	150 151 152 case: p, fuel av3SD 188 189 190 191 192 193 194 195 196 197 198	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.1 5.1 5.1 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24 17.24	20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24 20.24	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 4.5 4.5 4.5 4.5 4.5 4.5 3.5 3.5 3.5 3.5 3.5 3.5	3.82 3.22 4.42 4.42 5.02 3.82 3.82 4.12 4.42 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22 4.12 4.42 5.02 3.82 3.22 4.12	22204.5 16150.9 32569.6 42212.5 427	nistic extreme cas ation av3SD, fu av.+3SD, load av.
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timistic ext adiation av. ion av3SD,	162 163 164 163 164 164 164 164 164 164 164 164	150 151 152 Case: b, fuel av3SD 188 189 190 191 192 193 194 195 196 197 198 199 200 201 201 201 201 201 201 201	6.3 6.3 5.5 5.5 5.5 5.5 5.5 5.5 5.1 5.1	23.24 23.24 19.24 19.24 19.24 19.24 19.24 19.24 17.24 1	20.24 20	4.62 4.62 4.62 4.62 4.62 4.62 4.62 4.62	3.5 3.5 5 5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6.5 6	3.82 3.22 4.42 4.42 5.02 3.82 3.438 4.792 4.12 0.26	22204.5 16150.9 32569.6 32569.6 32569.6 42212.5 49730.1 34017.3 25948.1 34017.3 25948.1 34556.7 35969.7 Pessim inflation a C.total(NPC/NPV)(6) 31191.9 C.total(NPC/NPV)(6) 31198.3 33766.416 33188.34 3355.4	nistic extreme cas ation av3SD, fu av.+3SD, load av.

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:



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.

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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:

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m			Wind I Fuel i	nfl • me	t, the	re 1s R %	std	Dev ·	1rbin 0 5	e										
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*																				
			RESULI	'S:																
-			Total	Cost (NP	C): me	an 31	260.9	€. S	td. D	ev.: 4	4337.1									
			CO2 En	issions:	mean	1131.	17kgC	02/yr	. Std	. Dev	.: 252	2.4								
			Ren. i	rac.: me	an 64 skwb/	%. St	d. De	v.: 6	.02											
			Unmet	load: me	an 0 %	. Std	l. Dev	.: 0												
			Batter	ies life	span:	mean	8.9 y	ears.	Std.	dev.	: 0.86	5								
- 00			AC ger	. fuel:	mean 2	83.9	litre	/yr.	Std.	Dev.:	71.22	-								
			Wind t	urbines	group	energ	v: me	an Ok	wh/yr	. Std	. Dev.	: 0								
			Charge	energy	in Bat	tery	bank:	mean	957k	Wh/yr	. Std.	Dev.	: 22.	8						
			Energy	of AC g	enerat	or: m	iean 5	46kWh	/yr.	Std. 1	Dev.:	129.8								
9																				

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:

2									_	~
M Ser	nsitivity Analysis	5			Σ.	1	-1	-		~
Wind	Solar	Load	Interest and Inflation (general	al or electricity cost)	AC gen. fuel inflation	Components cost				
<u>s</u>	ENSITIVITY	ANALYSI	S OF LOAD							
I	Load 1: Case ba	ase: Average	e Daily Total Load: 4.11 k₩h							
	Ad	d	Remove last one				🔄 🔁 Graph			
					01					
					UK					

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:

👔 Sen	sitivity Anal	/sis						- 0	×
Wind	Sola	Load	Interest and Inflation	AC gen. fuel inflation	Components cost				
<u>S</u>	ENSITIVI .oad1: Cas	TY ANALYSIS	<u>S OF LOAD</u> 9 Daily Total Load: 4.11 kW	/h					
L	.oad 2: 🔘) Base Case x Scal) From file (hourly v. (Fichero de texto	le Factor 1.5 alues: 8760 of AC in Wh + 8760 o .txt de 8760*4 = 35040 files)	f DC in Wh + 8760 of H2 in kg ·	+ 8760 of water flow in m3/s)	Av. daily total load = 6.16 kW/h		Import	
		Add	Remove last one				Graph		
					ОК				

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 in "Graph" button and we can see the both cases for load:



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

🕅 Se	nsitivity An	alysis													-		×
Wind	Solar	Load	Interest	and Inflation (g	eneral or ele	ctricity cost)	AC ge	n. fuel inflatior	n C	omponents	cost						
٧	/ind1: Case	e base: Ave	rage Wind	Speed: 4	.66 m/s												
~	'ind 2: O) Base Case >) From file (ho	x Scale Fac urly values i	tor [1.2] n m/s)] Height	(m) 10						- 1	Import	Av. V	Wind = 5.59 r	n/s	
		Add		Remove	last one								🖾 Graph				

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%:

🕅 Ser	sitivity Analysis	;					-	×
Wind	Solar	Load	Interest and Inflation	AC gen. fuel inflation	Components cost			
S	ENSITIVITY	ANALYSIS	OF THE ACQUISITIO	N COST OF SOME CO	MPONENTS:			
	Pr 1: Case ha	e fusiue in l	ables of components) (Sca	le Factor v1)				
C		se (taldes in t	ables of components) (sca					
	Pr.2: Acquisi	tion Cost of PV F	Panels: x 0.8 (Scale Fac	tor); Wind Turbines Acq. Co	st: x 0.9 Batteries cost: x 0.9	H2 components cost: x 1		
	A	dd	Remove last one					
			Ttelilove lust one					
					ОК			

We could also define sensitivity analysis of irradiation, interest (price of money) and inflation (general or inflation of electricity cost). Not in this case.

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):

Sensitivity Analysis # 1	~
Sensitivity Analysis # 1	
Sensitivity Analysis # 2	
Sensitivity Analysis # 3	
Sensitivity Analysis # 4	
Sensitivity Analysis # 5	
Sensitivity Analysis # 6	
Sensitivity Analysis # 7	
Sensitivity Analysis # 8	

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

												[Sho	v diagram	
						Sensitivity	Analysis 🕯	2	\sim						
Wind	i.1: 4.66m/s	\sim	Rad	1.1: 5.49kWh/m2	\sim	Load.1: 4.1	kWh/day	\sim	(l-g)1: 4%-2%	\sim	Inf.F.1:Base	\sim	Pr.2:	x0.8 x0.9 x0.9	x ×
#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unr	net(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simula	te	Report	۲ ۸
1		13	337.4	99.54		0.7	0.05	INF	6.6	99.85	0.4712	SIMUL	ATE	REPORT	C
2		13	337.4	99.54		0.7	0.05	INF	6.6	99.85	0.4712	SIMUL	ATE	REPORT	C
3		14	J72.5	99.15		0.4	0.03	INF	6.6	99.78	0.4791	SIMUL	ATE	REPORT	C
4		14	J72.5	99.15		0.4	l 0.03	INF	6.6	99.78	0.4791	SIMUL	ATE	REPORT	C
5		14!	597.4	93.04		0	0	INF	9.9	100	0.4969	SIMUL	ATE	REPORT	C
6		14	597.4	93.04		0	0	INF	9.9	100	0.4969	SIMUL	ATE	REPORT	C
7		14	362.7	140.94		2.6	0.17	INF	6.9	98.19	0.5068	SIMUL	ATE	REPORT	C
8		14	362.7	140.94		2.6	i 0.17	INF	6.9	98.19	0.5068	SIMUL	ATE	REPORT	C
9		15	227.9	93.04		0	0	INF	9.9	100	0.5184	SIMUL	ATE	REPORT	C
<															>
COMF Gen. ((NPC) STRA	'ONENTS: PV iasoline 0.5kV = 13837.4€ (0. TEGY: LOAD I	modu 'A 0.5 ' 47 €/k FOLL(iles a VA // I :Wh) DWIN	Si12-Schott: ASI100 (11 Bat. Inverter STECA: X G. P1gen: INF. Pmin_g)0 W PC 1 jen: "	'p_dc): 4s.x 4p 600-48 of 160 150 W. Pcritica). (100% PV# 0 VA // PV b al_gen: 0 W.	t1: slop att. cha SOC s	e 40°, azimuth 0°) // I arge controller. STE(etpoint_gen: 20 %. S	Batterie CA: TAF :OC min	s OPZS-Hawker:T ROM 440 of 40 A // .: 20 %.	LS-3 (18 Unmet I	0 Ah): 2 oad = 0	4s. x 1p. // 1 x A % // Total Cos	¥C ∧ st

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:

Wind.1: 4.66m/s	\sim
Wind.1: 4.66m/s	
Wind.2: 5.59m/s	

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):

					Consitiuitu	Analusia d						Sho	w diagram	
Wind	1.2: 5.59m/s	∼ Ra	d.1: 5.49kWh/m2	\sim	Load.1: 4.1	kWh/day	· 0 ~	(I-g)1: 4%-2%	~	Inf.F.1:Base	~	Pr.2:	x0.8 x0.9 x0.9	}x ∨
#	Total Cost (N	PC)(€)	Emission (kgCO2/yr)	Unn	net(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(/ Ren(%	LCOE(€/kWh)	Simula	ate	Report	С ^
1		13837.4	99.54		0.7	0.05	INF	6.8	99.85	0.4712	SIMU	ATE	REPORT	C
2		13837.4	99.54		0.7	0.05	INF	6.8	99.85	0.4712	SIMU	ATE	REPORT	C
3		14072.5	99.15		0.4	0.03	INF	6.8	99.78	0.4791	SIMU	ATE	REPORT	C
4		14072.5	99.15		0.4	0.03	INF	6.8	99.78	0.4791	SIMU	ATE	REPORT	C
5		14597.4	93.04		0	0	INF	9.9	100	0.4969	SIMU	ATE	REPORT	C
6		14597.4	93.04		0	0	INF	9.9	100	0.4969	SIMU	ATE	REPORT	C
7		14862.7	140.94		2.6	0.17	INF	6.9	98.19	0.5068	SIMU	ATE	REPORT	C
8		14862.7	140.94		2.6	0.17	INF	6.9	98.19	0.5068	SIMU	ATE	REPORT	C
9		15227.9	93.04		0	0	INF	9.9	100	0.5184	SIMU	ATE	REPORT	C
<														> [×]
COMF Gen. ((NPC) STRA	PONENTS: PV m Gasoline 0.5kVA I = 13837.4€ (0.47 .TEGY: LOAD FC	odules a).5 VA // €/kWh) ILLOWIN	Si12-Schott: ASI100 (10 Bat. Inverter STECA: XI G. P1gen: INF. Pmin_g)0 W PC 1 en: 1	'p_dc): 4s.x 4p 600-48 of 1600 150 W. Pcritica	. (100% PV# IVA // PV b I_gen: 0 W.	⊧1:slop att.cha SOCs	ve 40º, azimuth 0º) // arge controller. STE etpoint_gen: 20 %. S	Batterie CA: TA SOC mit	es OPZS-Hawker:7 ROM 440 of 40 A // n.: 20 %.	LS-3 (1) Unmet	30 Ah): 2 Ioad = 0	4s.x1p.//1x/ %//TotalCos	¥C ∧ st
														\sim

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:

4	A	В	C	D	E	F	G	н	1	J	K	L	M	N	0	P	Q	R	S	
1	Project: Pr1-	Sens.hoga. E	Best system found	for each ca	se of the sensitivi	ity analysis														1
2	Sens.#		Wind (m/s)		Rad(kWh/m2/	'd)	Load(kWh/d)		Interest(%)		Inflation(%)		Infla.Fuel(%)		Pr.PV(x)		Pr.W.T.(x)		Pr.Bat(x)	1
3	1	L	4.66		5.49		4.1		4		2		5		1		1		1	1
4	2	2	4.66		5.49		4.1		4		2		5		0.8		0.9		0.9	
5	3	5	4.66		5.49		6.16		4		2		5		1		1		1	
6	4	1	4.66		5.49		6.16		4		2		5		0.8		0.9		0.9	
7	5	i i	5.59		5.49		4.1		4		2		5		1		1		1	
8	6	5	5.59		5.49		4.1		4		2		5		0.8		0.9		0.9	
9	3	/	5.59		5.49		6.16		4		2		5		1		1		1	
10	8	8	5.59		5.49		6.16		4		2		5		0.8		0.9		0.9	
11																				
1.00																				

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.

. 2 - 1 - 1 - 1 - 1 - 2 - 1 - 1 - 1 - 2 - 1 - 3 - 1 - 4 - 1 - 5 - 1 - 6 - 1 - 7 - 1 - 8 - 1 - 9 - 1 - 10 - 1 - 11 - 1 - 12 - 1 - 13 - 1 - 14 - 1 - 15 - 1 - 16 - 1 - 17 - 1 - 18 - 1 Project: Pr1-Sens.hoga. Optimal solution found for each sensitivity analvsis: SENSIT. ANALYSIS # 1 (Wind.1: 4.66m/s; Rad.1: 5.49kWh/m2; Load.1: 4.1kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.1: x1 x1 x1 x1): NPC = 14778.5 \in . CO2 Emissions = 99.544 kg/yr. Unmet load = 0.7 kWh/yr (0.05%). Days auton. = INF. E. renewable = 99.9% of demand. Levelized cost of energy = 0.503 €/kWh Components: PV Generator 1600 Wp (100% PV#1: slope 40°, 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: 5.49kWh/m2; Load.1: 4.1kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.2: x0.8 x0.9 x0.9 x1): NPC = 13837.4 €. CO2 Emissions = 99.544 kg/yr. Unmet load = 0.7 kWh/yr (0.05%). Days auton. = INF. E. renewable = 99.9% of demand. Levelized cost of energy = 0.471 €/kWh Components: PV Generator 1600 Wp (100% PV#1: slope 40°, 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: 5.49kWh/m2; Load.2: 6.16kWh/day; (I-g)1: 4%-2%; Inf.F.1:Base; Pr.1: x1 x1 x1 x1): NPC = 22434.7 €. CO2 Emissions = 171.808 kg/yr. Unmet load = 3.5 kWh/yr (0.15%). Days auton. = INF. E. renewable = 99.7% of demand. Levelized cost of energy = 0.51 €/kWh 0)

0) 🔛

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.

DC Voltage	150	۷
AC Voltage	230	V

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.

CONSTRAINTS:	7				
Maximum Unmet Load allowed: 100 % annual					
(Unmet load can be covered by AC grid if it exists and it is allowed in "LOAD / AC GRID" window)					
More Constraints					

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.

AC LOAD (W)	DC LOAD (W)	H2 LOAD (kgH2/h)	WATER (m3/day) FROM WATER TANK	PURCHASE / SELL E
Purchase fr	rom AC grid Unmet I Stand-alone system	_oad (Non Served)	Sell Excess Energy to AC grid	Prio
Fixed Buy P	rice (€/kWh)	Hourly Price	Fixed Sell Price (€/kWh) 0.12	Hourly Price
Annual Inflation	n (%): Emission 0.4	(kgCO2/kWh):	Pr. sell = pr. buy x 1 Annual Inflation (%): 3	
Fixed Pmax	x (kW) Fixed Cost	P (€ kW/yr)	Max. Power(kW) 3.45 🔽 =Pmax buy	
3.45 (Options 43.5	Hourly Values	Energy Generation Charge (Transfer Charge	e <u>) Price (€/kWh)</u>
Access Charge	Price (€/kWh)		Fixed Transfer price (€/kWh) 0	Hourly Price
Fixed Acces	ss price (€/kWh)	Hourly Price	Self-consumption and Net Mettering:	Sell only
Back-up Charge	<u>e Price (€/kWh)</u>		Net Metering: Energy, Annual (1 year rolling	credit) ~
Fixed Back-	up price (€/kWh) 0	Hourly Price	Cost of net metering service (€/kWh) 0	only
(Will be added	to the E purchased)]Add negative gen. charge	Buy-back: Export E is paid at (€/kWh)) To
				08
Total tax for electr	ricity costs (buy + charg	es) (%): 0	Total tax for electricity sold (%):	Losses i

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:

й I	NVERTERS AND BI-DI C	ONVERTERS											-	-		×
	Add from Database	e Zf	RO		~		Without Rec Rectifier w/c	tifier (charge PV controlle	r) er	I	•	•	×	+	-	
	Include only VDC suitab	le from family:	STECA			·	O Rectifier + M	IPPT PV con	troller							
	GENERAL DATA									E	FFICIEN	CY (%) VS	. OUTP	UTPOW	ER (%)	->
\prod	Name	Power(VA)	Lifespan (yr)	Cost (€)	Batt. Charger	lmax_ch_DC(A)	Ef_charger(%)	Vdcmin(V)	Vdcmax(V)	P∨ batt.	controller	Pmax_rei	n(W)	0% 2	% 3%	\$
Ľ	Grid	1000	10	400	OK	0	98	150	450	NO			1E15	0 3	0 50	_
<	hi-di inverters include batt	terv charge rec	ulator all of th	em must h	e of the same fa	mily (same contro	l data)									>
	or an invertero include bea	City charge reg	junator, an oran	en nuor bi	e or the serie re	anny (source contre	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,									
	Control Data					Grid					Мах. от	utput powe	r in sum	ultaions c	f	
	Select the minimum in to supply the maximu Select inverter	nverter required im AC load	88 80 72 64 56 80 64 80 84 80								30 mi 15 mi 10 mi <=5 mi	nutes: 20 nutes: 30 nutes: 30 nutes: 30	% hi % hi % hi % hi	gher thar gher than gher than gher thar	nomina nomina nomina nomina	d d d
			0 40 40 24 16 8								If P. ma	ax. renewa t P. from re	ble DC >	P.max. CtoPma	ren. : < ren.	
	Proportional to 1st or Inverter rated power batt. duration (hours): OK	ne: for : 4	0 L 0 Maxin Avera	10 num power ige power i	20 demanded by s 17% of rated p	30 40 OUTPUT POWE load is 637.48 VA power of the selec	50 60 ER (% OF RATED . The inverter se ted inverter. Inve	70 { D)	30 90 one of 1000 V, efficiency cor	100 A nsidered	Ulso	card that c nly in bi-di 2 %	converte	ers		

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...**":

V MODULES					-		×
Add PV module Zero Add PV modules family SiM12-Aters	× 14	4 4 Þ Þ + =	▲ ✓ × (*				
PHOTOVOLTAIC MODULES DATA:							
Name aSi12-Schott: ASI100	Nom.Volt.(V) Isc(A) 12 6.79	Power(Wp) Cost(6) 100 110	C.O&M(6/yr) Life(years 1.1 25) NOCT(*C) Power - 49	F. coef.(%/ºC) BIFACIAL -0.2	ITY(0-1) CF 0 N(
< Efficiency due to degradation of the modules. Standard conditions PV inverter or battery charge regulator inc	, losses in wires, dirt in pane Iudes Maximum Power Poir	als, etc. 0.8 nt Tracking (MPPT))	F	> ixed Operation a laintenance Cos 40 €/y	and st /r
Calculate number of PV modules in	serieal as: Vbus_dc/Vma:	x_p_module (grid-connected	d systems). Data: Vmax_p_	module/Vnominal_modu	le = 1.475		
Consider effect of 1 emperature Data of ambient temperature (*C) Monthly average From file (8760 hourly values)	nodel J 17.6 F 17.	9 M 17.8 A 18.5 M 19.4 FROM PVGIS year 2007	J 20.9 J 21.7 A 22.4 S	22.4 0 22 N 20.5 D	19.2 Wind for CPV		
PV generator is connected to AC bus (it	has its own inverter) -> 🛛 🔊	Jumber of PV modules in seri	al: 4 PV inverte	r data			
Annual Inflation Rate for PV Generator Cost:	-2 %	Max. Vo reduction Limit is reached in 59.6 years	ariation of PV gen. Cost (e.g., fi on on current PV gen. cost, intr	or an expected 70% oduce "-70%"):	-70 %		
		ОК					

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 the nominal DC voltage divided by that value: 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_dc): 9s.x 1p. (100% PV#1: slope 40^e, azimuth 0^e) // Bat. Inverter Grid of 1000 VA // Unmet load = 49.3 % // Total Cost (NPC) = 7568.7 € (0.26 €/kWh)

We see that the load consumption is 1497.8 kWh/year, the energy generated by the PV modules 1381.9 kWh/year, the export energy (excess energy which cannot be used by the load) 545.9 kWh/year, of that excess 484 kWh/year are sold to the AC grid (the rest is lost in the inverter), and 745 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
1497.8	1381.9	1381.9	0	0	545.9	484	745	0

If we see the simulation:



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



If we also click the "Export Energy" checkbox, the graph shows that, in each hour, the energy sold is less than the export energy (grey), since the export energy is the excess energy (generated energy which is not used by the system, and can be exported to the grid) before passing through the inverter, that is, not counting the losses in the inverter. Energy sold to the grid is the export energy multiplied by the inverter efficiency (which depends on the output power).

37. Grid-connected systems with batteries.

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 grid, not to sell it. With the batteries (charge/discharge) we can manage the energy that is purchased from the grid.

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:

DC Voltage	350	۷
AC Voltage	230	۷

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	/) H	2 LOAD (kg/h)	WATER	(m3/day) FROM V	VATER T	ank (Pr	EVIOUSL	Y PUMPI	ED) P	URCHAS	E / SELI	- 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	15-16
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
<																>
		ſ	Scale fact	or for Mond	lay to Frida	y: 2		Scale fac	tor for the v	weekend:	2.4]				

We click on "Generate" and we obtain an average daily consumption of 8.18 kWh / day, more suitable to use the Tesla batteries.

Generate	AC load power factor (cos fi):
Add load of [WAC v during 5 min day 1 month 1 Repeat every 1 days
OK Average daily	Graph in steps of 60 ~ min.

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:

▼ Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system)	Sell Excess Energy to AC grid
Fixed Buy Price (€/kWh) 0.15 Hourly Price	Fixed Sell Price (€/kWh) 0.12 Hourly Price ✓ Pr. sell = pr. buy x 1
3 0.4	Annual Inflation (%): 3
Fixed Pmax (kW) Fixed Cost P (€/kW/yr)	Max. Power(kW) 3.45 🔽 =Pmax buy
3.45 Options 43.5 Hourly Values	Energy Generation Charge (Transfer Charge) Price (€/kWh)
Access Charge Price (€/kWh)	
Fixed Access price (€/kWh) U Hourly Price	Self-consumption and Net Mettering:
Back-up Charge Price (€/kWh)	No net mettering
Fixed Back-up price (€/kWh) 0 Hourly Price	Cost of net metering service (€/kWh) 0
(The cost of the back-up toll will be added to the E purchased)	Buy-back: Excess E is paid at (€/kW/h) 0
Total tax for electricity costs (buy + charges) (%): 0	Total tax for electricity sold (%): 0

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" button:

Purchase from AC grid L Energy by Stand-alone	Jnmet Load system)	(Non Served
☐ Fixed Buy Price (€/kWh)	0.15	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:

HOURLY PRICE OF THE ELECTRICITY PURCHASED FROM THE AC GRID
Hourly Price Data (€/kWh)
O Hourly, all days the same
O From file (8760 hourly values) Import hourly Price
Hourly Periods
Hourly Periods: Number of Hourly Periods: SumperAvinter Mon-Fri/Weekend O Hourly (from file)
Summer calendar:
From day (30) month 3
To day 26 month 10
Period P3 Price: 0.0657
SUMMER periods distribution:
U-1h 1-2h 2-3h 3-4h 4-5h 5-6h 6-7h 7-8h 8-9h 9-1Uh 1U-11h 11-18h
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$
12-13h 13-14h 14-15h 15-16h 16-17h 17-18h 18-19h 19-20h 20-21h 21-22h 22-23h 23-24h
P1 v P1 v P1 v P2 v P2 v P2 v P2 v P2 v
WINTER periods distribution:
0-1h 1-2h 2-3h 3-4h 4-5h 5-6h 6-7h 7-8h 8-9h 9-10h 10-11h 11-12h
P3 v
12-13h 13-14h 14-15h 15-16h 16-17h 17-18h 18-19h 19-20h 20-21h 21-22h 22-23h 23-24h
ОК

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







We return to the main screen with "Back" button and then "OK" button.

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.

Add PV modules family	SiM12-Ater	sa	~		• • •	• × × ¢					
PHOTOVOLTAIC MODI	ILES DATA:										
Jame		Nom.Volt.(V)	lsc(A)	Power(Wp)	Cost(€)	C.O&M(€/yr)	Life(years)	NOCT(*C)	Power T. coef.(%/ºC)	BIFACIALIT	TY(0-1) CF
1Si12-Schott: ASI100		12	6.79	100	110	1.1	25	49	-0.2		0 N(
											>
Efficiency due to degradation	of the modules	s, losses in wires,	, dirt in pane	els, etc. 0.8						Fixe	> ed Operation
Efficiency due to degradation Standard conditions	of the modules	s, losses in wires,	, dirt in pane	els, etc. 0.8						Fixe Ma 4	> ed Operatior intenance Co 0 €
Efficiency due to degradation Standard conditions	of the modules	s, losses in wires. cludes Maximum	; dirt in pane	els, etc. 0.8 nt Tracking (MP	PT)					Fix Ma 4	> ed Operatior intenance Ct 0 €
Efficiency due to degradation Standard conditions V EV invader or battery charge Calculate number of	of the modules re regulator inc	s, losses in wires cludes Maximum 1 serieal as: Vbu:	; dirt in pane I Power Poi s_dc/Vma	els, etc. 0.8 nt Tracking (MP x_p_module (c	PT)	systems). Det	a: Vmax_p_m	odule / Vnomi	nal_module = 1.475	Fix Ma 41	> ed Operation intenance Co 0 €
Efficiency due to degradation Standard conditions	of the modules ie regulator inc PV modules in <u>mperature</u> (C)	s, losses in wires, cludes Maximum n serieal as: Vbu	, dirt in pane 1 Power Poi s_dc / Vma	els, etc. 0.8 nt Tracking (MP x_p_module (c	PT) rid-connected	systems). Dat	a: Vmax_p_m	odule / Vnomi	nal_module = 1.475	Fix Ma 4	ed Operation intenance Cr 0 €
Efficiency due to degradation Standard conditions Vinventer or battery charge Calculate number of T U Consider effect of Te Data of ambient tempe (Monthly average	of the modules regulator inc PV modules in mperature erature (*C) Erbs r	s, losses in wires cludes Maximum 1 serieal as: Vbu model J [, dirt in pane 1 Power Poi s_dc / Vma 17.6] F 17.	els, etc. 0.8 nt Tracking (MP x_p_module (c 9 M(17.8 A(1	PT) rid-connected 8.5 M 19.4	systems). Dat	a: Vmax_p_m A[22.4] S[22	adule / Vnomi 4_0[22N	nal_module = 1.475 20.5 D[19.2 Win	Fixe Ma 41	> ed Operation iintenance Co 0 €
Efficiency due to degradation Standard conditions	of the modules re regulator inc PV modules in <u>mperature</u> arature ([±] C) [√] Erbs r rdy values)	s, losses in wires cludes Maximum n serieal as: Vbu model J	, dirt in pane Power Poi s_dc/Vma 17.6 F 17. Import	els, etc. 0.8 nt Tracking (MP x_p_module (g 3 M(17.8 A(1 FROM PA	PT) rid-connected 8.5 M [19.4] GGI year 2007	systems). Det	a: Vmax_p_m A[22.4] S[22	odule / Vnomi 4 0 22 N	nal_module = 1.475 20.5 D[19.2 Win Graph	Fixe Ma 4	> ed Operation intenance Cr 0 €
Efficiency due to degradation Standard conditions Visuater or battery charg Calculate number of Data of ambient tempo Monthly average From file (8760 hou PV generator is connected	of the modules re regulator inc PV modules in mparature reture (°C) ✓ Erbs r rty values)	s, losses in wires cludes Maximum n serieal as: Vbu model J has its own inve	, dirt in pane I Power Poi s_dc / Vma 17.6 F 17. Import rter) → ►	els, etc. 0.8 nt Tracking (MP x_p_module (g 9 M 17.8 A 1 FROM P Vumber of PV m	PT) rid-connected 8.5 M [19.4 /GIS year 2007 odules in seria	systems). Detr J [20.9] J [21.7] u: [10]	a: Vmax_p_m A 22.4 S 22	odule / Vnomi 4 0 22 N tata	nal_module = 1.475 20.5 D 19.2 Win Graph	Fixa Ma 4	> ed Operation iintenance Co 0 €
Efficiency due to degradation Standard conditions Standard conditions Calgulate number of Ta Cangulate number of Ta Data of ambient temp Monthly average From file (8760 hou PV generator is connected Annual Inflation Generator Cost	of the modules re regulator inc PV modules in mperature (*C) (* Erbs r rty values) d to AC bus (tt Rate for PV :	s, losses in wires cludes Maximum n serieal as: Vbu model J :has its own inve	, dirt in pane I Power Poi s_dc/Vma 17.6]= 17. Import rter) → N	els, etc. 0.8 nt Tracking (MP x_p_module (g 9 м 17.8 А [1 FROM P Number of PV m	PT) rid-connected 8.5 M [19.4 /GIS year 2007 odules in seried Max. Va reduction	systems). Detr J 20.9 J 21.7 at: 10	a: Vmax_p_m A 22.4 S 22 PV inverter of Cost (e.g., for en. cost intro.	odule / Vnomi 4 0 22 N iata an expected 1 uce "-70%"):	nal_module = 1.475 20.5 D 19.2 Win Graph	Fixe Ma 4	ed Operation intenance Co 0 c

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

PV inverter cost included in the PV cost; PV inv. replacement included in O&M PV cost
Rated power of the inverter = 1 x Peak power of the PV generator Limit the output power of the PV to the rated P. of the inverter
Inverter efficiency (%) output power (% of rated):
0% 2% 3% 4% 5% 10% 20% 30% 0 30 50 70 85 93 92 90
40% 50% 60% 70% 80% 90% 100% 89 88 87 86 85 84 83
96 64 32 0 0 20 40 60 80 100 Output power (%)
ОК

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 $150 \in$.

Ρ	PHOTOVOLTAIC MODULES DATA:								
	Name	Nom.Volt.(V)	Isc(A)	Power(Wp)	Cost(€)				
I	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.

M BATTERIES		- 0	×
Add Battery Zero Add Batteries family OPZS-Hawker			
BATTERIES DATA:	Float life at 20 °C Cycles to Failure vs. Depth of Discharge (%)		
Name Cnom.(Ah) Volt.(V) Cost(€) C.01M(€	がI SOCmin(%) Self_d(%/mon.) Imax(A) Eff(%) Float(yr) 10% 20% 30% 40% 50% 60% 70% 80%	90% 100%	TYPE \
Tesla: Powerwall 2 DC 38.57 350 6100 30	10 2 14.3 91.8 15 28800 14400 9600 7200 5760 4800 4114 3600	3200 2500	Li
✓ Betteries Model Fixed ● Ah ✓ Lion model Ah Fixed Auxilie Auxilie Auxilie Copeti 1934 Schiffer 2007 Auxilie Temp. J 18 F 18 M/20 A 22 J 22 VECept Schiffer 2007 20 N 18 D 18 Mon. Except Schiffer model.consider Import hourly file Mon. Hour Float life reduces 50% for every10 *C increase E T Greph V Oycle life depends on T Data Hour Capacity depends on T Data Ead-acid Aging battery model Urion Aging battery model Orange tal. 2011 (LIFEPO4) Savena et al. 2011 (LIFEPO4) Savena et al. 2015 (LIFEPO4) Savena et al. 2016 (LIFEPO4) Starena et al. 2010 (LIFEPO4) Perameters Parameters Naumann 2020 (LIFEPO4 cyc+coi) Perameters Remaining capacity at battery end of life (%): 80 If there is an An AC Gen. every 14 days or 8 equivalent full	peration and Maintenance Cost: 50	iv / KWh capacit	y
ОК			

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".

Include only VDC suitable from fam	SMA: Sunny Boy ly: STECA	/ Stora		~ +	Without Rectifier (charge Rectifier w/o PV controll Rectifier + MPPT PV co	er M	 ★ ▶ ▶ ▶ + -
GENERAL DATA					0	E	FFICIENCY (%) vs. OUTPUT POWER (%) -
Name Power(V/	 Lifespan (yr) 	Cost (€)	Batt. Charger	lmax_ch_DC(A)	Ef_charger(%) Vdcmin(V)	Vdcmax(V) PV batt.	controller Pmax_ren(W) 0% 2% 3%
Control Data	egulator, all of th PT	iem must bi	e of the same fa	unily (same contro SMA: Sunny E	oldata) Bov Stora		Max. output power in sumultaions of
Select the minimum inverter requi to supply the maximum AC load	red 88 80 72	\int					30 minutes: 20 % higher than nominal 15 minutes: 30 % higher than nominal
Select inverter	(%) 64 56 48 48						<=5 minutes: 30 % higher than nominal
Select inverter	64 56 48 40 32 24 24						Formulaes: 30 % higher than nominal <=5 minutes; 30 % higher than nominal If P. max. renewable DC > P. max. ren.; O Limit P. from renew DC to P. may. ren.

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):

MIN. AND MAX. No COMPONEN	NTS IN PARALLEL:
Bateries in parallel: Min. 1	Max. 1
PV mod. in parallel: Min. 🛛	Max. 3
Wind T. in parallel: Min. 1	Max. 2
AC Gen. in parallel: Min. 1	Max. 1

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 could be discarded). We define unmet load as energy not supplied neither by the autonomous system nor by the AC grid.

CONSTRAINTS: <u>Maximum Unmet Load allowed:</u> 0.1 % ann <mark>u</mark> al
Unmet load refers to:
More Constraints

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

🕅 CONSTRAINTS	_		\times
If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (assigned infinite cost):	for that cor	nbination i	t is
Maximum Unmet Load allowed: 0.1 % of annual load (Max. energy not supplied by the stand-alone system nor by the AC grid)			
Minimum number of days of autonomy (batteries+hidrogenl): 4.5 days (if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, number of o	days of auto	onomy = i	nfinitum)
Nominal capacity of batteries bank (Ah) < 20 x (shortcut current of PV generator + current from Wind Turbines gru () if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, do not take	op at 14m/ into accou	's <mark>) (A)</mark> int this coi	nstraint))
Minimum renewable fraction: 0 %			
Maximum Levelized Cost of Energy: 1000 €/kWh			
ΟΚ			

In the main screen, "CONTROL STRATEGIES" tab, check "Batt. 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.

Global strategy	<i>r</i> .		ENERGY ARBITRAGE: System with batteries and grid connected			
Load Follow	ring		Batt. charged by the AC grid // discharged if: 🛛 (also for Elyzer> H2) 🗌 Elyzer. full load			
Cycle Charging Continue up to SOC stp			Price E<= 0.07 €/kWh // Price E>= 0.19 €/kWh D-% (Compare with Sel price			
🔿 Try Both			Optimize strategy of grid-conneted batteries:			
Variables to on	timize relative to the	global strategy:				
Pmin_gen	Pmin_FC	H2TANKstp				

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	(۸
1	23419.3	1292.25	0	0	INF	0	0	0.4012	SIMULATE	REPORT	C
2	23846.3	807.17	0	0	INF	5.7	42.11	0.4085	SIMULATE	REPORT	C
3	25153.8	703.5	0	0	INF	2.8	53.59	0.4309	SIMULATE	REPORT	C
4	26947.2	705.44	0	0	INF	1.9	56.52	0.4616	SIMULATE	REPORT	C
	MNENTS: Batteries Teels	a: Powerwall 2 DC (38	6 Ab):1e y1n // Br	at Invertor S	MA-S	unny Boy Store of 25	10 \/& /	/ Bectif included i	in hi-di inverter /	/ P\/ hatt	>
CUMPONENTS: Batternes 1 esta: Powerwall 2 UC (36.6 Ah): 1s. x 1p. // Bat. Inverter SMA: Sunny Boy Stora of 2500 VA // Rectit. included in bi-di inverter // PV batt. charge controller included in bi-di inverter // Unmet load = 0% // Total Cost (NPC) = 23419.3 € (0.4 €/kWh) STRATEGY: LOAD FOLLOWING. SOC min: 10 %, Arb.: Control variables for grid-connected batteries: charge (buying E. to the AC grid) if price of E. is lower than 0.07											
UNAN	, aison, (norm)ecting P to t	ne gnaj ir price E. nigr	er trair 0.13 G/KWII								~

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).





We can see in the results table or in the report that battery lifetime is 15 years.

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. On the main screen, CONTROL STRATEGIES tab, check "Batteries can inject electricity to the AC grid".

Global strategy: © Load Following			Batt. charged by the AC grid // discharged if. 🔽 (also for Elyzer> H2) 🗌 Elyzer. full load			
Cycle Charging Continue up to SOC stp			Price E<= 0.07 €/kWh // Price E>= 0.19 €/kWh □D-% □ (Compare with Sell price			
○ Try Both			Optimize strategy of grid-conneted batteries:			
Variables to opt	mize relative to the	global strategy:				
gon						

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:

AC LOAD (W)	DC LOAD (W)	H2 LOAD (kg	H2/h)	WATER (m3/day) FROM WATER TANK	PURCHASE / SE			
Purchase fr	rom AC grid Unmet L Stand along gustam	.oad (Non Serv	ed	Sell Excess Energy to AC grid				
Fixed Buy P Annual Inflatio Fixed Pma Fixed Pma 3.45 Fixed Pma Access Charge Fixed Access Back-up Charge Fixed Back- (Will be added	Stand-alone system, rice (¢/kWh) 0.15 n (%): Emission (0.4 0.4 x (kW) Fixed Cost Options 43.5 Price (¢/kWh) 0 a Price (¢/kWh) 0 a Price (¢/kWh) 0 up price (¢/kWh) 0 to the E purchased) 0	Hourly kgCO2/kWh): Emissions da P(6/kW/yr) Hourly Hourly Hourly Hourly Hourly Hourly	y Price tta / Values ly Price n. charge	Fixed Sell Price (€/kWh) 0.12 Pr. sell = pr. buyx 0.7 Annual Inflation (%): 3 Max Power(kW) 3.45 9 Pmax buy Energy Generation Charge (Transfer Charge Fixed Transfer price (€/kWh) 0 Self-consumption and Net Mettering: No Net Metering 0 Cost of net metering service (€/kWh) 0 0 Buy-back: Export E is paid at (€/kWh) 0	Hourly Price			
Total tax for elect	ricity costs (buy + charge	es) (%): 0]	Total tax for electricity sold (%): 0	Lo			

We accept, save the project and calculate.

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	۲ م
1	25242.9	2066.54	0	0	INF	2.8	0	0.4324	SIMULATE	REPORT	C
2	25421	2088.45	0	0	INF	1.9	0	0.4355	SIMULATE	REPORT	C
3	25498.5	2119.38	0	0	INF	5.7	0	0.4368	SIMULATE	REPORT	C
4	25627.9	2448.16	0	0	INF	0	0	0.439	SIMULATE	REPORT	C
<			100 \\\\	2- /100%	D) (#1	1	//D-#-			Ab). 1 1	>
COMH Bat. In (NPC)	ONENTS: PV modules at verter SMA: Sunny Boy Str = 25242.9 € (0.43 €/KWh)	Si12-Schott: ASI100-2 (pra of 2500 VA // Rect	100 Wp_dc): 10s.x if. included in bi-di	2p. (100% inverter // F	PV#1:s PV batt.	lope 40°, azımuth 0°) charge controller inc	// Batter duded in	ries Testa: Power i bi-di inverter // U	nwall 2 DC (38.67 Jnmet load = 0 %	Ah): 1s. x 1p. // 6 // Total Cost	^
€/kWh	; disch. (load + injecting to	3. SUC min.: 10 %. Arb the grid) if price E. hig	.: Control variable: her than 0.19€/kW	s tor gria-cc h	innecte	d batteries: charge (t	ouying E	to the AC grid) if	price of E. is lov	ver than U.U7	~

The optimum obtained is different, in this case it includes PV.

COMPONENTS: PV modules aSi12-Schott: ASI100-2 (100 Wp_dc): 10s.x 2p. (100% PV#1: slope 40^o, azimuth 0^o) // Batteries Tesla: Powerwall 2 DC (38.6 Ah): 1s. x 1p. // Bat. 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) = 25242.9 \in (0.43 \in /kWh).

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

The price of kWh consumed (LCOE) is $0.43 \in /$ kWh, higher than the LCOE of the optimal combination of the previous project. We force to inject to the grid at peak times, increasing the degradation of the battery, which must be replaced in few years, therefore increasing the NPC (comparing with the case where we don't force to inject electricity from the battery to the grid). If the electricity price at peak period was higher, NPC could be lower than in the previous project.

In the table or in the report we can see that the battery lifetime is 7.45 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 (2 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.

Wind Turbines

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

Scale factor for Monday to Friday: 10 Scale factor for the weekend: 12	Scale factor for Monday to Friday:	10	Scale factor for the weekend:	12	

And "Generate" hourly load, obtaining 40.69 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 load 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:

I aSi12-Schott: ASI100x10 12 67.9 1000 1100 111 25 49 -0.2	0 N(

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:							Fle	oat life a	at 20 °	c	Cj	cles to	Failure	vs. Dej	oth of Di	ischarg	e (%)			
	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
Þ	OPZS-Hawker:TZS-24	3360	2	1010	10.1	20	3	672	85	18	12000	6500	4250	3100	2500	2050	1800	1600	1500	LA	
Г																					

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

	GENERAL	DATA							EFFICIEN	CY (%) vs. OUT	PUT 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%
D	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:										FUEL				
10	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)	Ē
	Diesel 1.9kVA	1.9	800	0.14	10000	30	Diesel	litre	1.3	5	3.5	0.246	0.08145	110	
I															

And allow availability throughout the whole day:

AC GENERATOR H	OURLY AVAILABILITY:
Monday-Friday:	Weekend:
 ○ 0-1 h ○ 1-2 h ○ 2-3 h ○ 3-4 h ○ 4-5 h ○ 5-6 h ○ 5-6 h ○ 7-8 h ○ 8-9 h ○ 9-10 h ○ 10-11 h ○ 10-11 h ○ 10-11 h ○ 11-12 h ○ 12-13 h ○ 12-13 h ○ 13-14 h ○ 14-15 h ○ 15-16 h ○ 1	 y 0 - 1 h y 1 - 2 h y 2 - 3 h y 3 - 4 h y 5 - 6 h y 5 - 6 h y 5 - 6 h y 7 - 8 h y 9 - 10 h y 10 - 11 h y 10 - 11 h y 11 - 12 h y 12 - 13 h y 13 - 14 h y 13 - 14 h y 14 - 15 h y 16 - 17 h y 17 - 18 h y 18 - 19 h y 18 - 19 h y 18 - 20 h y 21 - 22 h y 22 - 24 h
0	<

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:

-MIN. AND MAX. No COMI	PONENT	TS IN PA	ARALLEL:
Bateries in parallel: Min.	1	Max.	2
PV mod. in parallel: Min.	0	Max.	5
Wind T. in parallel: Min.	1	Max.	2
AC Gen. in parallel: Min.	1	Max.	4

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

	,		
F	™ mod. in parallel: Min. 0	Max. 🙎	

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 have a lower NPC and emissions).

Save and click on the **CALCULATE** button. We get:



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 batteries try to supply the net load, but when they are at minimum SOC, 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. Diesel generators have a minimum output power, so if the load is lower than its power, the surplus is used to charge the battery. 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 (using Schieffer et al. model we would see this, as in next section).

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).

S	R	Q	Р	0	N	M	L	K	J	1	Н	G	F	E	D	C	В	A
													n#1	r.hoga. Solutio	2022\DieselPa	GA 3.4-10-12-	OVECTOS IHOC	Project: D:\P
							000 VA.	it. Inverter of 8	61280 Wh. B	ery bank of 1	of 1900 W. Batt-	Generator o	imuth 0º). 3 x AC	1: slope 40º, az	dc (100% PV#:	of 8000 Wp_	S: PV generator	COMPONEN
										o %.	%. SOC min.: 2	stp_gen: 20	al_gen: 0 W. SOC	570 W. Peritic	W. Pmin_gen:	G. P1gen: INF	AD FOLLOWIN	STRATEGY: L
								ı).	in energy (W	the batteries	he SOC data of	HV of H2). Th	eferring to the H	12. load is in W	oressed in W (H	alues are exp	JES. All power v	HOURLY VAL
										l (m3).	e volume storer	olume) is the	le (Water_tank_)	water (Wh) whi	to pump the v	nergy needed	Vater_tank) is e	Nater tank (
pressed in lit	el Gen) is exp	Gon. AC (Fu	umption of the	rs. The fuel cor	f AC generate	t-up penalty)	nalty and star	ut-of-range pe	urs (including	uivalent hou	ne number of er	eq Gen is th	time step. Hours	ing during this	s that are runn	AC generator	the number of	No.Gen_on i
ash flow val	€. They are c	xpressed in ·	Cost.Buy) are es	rid (Inc.Sell an	g E to the AC	d costs of buyin	f selling E and	and incomes of	C.fuel.ext FC	he fuel cell (al fuel used by	of the extern	I.Cost), the cost of	e AC Gen. (Fue	fuel cost of th	the grid, the	asing energy to	Costs of pure
	kg of H2.	xpressed in k	Prod_H2) are ex	he electrolyzer	generated by t	and hydrogen	(Fuel.ext_FC)	ally purchased	I.FC) or exter	H2 tank (Fue	fuel cell, from), H2 used by	(H2_Tank_mass	f H2. H2 in tank	essed in kg/h o	mass) is expre	gen (H2_load_	Load of Hydr
	· \					/							H2	in Wh HHV of	V) is expressed	H2_Tank_HH	red in H2 Tank (Hydrogen sto
Fuel.FC(kg	F.C.(W)	el.Cost(€)	ons.Fuel(litreFue	Hours_eq_Ge	No.Gen_on	AC.Gen.(W)	Ef_turb(perc	Hydro(W)	Wind(W)	/(W)	Water_load(V P	Load_mas V	H2_load(HHV H2	DC_load(W)	AC_load(W)	Load(W)	Hour	Date
4		0	0	0	0	0		0	(2936.78	0	0	0	0	1848	1848	15:00	08-January
4		0	0	0	0	0		0	(2042.84	0	0	0	0	1599.84	1599.84	16:00	08-January
0		0	0	0	0	0		0		1286.91	0	0	0	0	2175.36	2175.36	17:00	08-January
0		0.5729	0.4407	1.08	1	1162.42		0	(47.8	0	0	0	0	3020.16	3020.16	18:00	08-January
0		1.4763	1.1356	2.52	2	3358.08		0		0	0	0	0	0	3358.08	3358.08	19:00	08-January
0		2.0377	1.5674	3.08	3	4484.4		0		0	0	0	0	0	4484.4	4484.4	20:00	08-January
0		1.4155	1.0888	2.17	2	3168		0	(0	0	0	0	0	3168	3168	21:00	08-January
0		1.3589	1.0453	2	2	2991.12		0		0	0	0	0	0	2991.12	2991.12	22:00	08-January
0	(0.5423	0.4171	1	1	1066.56		0	(0	0	0	0	0	1066.56	1066.56	23:00	08-January
0		0.3835	0.295	1.25	1	570		0	(0	0	0	0	0	271.92	271.92	0:00	09-January
0		0.3835	0.295	1.25	1	570		0		0	0	0	0	0	258.72	258.72	1:00	09-January
0	(0	0	0	0	0		0	(0	0	0	0	0	264	264	2:00	09-January
0		0.3835	0.295	1.35	1	570		0	(0	0	0	0	0	258.72	258.72	3:00	09-January
4		0.3835	0.295	1.25	1	570		0	(0	0	0	0	0	264	264	4:00	09-January
0	(0	0	0	0	0		0	(0	0	0	0	0	261.36	261.36	5:00	09-January
0		0.6046	0.4651	1.08	1	1261.36		0	(0	0	0	0	0	1333.2	1333.2	6:00	09-January
4		1.045	0.8038	2.08	2	2009.39		0	(43.29	0	0	0	0	2048.64	2048.64	7:00	09-January
0	(0.4239	0.3261	1.17	1	696.46		0	(916.86	0	0	0	0	1536.48	1536.48	8:00	09-January
0		0	0	0	0	0		0	(2049.24	0	0	0	0	1333.2	1333.2	9:00	09-January
		0	0	0	0	0		0	(2666.95	0	0	0	0	1359.6	1359.6	10:00	19- January

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 et al. model for the batteries, much more precise model, which takes into account the real operating conditions of the batteries. We select the "**Schiffer 2007**" model on the batteries screen, leaving everything else unchanged:

Batteries Model		Fixed Operation and Mai
OAh 🔽 L	i model Ah	
C KiBaM (Manwell-	McGowan 1993)	
C Copetti 1994	Control Data	
Schiffer 2007	Schiffer bat, data	
Temp. J 18 F 18	M 20 A 20 M	20 J 22 Mean (®C)
([®] C) J 22 A 22	S 22 0 20 N	18 D18
Except Schiffer m Tmean>=Tfloat li	iodel, consider Imp	oort hourly file
Float life reduces 50	% for every 10 °C	increase 🛛 📐 T Graph
Cycle life depend	Is on T Data	
Capacity depend	s on T Data	
Lead-acid battery mo	del Li-ion battery	model
C Rainflow (cycle	: counting)	
C Equivalent full	cvoles	
G. Cohiffer agains	madal	
• Schiffer ageing	moder	

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	(۸
	1	537313.6	18889.55	0	0	INF	24.7	63.12	1.8442	SIMULATE	REPORT	C
	- 0	101400.0	0004.05	0		16.077	047	0.01	0.0000	OBJULATE.	DEDODT	(

This large difference in costs compared to the classical model of batteries is due to the estimated life of the Schiffer model is 0.84 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

 3459
 3550
 0
 5478.6
 0
 5941.09
 0.84
 3988
 23

Therefore, maybe another control strategy could improve the results.

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).

Global strategy:	
O Load Following	
○ Cycle Charging	Continue up to SOC stp
Try Both	

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%).

👔 Non-optimizable control variables (fi	ixed value)	- 🗆 X					
	Values of Power in W, H2 in kg						
Pmin_gen	Pmin_FC	H2TANKstp_gen					
Pmin recommended by manufact.	Pmin recommended by manufact.	Fix value to 0					
O Set value to (% of Pnom.): 30	O Set value to (% of Pnom.): 10	O Set value to: 0					
P1_gen	P1_FC	P2					
Calculated value	Calculated value	Calculated value					
O Set value to: 1000	O Set value to: 1000	O Set value to: 1000					
SOCstp_gen	SOCstp_FC	SOCmin					
O SOCmin recommended by manuf.	SOCmin recommended by manuf.	SOCmin recommended by manufactorial commended					
Set value to (% SOCmax):	O Set value to (% SOCmax): 100	O Set value to (% SOCmax): 50					
Pcritical_gen	Pcritical_FC	Plimit_charge					
Calculated value	Calculated value	Calculated value					
O Set value to: 1000	O Set value to: 1000	O Set value to: 1000					
ОК							

Save the project and CALCULATE.

Now the optimal combination uses the control strategy *Cycle charging, continue to SOCstp.* The battery life is estimated to be 10.65 years.

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
1	181437.4	9221.45	2.3	0.02	INF	24.7	54.95	0.6229	SIMULATE	REPORT	(
2	185216.5	9509.35	0	0	INF	24.7	54.37	0.6357	SIMULATE	REPORT	(
3	186046.8	9581.15	0	0	INF	24.7	54.28	0.6386	SIMULATE	REPORT	(
4	230098.5	9921.53	4.6	0.03	INF	49.5	56.25	0.79	SIMULATE	REPORT	(
5	232769.6	10204.36	0	0	INF	49.5	55.65	0.799	SIMULATE	REPORT	(
6	233344.3	10235.14	0	0	INF	49.5	55.61	0.8009	SIMULATE	REPORT	(
7	INF	8615.27	140.4	0.94	INF	24.7	56.64	INF	SIMULATE	REPORT	(
8	INF	9282.06	163.9	1.1	INF	49.5	57.76	INF	SIMULATE	REPORT	(
9	INF	13941.03	307.3	2.07	INF	49.5	25.75	INF	SIMULATE	REPORT	٢.,
1											> ×
											·
COMP // 2 x A load = STRA	20MPONENTS: PV modules a5112-Schott. AS110X10 (1000 Wp_dc): 4s x 2p. (100% PV#1: slope 40% azimuth 0% // Batteries OP2S-Hawker:TZS-24 (3360 Ah): 24s. x 1p. ~ / 2 x AC Gen. Dissel 1 9 XVA 1.9 VA // Batt Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // PV batt. charge controller Generic of 177 A // Unmet add = 0 % // Total Cost (NPC) = 181437.4 € (0.62 €/kWh) STRATEGY: CYCLE CHARGING, continue up to SOCstp. P1aen: 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 (2x1900 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 $60A \cdot (approx. 48V) = approx. 2880$ W the battery charging power, note that battery voltage changes during each time step and it is not exactly 48 V). 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). We mark these variables to optimize:

ariables to optin	nize relative to the	e global strategy:
🗹 Pmin_gen	Pmin_FC	H2TANKstp
P1_gen	P1_FC	P2
SOCstp_gen	SOCstp_FC	🗹 SOCmin
Pcritical_gen	Poritical_FC	Plim_charge

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 570 W and *SOC_min* 36%) and whose cost is slightly lower.

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	٢.
1	177099.1	8835.83	13.3	0.09	INF	24.7	56.23	0.6084	SIMULATE	REPORT	(
2	181437.4	9221.45	2.3	0.02	INF	24.7	54.95	0.6229	SIMULATE	REPORT	(
3	185216.5	9509.35	0	0	INF	24.7	54.37	0.6357	SIMULATE	REPORT	(
4	186046.8	9581.15	0	0	INF	24.7	54.28	0.6386	SIMULATE	REPORT	(
5	224211	9508.67	6.6	0.04	INF	49.5	57.38	0.7699	SIMULATE	REPORT	(
6	230098.5	9921.53	4.6	0.03	INF	49.5	56.25	0.79	SIMULATE	REPORT	(
7	232769.6	10204.36	0	0	INF	49.5	55.65	0.799	SIMULATE	REPORT	(
8	233344.3	10235.14	0	0	INF	49.5	55.61	0.8009	SIMULATE	REPORT	(
9	INF	14167.77	55.6	0.37	INF	49.5	24.53	INF	SIMULATE	REPORT	٢.,
<	<										
COMP //1×A load = STRA	COMPONENTS: PV modules aSi12-Schott: ASi100x10 (1000 Wp_dc): 4s.x 2p. (100% PV#1: slope 40%, azimuth 0%) // Batteries OPZS-Hawker:TZS-24 (3360 Ah): 24s.x 1p. // 1 x AC Gen. Diesel 1.9kVA 1.9 VA // Bat. Inverter Generic: 8000 CH of 8000 VA // Rectif. included in bi-di inverter // PV batt. charge controller Generic of 177 A // Unmet load = 0.1 % // Total Cost (NPC) = 177099.1 € (0.61 €/kWh) STRATEGY: CYCLE CHARGING, continue up to SOCstp. P1gen: INF. Pmin_gen: 570 W. Pcritical_gen: INF. SOC setpoint_gen: 100 %, SOC min.: 36 %.										
											\sim

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 to 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 1minute 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 $5 \notin$ / kg.

Sell surplus H2 in tank (difference between the H2 in the tank at the end of the year and at the beginning)				
Price (€/kg)	Annual Inflation (%):			
5	3			

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.

COMPONENTS	
✓ PV panels	T
Wind Turbines	*
🗌 Hydro Turbine	4
🗹 Battery bank	
AC Generator	
✓ Inverter	
✓ H2 (F.C Elyzer.)	- 'i i:

Then we click on H2 (F.C. - Elyzer)

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, the water cost is 0, the stack replacement cost is 40% of acquisition cost and there is a cold start time of 20 min and an extra ageing due to each start of 100 min. We leave these default data.

Clicking in "**Availability**" button we can see the electrolyzer will be available all the time by default (we leave the default data), therefore when there is not enough power to run the minimum power of the electrolyzer (20% of rated), it will be at standby (consuming 10% of the rated power).

		ELECT	FROLYZER HO	URLY AVAILA	BILITY		
🔽 0 - 1 h	🔽 1 - 2 h	🔽 2 - 3 h	🗹 3 - 4 h	🗹 4 - 5 h	🗹 5 - 6 h	🗹 6 - 7 h	🗹 7 - 8 h
🗹 8 - 9 h	🗹 9 - 10 h	🗹 10 - 11 h	🗹 11 - 12 h	🔽 12 - 13 h	🗹 13-14 h	🗹 14 - 15 h	🗹 15 - 16 h
🔽 16 - 17 h	🗹 17 - 18 h	🗹 18 - 19 h	🗹 19 - 20 h	🔽 20 - 21 h	🗹 21 - 22 h	🔽 22 - 23 h	🔽 23 - 24 h
	✓ Jan. ✓ Jul.	✓ Feb. ✓ Aug.	✓ Mar. ✓ Sep.	✓ Apr. ✓ Oct.	✓ May ✓ Nov.	✓ Jun. ✓ Dec.	
Not avail	able during no su able if calm wind	n hours if there is during 6 c	PV generator onsecutive hours	and there is Win	d turbine		
				ОК			

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.

H2 COMPONENTS	_	×
I Cells Electrolyzers H2 Tank		
Acquisition cost 1000 €/ka of max. cao.		
· · · · · · · · · · · · · · · · · · ·		
Maximum allowed size: 10 kg Minimum level of H2 (% of max. size): 0 (Fuel Cell will not run if tank level lower)		
H2 tank size is the maximum allowed size		
Capacity at the beginning of the simulation: 1 kg		
Lifespan 25 vears		
O&M Cost 500 €/yr		
In H2 generating systems, do not consider H2 tank (costs 0, infinite allowed size)		

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).

Add from Database	Zero	G	eneration of Elec	trical Energy	by Hydrogen						
Name				• • •		I					
Zero FC1	P. Nom(kW) 0 1	Acq. cost (€) 0 7000	C. O&M (€/h) 0 0.2	Lifespan (h) 100000 15000	A (kg/kWh) 0.06 0.05	B (kg/kWh) 0 0.004	Plimit_ef (% Pn) 20 20	Fef 1 1	P. min. (%) 10 10	^	
output power (P) is lower that output power (P) is higher that FC1.1	n Plimit_ef (% Pn an Plimit_ef (% P Consumption(kg/1): H2 consumption n): H2 consumption n) and Efficiency(%L	(kg/h) = B·Pn(kW) + / (kg/h) = B·Pn + A·P·(HV)	4-P (kW) (1 + Fef (P/Pn - F	limit_ef/100))	Stack repl	acement cost (% of LHV H2 = 33.3	acq. c kWh/l	cost): 40 Ava	✓	
S) 0.08 0.064 0.048 0.032 0.032 0.016 0.016 0.02	0.4 OUTPUT F	0.6 POWER (KW)		ни дн 200 %) монерация 100 %) Fuel f ● H2	Fuel Cell	H ₂					

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

HOGA	×
RECOMMENDED MAXIMUM POWER: PV Generator 24.2 kWp AC Generator 20.2 kW Inveter 6.2 kVA Electrolyzer 24.2 kW; Fuel Cell 18.7 kW	
ELECTRICITY STORAGE FOR 4.5 DAYS AUTON. (E.MAX.DAY.DC*1.2 = 75.7 kWh/day): Batteries bank capacity 8866 Ah (425.6 kWh) H2 tank size: 36.3068 kg	
	ОК

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:

-MIN. AND MAX. No COM	PONENT	'S IN PA	ARALLEL:
Bateries in parallel: Min.	1	Max.	3
PV mod. in parallel: Min.	0	Max.	7
Wind T. in parallel: Min.	1	Max.	2
AC Gen. in parallel: Min.	1	Max.	1

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

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	C ^
1	170922.8	1782.45	11.5	0.05	INF	7.1	98.86	0.4158	SIMULATE	REPORT	С
2	175344.5	2106.59	5	0.02	INF	7.1	97.8	0.4264	SIMULATE	REPORT	С
3	176711.7	2598.84	13.1	0.06	INF	8.2	95.81	0.4299	SIMULATE	REPORT	С
4	183524	3476.54	24.3	0.12	INF	9.9	92.59	0.4467	SIMULATE	REPORT	С
5	196570.4	2691.59	20.7	0.09	INF	8.2	96.17	0.4592	SIMULATE	REPORT	С
6	199688.8	2793.44	19.8	0.09	INF	7.1	95.74	0.4664	SIMULATE	REPORT	С
7	201468.1	3314.16	28.1	0.13	INF	8.2	93.74	0.4708	SIMULATE	REPORT	С
8	202266.5	2265.65	0	0	INF	7.1	97.9	0.472	SIMULATE	REPORT	С
9	207933	2064.06	0.1	0	INF	14.1	99.57	0.5055	SIMULATE	REPORT	С
<											> `
COMP //1×A include STRA W. Pm	ONENTS: PV modules a C Gen. Diesel 1.9kVA 1.9 ed in bi-di inverter // PV b TEGY: LOAD FOLLOWIN in_FC: 100 W. Pcritical_ge	Si12-Schott: ASI100x10 VA // Fuel Cell FC1 of att. charge controller G G. P. lim. charge: 1276 en: 0 W. SOC setpoint_) (1000 Wp_dc): 4s. 1 kW // Electroliz. eneric of 618 A // U 9.3 W. AC Gen. first gen: 20 %. SOC mi	x 7p. (100% Elec2 of 2 k Jnmet load ; FC second n.: 20 %. H2	977#1: W, H2 = 0.1 % d at dis	slope 40°, azimuth 0 tank of 2.029 kg // // 5 // Total Cost (NPC) charge at low power. stp.: 0 kgH2.	²) // Ba Bat. Inv = 1709; P1ger	tteries OPZS-Haw/ retter Generic: 800 22.8 € (0.42 €/kWh) n: INF. P1FC: 5080.	ker:TZS-24 (336 0 CH of 8000 VA 4 W. P2: 767.6 V	0 Ah): 24s. x 1p .// Rectif. √. Pmin_gen: 5	70
											\sim

The optimal solution (first row) includes 28 modules (4s x 7p) of 1000 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 2.03 kg.

Click on "SIMULATE" of the first row. Check the boxes "AC" and "H2" to see the AC and H2 load.



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 = 5080.4 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 = 5080.4 W, it will be supplied by the Fuel Cell. If the Fuel Cell cannot supply the whole and the rest is lower than P1FC = 5080.4 W, it 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):

GENERAL DATA (OPTIMIZATION	CONTROL STRAT	EGIES
-CONTROL STRATEG	Y AND VARIABLES	TO OPTIMIZE	
Global strategy:			Sys
Coad Following	ng		
C Cycle Chargi	ng 🔽 Continue up	to SOC stp	
C Try Both			
Variables to optim	nize relative to th	e global strategy:	
Pmin_gen	Pmin_FC		
P1_gen	P1_FC	🔽 P2	
🔲 SOCstp_gen	🗖 SOCstp_FC	🔲 SOCmin	
Pcritical_gen	Pcritical_FC	Plim_charge	

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

#	Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(۸
1	170893.8	1774.33	11.3	0.05	INF	7.1	98.87	0.4157	SIMULATE	REPORT	C
2	175344.5	2106.59	5	0.02	INF	7.1	97.8	0.4264	SIMULATE	REPORT	C
3	176711.7	2598.84	13.1	0.06	INF	8.2	95.81	0.4299	SIMULATE	REPORT	C
4	183524	3476.54	24.3	0.12	INF	9.9	92.59	0.4467	SIMULATE	REPORT	C
5	194832.9	2635.51	43.1	0.2	INF	8.2	96.08	0.4556	SIMULATE	REPORT	C
6	199479.8	2776.28	19.8	0.09	INF	7.1	95.8	0.466	SIMULATE	REPORT	C
7	199830.5	1975.36	0	0	INF	7.1	98.6	0.4663	SIMULATE	REPORT	C
8	201295.4	3297.73	28	0.13	INF	8.2	93.82	0.4704	SIMULATE	REPORT	C
9	207849	2056.65	0.5	0	INF	14.1	99.57	0.5053	SIMULATE	REPORT	٢.,
1											, Y
COMP //1xA include	ONENTS: PV modules at C Gen. Diesel 1.9kVA 1.9 ed in bi-di inverter // PV bi TEGX: LOAD FOLLOWINI	Si12-Schott: ASI100x10 VA // Fuel Cell FC1 of att. charge controller G G. P. lim. charge: 1276	I (1000 Wp_dc): 4s 1 kW // Electroliz. eneric of 618 A // U	x 7p. (100% Elec2 of 2 k Jnmet load	\$ PV#1: \$W, H2 = 0.1 %	slope 40°, azimuth 0 tank of 2.106 kg // // 1 5 // Total Cost (NPC) charge at low power	²) // Ba Bat. Inv = 1708: ₽1co	tteries OPZS-Haw ′erter Generic: 800 33.8 € (0.42 €/KWh) o: INE P1EC: 5080	ker:TZS-24 (336 0 CH of 8000 VA 1 4 W P2: 614 1 V	i0 Ah): 24s. x 1p \// Rectif. \/ Pmincon: 5	70
W. Pm	in_FC: 100 W. Poritical_ge	a. P. IIII. Charge. 1276 en: 0 W. SOC setpoint_	gen: 20 %. SOC mi	in.: 20 %. H2	2TANK	stp.: 0 kgH2.	riger	I. IINI . F I F G. 3000.	9 VV. F 2. 019.1 V	v. ennin_gen. s	~

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.

We can minimize 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. 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 ".

GENERAL DATA OPTIMIZATION CONTROL STRATEGIES FINANCIAL DATA RESULTS CHART
OPTIMIZATION TYPE:
C TEMPORARY INTERVAL: ALL USEFUL LIFE OF THE SYSTEM (FIXED INSTALLATIONS)
TEMPORARY INTERVAL: LESS THAN ONE YEAR (TRANSPORTABLE FACILITIES, ONLY FOR PV-DIESEL-BATTERIES)
MINIMIZE TRANSPORT WEIGHT O MINIMIZE COST (TRANSPORT+)
Interval starts: Month: 7 Day: 1 Number of days: 30 Distance: 200 km
Diesel density: 845 kg/m3; Min. to transport. 100 litres; Transport cost 0.1 €/tor/km
Extra ageing: PV panels: 30 %; Batteries: 15 %; Generator: 0 %; Inverter: 0 %

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%:

Ņ	BATTERIES																		-		×
	Add Battery	Zero			~	14		NI													
	Add Batteries family	OPZS-H	awker		~			Pl	Ŧ	-											
BA	TTERIES DATA:							FI	oat life	at 20 🛛 ۹	°C 0'	C	ycles to	Failure	vs. De	pth of E	Dischar	ge (%)			
	Name	Cnom.(Ah)	Volt(∨)	Cost(€)	C.O&M(6/yr)	SOCmin(%)	Self_d(%/mon.)	Imax(A)	Eff(%)	Float(yr)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	TYF 🔨
	OPZS-Hawker:TLS-3	180	2	127	1.27	20	3	36	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	1000	LA
	OPZS-Hawker:TLS-5	270	2	178	1.78	20	3	54	85	18	12000	6500	4350	3100	2500	2050	1800	1600	1500	1000	LA
	Zero	0	2	0	0	20	0	0	100	100	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	LA
																					~
1																					>
																					,
Ba	tteries Model							50													
۲	Ah 🔽 Li-ion mo	del Ah			Fixed Oper	ation and Mai	ntenance Cost	50 E,	fyr		Equiv	alent CU	2 emissi	ons (mar	utacturin	ig): 55	i ko	1 CO2 ec	µuiv / KW	h capaci	ty
0	KiBaM (Manwell-McGow	an 1993)			Auxiliary co	oling, BMS (cons. AC (% of m	nax. P): 0			SOC	at the be	gining of	simulatio	n: 5 0	% of S	SOCmax	J			
0	Copetti 1994							DC co	ins.		Li-ion	batteries	s maximu	m SOC:	100	%					

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.

#	Cost (€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
1	72	9.03	0	0	17.9	5.2	100	0.595	SIMULATE	REPORT	(
2	75.7	9.03	0	0	INF	5.2	100	0.625	SIMULATE	REPORT	(
3	76.3	9.16	0	0	26.8	7.7	100	0.6305	SIMULATE	REPORT	(
4	81.2	11.23	0.3	0.27	INF	6.6	98.75	0.6708	SIMULATE	REPORT	(
5	79.8	9.03	0	0	INF	5.2	100	0.6592	SIMULATE	REPORT	(
6	75.9	7.46	0.3	0.25	26.8	9.9	99.75	0.6271	SIMULATE	REPORT	(
7	80	9.16	0	0	INF	7.7	100	0.6606	SIMULATE	REPORT	(
8	81.8	10.31	0.2	0.16	INF	6.6	98.43	0.676	SIMULATE	REPORT	(
9	81.2	8.63	0.1	0.05	INF	9.9	99.67	0.6708	SIMULATE	REPORT	C)
<											×
COMF Bat. In kg STRA	ONENTS: PV modules Si verter STECA: XPC 1600-4 TEGY: LOAD FOLLOWIN	P12-TAB:PV-135-moc 88 of 1600 VA // PV ba G. SOC min.: 20 %.	ł (135 Wp_dc): 4s.x tt. charge controlle	4p. (100% F r. STECA: F	PV#1: s >TARC	slope 40°, azimuth 0°) DM 4055 of 55 A // Un	// Batti imet loi	eries OPZS-Hawk ad = 0 % // Cost = 7	er:TLS-3 (180 A) 72 € (0.59 €/KWh	h): 24s. x 1 p. //); Weight: 1363	3.2

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

	Weight (kg)	^
0	1363.2	
0	1545.2	
0	1641.6	
ð	1665.7	
0	1752.2	
ð	1763.2	
0	1823.6	
0	1873.1	
0	1944.9	

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 1st. You can see how on July 1st at 0h the SOC of the batteries drops to 50% (to start the simulation of the period we are interested in).



42. Optimization of a system with AC grid connection in which the AC grid is unavailable during certain periods of time.

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):

COMPONENTS	7
Wind Turbines	\sim
Hydro Turbine	4
Battery bank	
AC Generator	
✓ Inverter	
🗌 H2 (F.C Elyzer.)	1

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".

CONSTRAINTS: <u>Maximum Unmet Load allowed:</u> 0 % annual
Unmet load refers to: E. not supplied by the stand-alone system E. not supplied by the system nor by the AC grid
More Constraints

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%:

	_		×
If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (for assigned infinite cost):	that con	nbination i	t is
Maximum Unmet Load allowed: 0 % of annual load (Max. energy not supplied by the stand-alone system nor by the AC grid)			
Minimum number of days of autonomy (batteries+hidrogenl): 4.5 days (🔽 if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, number of days	ys of auto	onomy = ii	nfinitum)
Nominal capacity of batteries bank (Ah) < 20 x (shortcut current of PV generator + current from Wind Turbines gruop (if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, do not take in	at 14m/ to accou	<mark>s) (A)</mark> Int this cor	nstraint))
Minimum renewable fraction: 🔲 🌫			
Maximum Levelized Cost of Energy: 100 €/KW/h			
OK			

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 $0.15 \notin$ /kWh (plus $0.1 \notin$ /kWh of default access charge, that is, the total cost of electricity is $0.25 \notin$ /kWh). Also suppose that the maximum power from the grid (contract power) is 3 kW at a cost of $40 \notin$ /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.

AC LOAD (W) DC LOAD (W) H2 LOAD (kgH2/h)	WATER (m3/day) FROM WATER TANK PURCHASE / SI	
AC LOAD (W) DC LOAD (W) H2 LOAD (kgH2/h) Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Fixed Buy Price (£/kWh) 0.15 Hourly Price Annual Inflation (%): Emission (kgC02/kWh): 3 0.4 Emissions data Fixed Pmex (kW) Secess Charge Price (£/kWh)	WATER (m3/day) FROM WATER TANK PURCHASE / Si Sell Excess Energy to AC grid ✓ Fixed Sell Price (€/kWh) 0.12 Pr. sell = pr. buyx 1 Annual Inflation (%): 3 Max Power(kW) 3 Terray Generation Charge (Transfer Charge) Price (€/kWh) ✓ Fixed Transfer price (€/kWh) 0	AC GRID AVAILABILITY Priority to supply E not covered by renewables: Storage/Generator Sto./Gen. priority if Pr.buyE >= Stol./Gen. priority if Pr.buyE >= Sell surplus H2 in tank (difference between the H2 in the beginning) Price (6/kg) Annuel Inflation (%):
Fixed Access price (c/kWh) 0.1 Hourly Price Back-up Charge Price (c/kWh) Fixed Back-up price (c/kWh) Fixed Back-up price (c/kWh) Generative gen. charge (Will be added to the E purchased) Add negative gen. charge	Self-consumption and Net Mettering; ✓ Self only No net mettering ✓ Cost of net metering service (€/kWħ) 0 Buy-back: Export E is paid at (€/kWħ) 0	10 3 Data to compare with electrical supply only from AC conventional grid: Total cost installation of AC grid: 3000 € 0&M annual cost of grid: 100 €
Total tax for electricity costs (buy + charges) (%): 0	Total tax for electricity sold (%): 0	sses in wire and transformer (%); 0

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

AC GRID HOURLY AVAILABILITY										
 Hourly all r 	laus the same									
Froundly, an usays the same From file (8760 hourly values, Each row; 1-> available; 0-> not available)										
✔ 0-1h	🔽 1 - 2 h	🔽 2-3h	🔽 3-4h	🔽 4-5h	🔽 5-6h	🔽 6-7h	🔽 7-8h			
✔ 8-9h	🔽 9-10 h	🔽 10-11 h	🔽 11 - 12 h	🔽 12-13 h	🔽 13-14h	🔽 14-15 h	🔽 15-16 h			
✔ 16-17h	🔽 17-18 h	🔽 18-19 h	🗖 19-20 h	🗖 20 - 21 h	🔽 21 - 22 h	🔽 22-23 h	🔽 23-24 h			
7 If priority is AC grid and the max, power of the renewable source is lower than 20 \$\overline{2}\$ of the maximum load, when the AC grid is available, fully charge the batteries										
E Dum OK										

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":

NVERTERS AND BI-DI CONVERTERS							
Add from Database	ZERO ~						

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.

℟ PARAMETERS OF THE OPTIMIZATION
MAIN ALGORITHM (OPTIMIZATION OF COMPONENTS)
OPTIMIZATION METHOD:
⊖ GENETIC ALGORITHMS
GENETIC ALGORITHM:
Generations: 15 Population: 18
Crossover rate: 90 👷 Mutation rate: 1 🕺 🗌 Mutation Uniform
STOPPING CRITERION:
Stop execution of main algorithm if after 15 generations
it cannot improve 1 % in 5 consecutive generations
EVALUATE ALL COMBINATIONS:
Display best: 100

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:



We can see that the optimum system includes PV generator and batteries. This is due to the fact that the price of the electric energy of the AC network is quite high ($0.25 \notin kWh$, considering the cost of energy plus the access charge); if that price was sufficiently low the optimum system might not include PV 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 (19-21h). 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 without PV generator is the number 28, with a configuration only with AC grid and batteries (plus inverter).

27	21232.1	273.24	U	U	INF	9.9	69.56	0.7227	SIMULATE	REPORT	C
28	21449.9	655.92	0	0	INF	0	0	0.7301	SIMULATE	REPORT	C
/											, ×

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.hoga" project and save it as "Pr1-Multiperiod.hoga". In the upper menu, **Project-** >**Options**.

Select "Mutiperiod: simulate all the years of the system lifetime..."

Simulation and optimization:	
◯ Simulation of the 1st year and extrapolate results	
Multiperiod: simulate all the years of the system lifetime (25 years) Options	
Economic optimization:	
$igodoldsymbol{igo$	Min. NPC
Maximize Net Present Value (NPV), usually for low load or no-load on-grid systems>	Max. NPV
	 Min. LCOE Min. LCOH Max. Cap.F. min. LCOE Max. IRR
When saving the project, update all the results of the table to the present conditions	
Number of decimal places in results of costs 1 \sim	
Number of decimal places in results of energy 1 🗸 🗸	

Then click in **Options** button.

MULTIPERIOD SIMULATION AND OPTIMIZATION OPTIONS:	[Obtain re	ndom values	for	PURCHASE	E. price inc.	~ Av	erage (%)	3	Std. dev	. (%):	1				
Show in the simulation during one year.	Obtain random values for			for	rradiation var	riation over (ave ~ Av	erage (%)	0	Std. dev	. (%):	2				
Aerage year	An	nual increa	ase in price	s and loa	d (%) / Varia	ation over	average i	in resour	rces (%) / O&M PV - WT (%):							
Vernumber 1	Year	Purch.E.	Sell E.	Sell H2	Inc. AC	Inc. DC	Inc. H2	Inc. W.	Irrad.	Wind	OM.P.	OM.W.	^			
	1															
Annual increase in electricity and H2 price: Fixed	2															
(if fixed, same values as price inflations of LOAD/AC GRID)	3															
AC grid Electricity: Purchase: 3 %; Sell : 3 %	4															
H2 sold: 3 % Each year diff. hourly sell price: Data	5															
Hourly buy price = sell x 1	6															
Annual increase in load consumption: Fixed	7															
AC: 1 % DC: 1 %	8															
H2: 1 % Water: 1 %	9															
	10	For var	iable unseled	t "Fixed"	F	or variable ι	inselect "Fi	(ed"	Unched	:k "No ch."	Unche	ck "Fixed				
Annual decrease in generation:	11															
PV:1styear: 3 %; otheryears: 1 %	12															
Wind Turbines: 1 %	13															
Hydro Turbines: 0 %	14															
	15															
Battery and of life when capacity reduction of 20 %	16															
Annual variation over average in resources:	17															
	18												~			
Annual USM for PV and Wind L. V Fixed		L														
		ок														

By default, an annual increase of 3% in electricity and H2 price is considered (although in this case it will not be considered as energy is not bought or sold).

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 lost 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.

MULTIPERIOD SIMULATION AND OPTIMIZATION OPTIONS:	Obtain random values for PUI			JRCHASE I	E. price inc.	✓ Av	erage (%)	3	Std. dev	. (%): 1		
Show in the simulation during one year:	Obtain random values for Irra			adiation var	iation over a	ave ~ Av	erage (%)	0	Std. dev	(%): 2		
Aerage year	4	nnual incre	ase in price	es and load	l (%) / Varia	ation over	average i	in resour	ces (%) /	O&M PV	- WT (%):	
Vearnumber 1	Year	Purch.E.	Sell E.	Sell H2	Inc. AC	Inc. DC	Inc. H2	Inc. W.	Irrad.	Wind	OM.P. OM.W.	1
	1				0	0	0	0				17
Annual increase in electricity and H2 price: 🗸 Fixed	2				1	-	1	1				
fixed, same values as price inflations of LOAD/AC GRID)	3			L	5	1] 1	1				
AC grid Electricity: Purchase: 3 %; Sell : 3 %	4				1	1	1	1				
H2 sold: 3 % Each year diff. hourly sell price: Data	5				1	1	1	1				
Hourly buy price = sell x 1	6				1	1	1	1				
Annual increase in load consumption: Fixed	7				1	1	1	1				
AC: 1 % DC: %	8				1	1	1	1				
H2: 1 % Water: 1 %	9		For variable unselect "Fixed"			1	1	1				
	10	Forva				1	1	1	Uncheck "No ch."		Uncheck "Fixed	
Annual decrease in generation:	11				1	1	1	1	1 1 1			
PV:1styear: 3 %; otheryears: 1 %	12				1	1	1	1				
Wind Turbines: 1 %	13				1	1	1	1				
	14					1	1	1				
Hydro Lurbines: 0 %	15			1	1	1	1					
20	16				1	1	1	1				
Dattery end of the when capacity reduction of 20 1%	17				1	1	1	1				
Annual variation over average in resources: VNo change	18				1	1	1	1				
Annual O&M for PV and Wind T.: 🔽 Fixed					_				_			_

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%:

	Annual variation over average in resources: 🗖 No change	
	Annual O&M for PV and Wind T.: 🔽 Fixed	
Obtain random values for	PURCHASE E. price inc. Average (%): 3 Std. dev. (%): 1	
Obtain random values for	Irradiation variation over ave 🔻 Average (%): 0 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):

Show in the simulation during one year:		Obtain re	andom values	s for In	adiation var	iation over a	we v Av	erage (%)	: 0	Std. dev	v. (%): 3
Aerage year	,	nnual increa	ase in price	s and load	l (%) / Varia	ation over	average	in resour	ces (%) /	O&M PV	- WT (%):
	Year	Purch.E.	Sell E.	Sell H2	Inc. AC	Inc. DC	Inc. H2	Inc. W.	Irrad.	Wind	OM.P. OM.W.
)Year number: 1	1				0	0	0	0	-5.36	0	
ual increase in electricity and H2 price:	2				1	1	1	1	4.81	0	
ed, same values as price inflations of LOAD/AC GRID)	3				5	1	1	1	0.88	0	
grid Electricity: Purchase 3 %; Sell : 3 %	4				1	1	1	1	2.08	0	
sold: 3 % Each year diff. hourly sell price: Data	5			1	1	1	1	2.41	0		
Hourly buy price = sell x 1					1	1	1	1	0.61	0	
ual increase in load consumption: Fixed	7				1	1	1	1	1.6	0	
1 % DC 1 %	8		1	1	1	1	5.64	0			
1 % Water: 1 %	9			1	1	1	1	3.47	0	Uncheck "Fixed	
	10	For variable unselect "Fixed"			1	1	1	1	1.31		0
ual decrease in generation:	11				1	1	1	1	1.71	0	
/: 1styear: 3 %; otheryears: 1 %	12				1	1	1	1	0.13	0	
ind Turbines: 1 %	13				1	1	1	1	-2.89	0	
due Tardeira en Olimpier	14				1	1	1	1	-0.2	0	
ara rumpines. 💌 🛪	15				1	1	1	1	-1.14	0	
envend of life when canacity reduction of 20 %	16				1	1	1	1	-1.67	0	
	17				1	1	1	1	6.18	0	
var variansmaver average in rescultable. [] No change	18				1	1	1	1	-3.1	0	
ual O&M for PV and Wind T.: V Fixed											-

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 (it will take several seconds). 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 higher than the maximum allowed of 0,3%, therefore the NPC is assigned the value INF (shown in the graph with 0 as NPC).

	HOGA						×			
	Constrain - Unmet	nts that are no load (7.5367	ot met: %) > M	ax. U	nmet load allo	owed (0.3%))			
	If there is PURCHAS	AC grid avai SING electrici	ilable, c ity to th	onsio e AC	der to allow th grid.	e option of				
	NPC set t	o INFINITE (s	hown a	s 0 in	the graph)					
						OK				
	L									
Cost (NPC)(€) Em	ission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(v	[^] Ren(% LCOE(€/	kWh)	Simulate	Report	٢ ۸
INF	557.04	132.2	7.54	INF	6.6	83.36	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 7.54%.

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 (year 12):

Tota



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



Hourly simulation	Hourly values se	parately Mont	nly and Annual	Average Po	wer Monthl	y Energy A	nnual Energy	Hydrogen	AC Gene	erator Water lo	ad/PHS M	JLTIPERIOE)
			HO	URLY POW	/ER DURIN	G THE YEA	R (kW), EN	ERGY IN (kV	Vh)				
	Total Lo	ad				PV Generato	r				Wind Turbines		
0.6 0.4 0.2			ana ani	0.8 0.6 0.4 0.2 0				endlicht.	0				
0	2,000 4,000	6,000	8,000	0	2,000	4,000	6,000	8,000	0	2,000	4,000	6,000	8,000
	Hydro Turbin	e / TEG				AC Generato	r				Export		
0 -				0.4 0.2 0					0.002 0.001 0				
0 :	2,000 4,000	6,000	8,000	0	2,000	4,000	6,000	8,000		0 2,000	4,000	6,000	8,000
	Fuel Ce	1				Electrolyzer				Energy (HHV of	H2) in H2 tan	k // accum. S	Sold
0 -				0 -					0 -				
0 2	2,000 4,000	6,000	8,000	0	2,000	4,000	6,000	8,000			0		
	Battery bank	Charge			Batt	ery bank Disc	harge			Ener	rgy in Battery	bank	
0.4 0.2		Loop And Ale	halden	0.6 0.4 0.2 0	uldanhaan	luquin qu	Alleiten.	h, , tuluí	4 3 2 1 0				
0	2.000 4.000	6,000	8.000	0	2,000	4,000	6,000	8,000	0	2,000	4,000	6,000	8,000
Unr	met load (by the sta	indalone system)		Purc	hased from A	C grid		_	:	Sold to AC gri	d	
0.4 0.3 0.2 0.1 0	עין אנא קרע אין וייז איזא קרע אין		uri il kubit	0 -					0				
0	2,000 4,000	6,000	8,000	0	2,000	4,000	6,000	8,000	0	2,000	4,000	6,000	8,000
Simulation step (mi	in.): 60 🗸	Simulaltion m	ultiperiod year	25 🔻		🛃 Back	Sav	e data: All	~	Save Sir	mulation Data	Save	Prob. Data

We can optimize considering the multiperiod.

But, before optimizing, we will let a maximum of PV strings in parallel of 6, and 2 backup generators in parallel:

-MIN. AND MAX. No COM	PONENT	'S IN P	ARALLEL:
Bateries in parallel: Min.	1	Max.	3
PV mod. in parallel: Min.	0	Max.	6
Wind T. in parallel: Min.	1	Max.	2
AC Gen. in parallel: Min.	1	Max.	2

Also we delete the second type of PV module, allowing only one type:

PV MODULES									-	
Add PV module Ze Add PV modules family Site PHOTOVOLTAIC MODULES	ro M12-Atersa DATA:	~	4		▶ +	-				
Name	Nom.Volt.(V)	lsc(A)	Power(Wp_dc)	Cost(€)	C.O&M(6/yr)	Life(years)	NOCT([®] C)	Power T. coef.(%/ºC)	BIFACIALITY(0-1) CPV
aSi12-Schott: ASI100	12	6.79	100	110	1.1	25	49	-0.2		0 NO

We change the maximum execution time to 5 minutes.

OPTIM	IZATIO	DN PA	RAMETERS	SELECTED BY:			
●HOGA ○USER							
Maximum execution time:							
0	h.	5	min.	Parameters			
🗹 Mir	nimum	time f	or the Genetic	Algorithms			

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, 40 minutes. iHOGA will se genetic algorithms to perform the optimization in 5 minutes (but it is possible that it considers that a higher time is needed to make sure obtaining the optimal or a solution near the optimal).

			EVAL ALL	POP. (% ALL)	GEN. ALG. (% ALL)
MAIN AL	G. (COMB. CC	IMPUNENTS):	(1x2268)	31 (1.37%)	446 (19.75%)
SEC. AL	G. (COMB. ST	RATEGIES):	1	3 (300%)	41 (4100%)
	MAIN ALG.	SEC. ALG.	NUMBER OF CASES	%	TIME EXPECTED
OPTION 1:	EVAL. ALL	EVAL. ALL.	2268	100 %	0h 40' 8''
OPTION 2:	EVAL. ALL	GEN. ALG.	92988	4100 %	1 days 3h
OPTION 3:	GEN, ALG,	EVAL ALL	448	19.8 %	<u>0h 7' 55"</u>
OPTION 4:	GEN. ALG.	GEN. ALG.	18368	809.9 %	5h 24'
Warning!.	lf the selecti	on of the par	ameters of genetic	algorithms is no	ot correct, the optimal

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 8th 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 results with multiperiod are more realistic, including increase in load and variation in resources.

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 18 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 18 to 25 (the average unmet load during the system lifetime is 0.26%).

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 results. 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.

A	B C D	E F	G H	1	J K	L M	N	0	P Q	R S
Project: Pr1-Multipe	riod.hoga. Generation #15									
RESULTS DURING TH	HE YEARS OF THE SYSTEM LIFETI	ME, MULTIPERIOD SIMULA	TION.							
Costs and incomes a	are cash flow of each year (not p	resent value)								
(ear	Cum, Inf. Purch, F(%)	Cum. Inf. Sell F(%)	Cum. Inf. Sell H2(%)	AC load(%)	DC load(%)	H2 load(%)	Water load(%)	Irrad.(%)	Wind(%)
1	3	3	3	100	100		100	100	-5.36	
2	6.09	6.09	6.09	101	101		101	101	4.81	
3	9.27	9.27	9.27	106.05	102.01	10	2.01	102.01	0.88	
4	12.55	12.55	12.55	107.11	103.03	10	3.03	103.03	2.08	
5	15.93	15.93	15.93	108.18	104.06	10	4.06	104.06	2.41	
6	19.41	19.41	19.41	109.26	105.1	1	05.1	105.1	0.61	
7	22.99	22.99	22.99	110.36	106.15	10	6.15	106.15	1.6	
8	26.68	26.68	26.68	111.46	107.21	10	7.21	107.21	5.64	
9	30.48	30.48	30.48	112.57	108.29	10	8.29	108.29	3.47	
10	34.39	34.39	34.39	113.7	109.37	10	9.37	109.37	1.31	
11	38.42	38.42	38.42	114.84	110.46	11	0.46	110.46	1.71	
12	42.58	42.58	42.58	115.99	111.57	11	1.57	111.57	0.13	
13	46.85	46.85	46.85	117.15	112.68	11	2.68	112.68	-2.89	
14	51.26	51.26	51.26	118.32	113.81	11	3.81	113.81	-0.2	
15	55.8	55.8	55.8	119.5	114.95	11	4.95	114.95	-1.14	
16	60.47	60.47	60.47	120.69	116.1	1	16.1	116.1	-1.67	
17	65.28	65.28	65.28	121.9	117.26	11	7.26	117.26	6.18	
18	70.24	70.24	70.24	123.12	118.43	11	8.43	118.43	-3.1	
19	75.35	75.35	75.35	124.35	119.61	11	9.61	119.61	-6.36	
20	80.61	80.61	80.61	125.6	120.81	12	0.81	120.81	4.43	
21	86.03	86.03	86.03	126.85	122.02	12	2.02	122.02	-0.78	
22	91.61	91.61	91.61	128.12	123.24	15	3.24	123.24	5.37	
23	97.36	97.36	97.36	129.4	124.47	12	4.47	124.47	0.06	
24	103.28	103.28	103.28	130.7	125.72	12	5.72	125.72	-2.85	
25	109.38	109.38	109.38	132	126.97	12	6.97	126.97	1.12	

44. High power project, maximization of NPV.

Now we will create a high power project where there will be a power generating system 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....

	iHOGA type of project	
O LOW POWER PROJE	त्त: load in W, energy in kWh, currency in its m.u. (.hoga proje CT: load in kW, energy in MWh, currency in k m.u. (.kho projec	ect) :t)
	OK	

In the "creating new project" dialog, give the name High1, and the extension is .kho so the project will be **High1.kho**.

High1	-
iHOGA kW project (*.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).

	PV	ar DC Battery	AC Load / grid
℟ Project: D:\PROYECTOS IHOG/ Project Data Data Base Repo	A 3.4-10-12-2022\High1.kho rt Visual Help License Updates	-	- 🗆 X
V LOAD / AC GRID	GENERAL DATA OPTIMIZATION CONTR	OL STRATEGIES FINANCIAL DATA RESULTS CHART	
BESOURCES	COMPONENTS	MIN. AND MAX. No COMPONENTS IN PARALLEL:	OPTIMIZATION PARAMETERS SELECTED BY:
SOLAB	V Gen.	Bateries in parallel: Min. 1 Max 1	0
	_		HOGA USER
WIND	Wind Turbines	PV gen. in parallel: Min. U Max. 8	Maximum execution time:
HYDRO		Wind T. in parallel: Min. 1 Max. 1	0 h. 15 min. Parameters
COMPONENTS	Hydro T.	AC Gen in narallel: Min 1 May 1	Minimum time for the Genetic Algorithms
	Retton: bonk		In minimum one for the deneater signifiants
V GEN.		Constraints under NPV maximization:	Simulation
WIND TURB.	Backup Gen.	Max Investment cost 1E10 kf	Step (min.): Simulation starts:
HYDBO TUBB			60 v hour 0 day1 month 1
	✓ Inverter/char.	Min. Capacity Factor 0 % C Pmax_sell	
V BATTERIES		Min. Renew. Fraction 0 %	
VINVERTER/CHAR.	H2 (F.C Elyzer.)	Max. Unmet load 100 %	
BACKUP GEN.			
HR/E C. Ehren)			
Hz (F.C Elyzer)			
Water Pump in Load/AC grid			
DC Voltage 48 V SOCd.			
AC Voltage 400 V		BV	
		FV	
PRE-SIZING			
Energy storage: 4 days auton.			
Max bat. parallel -> Cn min.			
Max PV gen. parallel → P min.			→ ①
Max Wind T. parallel -> P min.		Inverter/Charger CAC	AC
Max AC Gen. parallel -> Pmin		inverter)	Load /
		T DC	grid
		<u> </u>	
Sensitivity Analysis		- +	
Probability Analysis		Battery	
Trobasing Analysis		Dattory .	
22 CALCULATE			
B REPORT			

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, or other types of optimization. We leave the default one (Max. NPV).

Simulation and optimization:	
Simulation of the 1st year and extrapolate results	
\bigcirc Multiperiod: simulate all the years of the system lifetime (25 years)	
Economic optimization:	
O Minimize Net Present Cost (NPC), usually for off-grid systems and high load on-grid	Min. NPC
Maximize Net Present Value (NPV), usually for low load or no-load on-grid systems	Max. NPV
	O Min. LCOE O Min. LCOH
DC renewable include own charger and controller	Max. Cap.F. min. LCOI
When saving the project update all the results of the table to the present conditions	0
Number of decimal places in results of costs $~~1~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~$	
Number of decimal places in results of energy 1 \checkmark	

In the main screen, we can see the database (menu Database):

Gen. Wind tu	rbines Ba	atteries AC	Generators	Inverter/Cha	rgers H	Hydro turbir	nes Electro	olyzers Fuel cells				
					◀ ▶	▶ + -		×Č				
Name	P.	nom(kWp_dc)	Cost (k€)	C. 0&M (%/yr)	Life ((years) N	OCT (°C) Po	ower T.coef. (%/ºC) BIF	ACIALITY(0-1)	CPV	Emissions (kgCO2/kWp)	^
Zero		0	0		0	100	43	-0.4	0	NO	800	
PV1		1	1		1	25	43	-0.4	0	NO	800	
∿/10		10	10		1	25	43	-0.4	0	NO	800	
PV100		100	100		1	25	43	-0.4	0	NO	800	
CPV10		10	12		1	25	43	-0.14	0	OK	800	
PV10BIF		10	11		1	25	43	-0.4	0.7	NO	800	
												~
						Multiply r	costs of PV b	y 1				•
	Clane sele	ected compon	ent	Add cor	nponent	Multiply i	costs of P∨ b project [ry 1	~			*
	Clone sele	ected compon	ent	Add cor	nponent	Multiply ts from the p	costs of P∨b project [y 1				v

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):

a ana 300100.											Hours	AC DO	H2	Water		
O Monthly Ave	erage 🖲) Load Profile	e 🔾 Impo	ort File (KW, tH	l2/h, dan	13/h)				- 8	$1 \sim \frac{Min}{Min}$	utes-each utes-1 per	hour in 1 ro row	w Im	port	Export
C LOAD (KW)	DC L	OAD (kW)	H2 I	_OAD (tH2/h	i) V	VATER (d	lam3/day)	FROMW	ATER TAI	NK PU	IRCHASE	/ 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	15-16ł 🔨
JANUARY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FEBRUARY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MARCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APRIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUGUST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPTEMBER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OCTOBER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOVEMBER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DECEMBER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		s	Cale facto	or for Monday	to Friday	e 1		Scale fact	tor for the w	eekend:	1					
oad profile: Zoro				\sim												
Toda biolile: 7610							AV	ERAGE LO	JAD IN JAI	NUARY (In	ncluded sc	ale factor),	TOTAL 0	kWh/day		
(ariability	Ac	dd Ioad profil	e					AC loa	d 🗹 🔲 D(Cload 🗹	📕 H2 (HH\) 🗹 🔳 W	/ater (E pu	mped)		
/ariability	Ac	d load profile		12			7	AC loa	d 🗹 🔲 D(Cload 🔽	H2 (HH)) 🗹 🔳 V	/ater (E pu	mped)		
/ariability Daily Variability	AC O	dd load profil DC % 0	e % 0	12 %				AC loa	d 🗷 🔲 D(Cload 🗵	H2 (HH)) ⊠∎ v	/ater (E pu	mped)		
/ariability Daily Variability Hourly Variability	AC O O	dd Ioad profile DC % 0 % 0	e H % 0 % 0	12 % %			V	AC loa	d F 🔲 D(Cload 🗹	H2 (HH)	n) 💌 🔳 W	/ater (E pu	mped)		
/ariability Daily Variability Hourly Variability Minutes Variability	AC 0 0 90	d load profil DC % 0 % 0 % 90	e % 0 % 0 % 90	12 % %	N		V	AC loa	d 🗷 🔲 D(Cload 🔽	H2 (HH)	n) 💌 🔳 W	/ater (E pu	mped)		
Variability Daily Variability Hourly Variability Minutes Variability Correlation minute	AC 0 0 , 90 s 0.9	dd load profil DC 0 % 0 % 90	e ⊢ % 0 % 0 % 90	12 % % %	kW	0-	M	AC loa	d 🔽 🔲 D(Cload 🔽	H2 (HH)	n) 🗷 🔳 Vi	/ater (E pu	mped)		
Variability Daily Variability Hourly Variability Minutes Variability Correlation minute Generate	Ac 0 0 90 s 0.9 AC lo	dd load profile % 0 % 0 % 90 ad power fac	e	12 % % %	κw	0-	v	AC loa	d	Cload 🗹	H2 (HH)) 🔽 🔳 V	/ater (E pu	mped)		
/ariability Deily Variability Hourly Variability Minutes Variability Correlation minute Generate Add load of	AC 0 90 s 0.9 AC lo	d load profile % 0 % 0 % 90 ad power fac	+ 0 % 0 % 0 % 90 ctor (cos fi)	12 % % %	K.	0-	v	AC load	d F 🔲 D(Cload 🔽	H2 (HH)) 🔽 🔳 V	/ater (E pu	nped)		
Ariability Daily Variability Hourly Variability Minutes Variability Correlation minute Generate Add load of	AC 0 0 90 s 0.9 AC lo	Idead profile %	e F % 0 % 0 % 90 ctor (cos f) c during	12 % % % % 1: 1 5 min Repeat every	ACma	0- 0 xx. hourly s	Ctive powe	AC loar	d 🔽 🔲 DO	AC pumpir	H2 (HH)) ♥ ■ V	/ater (E pur	mped)		
/ariability Daily Variability Hourly Variability Minutes Variability Correlation minute Generate Add load of m: min 0 hour	AC 0 0 90 s 0.9 AC lo 0 0 dey	Id load profil % 0 %	e % 0 % 0 % 90 tor (cos fi) during 1 F	12 % % % % 1 %	AC me Avera	0- 0 ex. hourly 8 ge hourly 9	Ctive powe	AC load	d 🔽 🔲 DC	AC pumpir kVA	12 hour ng): 0 kW; k	n) 🔽 🔳 V	/ater (E pur	mped) 18 kW		
Variability Daily Variability Hourly Variability Minutes Variability Correlation minute Generate Add load of m: min 0 hour OK	AC 0 0 , 90 s 0.9 AC lo 0 0 day	Id load profile DC % 0 % % % 30 Ad power face KW AC 1 month	e % % % % % 90 % 90 tor (cos fi) during 1 60	2 % % % % % %	AC ma Avera DC ma	0- 0 xx. hourly 8 ge hourly / xx. hourly p	ctive power AC power: A ower load	AC load	d 🔽 🔲 DC 6 6 7 (Aparent 0 0 KW; DC p	AC pumpir kVA sower hour	H2 (HH) 12 hour ng): 0 KW; M	7) 🔽 🖬 V lex in 1/2 h 0 KW	/ater (E pur	mped) 18 kW		

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.

C Monthly Average C Load Profile C Import File (kW, tH2/h,	, dam3/h)	Hours AC DC H2 Water 1 Minutes- each hour in 1 row Import Export Export
C LOAD (KW) DC LOAD (KW) H2 LOAD (tH2/h)	WATER (dam3/day) FROM WATER TANK PUR	RCHASE / SELL E
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Image: Stand-alone system Image: Stand-alone standard Image: Standard Standard Image: Standard Standard Image: Standard Standard Standard Image: Standard Standard Standard Image: Standard Standard Standard Standard Image: Standard Stand	✓ Sell Excess Energy to AC grid ✓ Fixed Sell Price (6/kWh) 0.12 Pr. sell = pr. buy x 1 Annual Inflation (%): 3 3 Max. Power(kW) 100 =Pmax buy Energy Generation Charge (Transfer Charge) Price (6/k Hour Self-consumption and Net Mettering. No net mettering Cost of net metering service (6/kWh) 0 Buy-back: Export E is paid at (6/kWh) 0 Total tax for electricity sold (%): 0	AC GRID AVAILABILITY rly Price Priority to supply E not covered by renewables: Storage/Generator C AC Grid Sell surplus H2 in tank (difference between the H2 in the tank at the end of the year and at the beginning) Price (£/kg) Price (£/kg) 10 3

We can see the default PV generator is of 10 kW:

й P	V GENERATORS									_		×
	Add PV Gen.	Zero		~								
	Add PV Gen. family					• - •	· ~ × (
	PHOTOVOLTAIC GENER	RATOR DA	TA:									
Na	ame		Power(kWp)	Cost(k£)	C.O&M(%/\/r)	Life(years)	NOCT(*C)	Power T. coef.(%/ºC)	BIFACIALITY(0-1) CPV	Emissions(kq0	O2/kWp)	
► P	V10		10	10	1	25	43	-0.4	0 NO	800		
<											>	
	Efficiency due to degradation o	if the module	es, losses in wir	es, dirt in pane	els, etc. 0.95					Fixe	d Operation	and
	Standard conditions									Mair	ntenance Co	ost
										U		/yr
	Consider effect of Ter	nperature										
	Monthly average	Erbs	model	J 4 F 5	M9 A11	м 16 J	21 J 23	A23 S19 014	N 9 D 5 V	Vind for CPV		
	From file (8760 hour	ly ∨alues)		Import					🖂 Graph			
							_					
	PV generator is connected	d to AC bus (it has its own in	verter) ->				PV inverter data				
	Annual Inflation Generator Cost	Rate for PV	-2 %	ő		Max. Vari reduction	ation of PV ger on current PV	n. Cost (e.g., for an expe gen. cost, introduce "-70	cted 70% %"): -70 s	%		
					Limit is reached	in 59.6 years						
						ОК						

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:

⊡ PV i inclu	nverter c ided in O	ostinclu &MPV c	ded in the ost	e PV co	st; PV inv	. replace	ement
Rated p	ower of the	inverter = It power of	1 f the PV to	x Pea	k power of P. of the ir	the PV ge werter	enerator
Inverte	er efficien	cy (%) o	utput pow	rer (% o	f rated):		
0%	2%	3%	4%	5%	10%	20%	30%
0	30	50	70	85	93	92	90
40% 89	50% 88	60% 87	70% 86	80% 85	90% 84	100% 83]
Efficiency (%)	96 64 32 0						
	0	20	40 Outpu	6 t power) 8 [%)	0	100
			OK				

We accept and return to the main screen of the software. By default, there can be from 0 to 8 PV generators in parallel:

MIN. AND MAX. No COMPONEI	NTS IN PARALLEL:
Bateries in parallel: Min. 1	Max. 1
PV gen. in parallel: Min. 0	Max. 8
Wind T. in parallel: Min. 1	Max. 1
AC Gen. in parallel: Min. 1	Max. 1

The default battery bank is of 48 kWh, Li-ion:

DALLENIES		- 0	
Add Bottery Zero ~			
Add Bottenes temily	Contractor College and College		
ATTERIES DATA:	Float life at 20 °C Cycles to Failure Vs. Depth of Discharge (%)		
Nome Cnom.(kAb) Volt.(V) Cost(kE) U0 Be#8kWh 1 48 7.5	MIXWJ SOChmický Selt_drivínkoný imexi(AV Eftýs) Floatyry 10% 28% 30% 40% 50% 50% 70% 80% 1 10 11 0.5 92 15 68080 30800 20080 15000 12000 10008 8571 7560	90% 100% 6667 6000	Li
atteries Model Ah I LHon model Ah Fis	d Operation and Maintenance Cost 9 6/yr Equivalent CO2 emissions (manufacturing) 55 kg CO2 eq	iv / kWh capac	ity
) KiBaM (Manwell-McGowan 1993) Au	illery cooling, BMS cons. AC (% of max. P): 0 SOC at the begining of simulation: 100 % of SOCmax DC cons. LHon batteries maximum SOC: 100 %		
Schiffer 2007			
mp. J 13 P 10 M 20 A 20 M 20 J 22 Mean PC 5 J 22 A 22 S 22 J 20 M 18 D 19 Mean PC Treash-Those the Consider Treash-Those the Consider Color the reduces SDK for wenty To PC increase Color the reduces SDK for wenty To P	9, 5, 344 9, 505 152, 786 9, 10 152, 786 152, 787 152, 787 153, 812 0, 10 10 10 10 10 10 10 10 10 10		
) Wang et al. 2011 (LinePO4)) Grott et al. 2016 (LiCoO2)) Full equivalent cycles Palantiow (cycle counting)) Neumann. 2020 (LiFePo4 cyc+cal)	Number of full equivalent cycles (only > SOCmin): 6000 Annual Inflation Rate expected for Batteries Costs: Annual Inflation Rate expected for Costs: Annual Inflation Cos	-60 %	
maining capacity at battery and of life (%): 80	Limit is reached in 45.4 years		
If there is an An AC Gen. every 14 days or 8 equivaler	full cycles → charae battery bank at least up to 95 %		

We want the possibility of not having battery in the system, changing its minimum to 0 in the main screen:

MIN. AND MAX. No COMPONEN	TS IN PARALLEL
Bateries in parallel: Min. 🛛	Max. 1
PV gen. in parallel: Min. 0	Max. 8
Wind T. in parallel: Min. 1	Max. 1
AC Gen. in parallel: Min. 1	Max. 1

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:

VVERIER/CHARGERS														-		
Add from Databas	se Ze	ro		×												
	hin form formile a								I		•	►	Þ	4		-
Include only VDC suita	wie nom iamily.				~											
GENERAL DATA									E	FFICI	ENCY	(%) v	s. OUT	PUTPO	WER (%)
GENERAL DATA	Power(kVA)	Lifespan (yr)	Cost (k€)	Imax_ch_DC(kA)	Ef_charger(%)	Vdcmin(V)	Vdcmax(V)	Pmax_ren(kW)	E 0%	2%	ЕNCY 3%	′ (%) ∨ 4%	5%	PUT PO 10%	20%	%)
GENERAL DATA Name Inv-Ch5kW	Power(kVA) 5	Lifespan (yr) 15	Cost (k€) 1.5	Imax_ch_DC(kA) 0.125	Ef_charger(%) 98	Vdcmin(V) 48	Vdcmax(V) 48	Pmax_ren(KW) 1E15	E 0% 10	2% 30	ENCY 3% 50	′(%)∨ 4% 70	r s. OUT 5% 85	PUT PC 10% 93	20% 92	%)
GENERAL DATA Name Inv-Ch5kW Inv-Ch10kW	Power(kVA) 5 10	Lifespan (yr) 15 15	Cost (k€) 1.5 2	Imax_ch_DC(kA) 0.125 0.25	Ef_charger(%) 98 98	Vdcmin(V) 48 48	Vdcmax(V) 48 48	Pmax_ren(kW) 1E15 1E15	E 0% 10 10	2% 30 30	ENCY 3% 50 50	(%) ∨ 4% 70 70	r s. OUT 5% 85 85	PUT PC 10% 93 93	20% 20% 92 92	%)
GENERAL DATA Name Inv-Ch5kW Inv-Ch10kW Inv-Ch20kW	Power(kVA) 5 10 20	Lifespan (yr) 15 15 15	Cost (k€) 1.5 2 4	Imax_ch_DC(kA) 0.125 0.25 0.5	Ef_charger(%) 98 98 98	Vdcmin(V) 48 48 48	Vdcmax(V) 48 48 48	Pmax_ren(kW) 1E15 1E15 1E15	E 0% 10 10 10	2% 30 30 30	ENCY 3% 50 50 50	(%) ∨ 4% 70 70 70 70	rs. OUT 5% 85 85 85	PUT PC 10% 93 93 93	20% 20% 92 92 92	%)

In the main screen, CONTROL STRATEGIES tab, we can see the grid-connected batteries never charge from the grid (price $E \le 0 \notin kWh$) and they discharge, injecting electricity to the grid, when the electricity price (of the energy sold to the AC grid, because "(Compare with Sell price)" is checked) is higher than $0.11 \notin kWh$ (it must be changed, default was 0), that is, always (sell electricity price was defined as a fixed value of $0.12 \notin kWh$). 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.

Project: D:\PROYECTOS IHO	GA 3.4-10-12-2022\High1.kho	- 🗆 X
Project Data Data Base Rep	oort Visual Help License Updates	
V LOAD / AC GRID	GENERAL DATA OPTIMIZATION CONTROL STRATEGIES	INANCIAL DATA RESULTS CHART
RESOURCES	CONTROL STRATEGY AND VARIABLES TO OPTIMIZE	ENERGY ARBITRAGE: System with batteries and grid connected
	Load Following	Batt. charged by the AC grid // discharged if. (also for Elyzer> H2) Elyzer. full load
HYDRO	Cycle Charging Continue up to SOC stp Try Both	Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E<= 0 Price E = 0
COMPONENTS		
🗸 PV GEN.	Variables to optimize relative to the global strategy:	
WIND TURB.	Pmin_gen Pmin_FC H2TANKstp	
HYDRO TURB.	SOCstp_gen SOCstp_FC SOCmin	Batteries can inject electricity to the AC grid
✓ BATTERIES	Pcritical_gen Pcritical_FC Plim_charge	When batteries are off, compensate autodisch.
✓ INVERTER/CHAR.	SOCmax Fix variables Variables accuracy: 5 = 10	1%
BACKUP GEN.	If SOCmin reached, disch. not allowed if SOC(%) < SOCmin(%) + 0	

In the main screen we can see the constraints to be considered in the type of projects of maximizing NPV: the maximum investment cost, in this case 1E10 k \in , that is this constraint by default is not considered; the rest of the constraints have a default value which also means that they are not considered.

Constraints under NPV maximization:



Also for the other constraints, the values set by default imply they are not considered.

If we optimize we obtain:



The optimal result is a generator of 80 kWp, without batteries and without inverter-charger, with NPV 89.916 k \in , investment of 100 k \in and internal rate of return (IRR) 14.46%.

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:

[Simulation and optimization:
	C Simulation of the 1st year and extrapolate results
	☞ Multiperiod: simulate all the years of the system lifetime (25 years) Options
	—

Click Options and:

- Uncheck "Fixed" of the Annual increase in electricity and H2 price.
- In the upper area, 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%.

MULTIPERIOD SIMULATION AND OPTIMIZATION OPTION	<u>s:</u>	Obtain re	indom value:	s for S	ELL E. price	inc.	~ Av	erage (%): 3	Std. dev	. (%): 1	
Show in the simulation during one year:	l	Obtain re	indom value:	s for In	adiation var	iation over	ave ~ Av	erage (%): 0	Std. dev	. (%): 2	
Aerage year	A	nnual increa	ase in price	es and load	d (%) / Varia	ation over	average i	n resou	rces (%) /	O&M PV	- WT (%):	
Vearnumber 1	Year	Purch.E.	Sell E.	Sell H2	Inc. AC	Inc. DC	Inc. H2	Inc. W.	Irrad.	Wind	OM.P. OM.W.	^
	1	3	4.28	3					-1.93	0		
Annual increase in electricity and H2 price:	2	3	2.46	3					-0.92	0		
(if fixed, same values as price inflations of LOAD/AC GRID)	3	3	2.88	3					1.95	0		
AC grid Electricity: Purchase: 3 %; Sell : 3 %	4	3	1.94	3					-2.01	0		
H2 sold: 3 % Each year diff. hourly sell price: Data	5	3	3.58	3					-0.5	0		
Hourly buy price = sell x 1	6	3	3.36	3					0.06	0		
Annual increase in load consumption:	7	3	5.97	3					-4.18	0		
AC: 1 % DC: 1 %	8	3	3.31	3					0.86	0		
H2: 1 % Water: 1 %	9	3	1.44	3					0.05	0		
	10	3	5	3	Fo	or variable (inselect "Fix	œd"	0.47	0	Uncheck "Fixed	
Annual decrease in generation:	11	3	1.93	3					-0.3	0		
PV:1styear: 3 %; otheryears: 1 %	12	3	3.04	3					1.79	0		
Wind Turbines: 1 %	13	3	3.52	3					1.58	0		
I hades Turbine so Dev	14	3	3.61	3					0.68	0		
nyuro rurbines: 💆 76	15	3	3.84	3					0.41	0		
Pattern and of life when expectitureduction of 20	16	3	2.79	3					-0.17	0		
	17	3	2.03	3					-0.7	0		
Annual variation over average in resources: No change	18	3	1.8	3					1.02	0		
Annual O&M for PV and Wind T.: 🔽 Fixed			-t]	_					J —		_
		ОК										

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 are different*).

#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Cost: 🔨
1	69.992	2.56	0	13.01	100	13.07	0.0769	SIMULATE	REPORT	COS

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	Cost: ^
1	69.992	2.56	0	13.01	100	13.07	0.0769	SIMULATE	REPORT	COS
2	67.536	2.56	0	12.71	101.875	13.07	0.0786	SIMULATE	REPORT	COS
3	66.717	2.56	0	12.61	102.5	13.07	0.0791	SIMULATE	REPORT	COS
4	63.443	2.56	0	12.22	105	13.07	0.0814	SIMULATE	REPORT	COS
5	61.242	2.24	0	13.01	87.5	13.07	0.0769	SIMULATE	REPORT	COS
6	58.787	2.24	0	12.67	89.375	13.07	0.0788	SIMULATE	REPORT	COS
7	57.968	2.24	0	12.55	90	13.07	0.0795	SIMULATE	REPORT	COS
8	57.819	2.67	0	11.57	109.375	13.07	0.0853	SIMULATE	REPORT	COS
9	55.368	2.67	0	11.31	111.25	13.07	0.087	SIMULATE	REPORT	cos
<										>
COMF	ONENTS: PV gen: PV10	(10 kWp_dc)x 8 (100%	PV#1: slope 60º, a	ر (» zimuth د	// Unmet load = 0	% // Total N	et Present Value (NPV) = 69.992 k	€, IRR = 13%.	~
STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. Arb.: 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.

In your project results will be different as random values are different.

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:

Ň	SOLAR RESOURCE		×.
	Latitude (º) (+N, -S) : 41.66	Get data from local DB	#1: PV panels slope (9): 60 ; PV panels Azimuth (9): 0
	Longitude (º) (+E, -W) : 0.86	Download hourly data	#2: PV panels slope (#): 60 ; PV panels Azmuth (#): U PV gen #1: 100 % Ground Beflectance: 02
	Locate on map for NASA	Download NASA data	Optimal Slope#1 Optimize PV#1 panels slope during the optimization of the system

After some seconds, we obtain the following screen, where it is shown that for this location the optimal slope for grid-connected systems is 34^o.

👔 Optimal slope for PV panels – 🗆 🗙								×			
Average daily irradiation for each month and for the whole year. Slope: 0, 15, 30, 45, 60, 75, 90° and optimal											
Azimuth (0*) is optim	al for northern latitude	35									
	Rad. 0t (KWh/day)	Rad. 15º (kWh/day)	Rad. 30º (kWh/day)	Rad. 45 [±] (kWh/day)	Rad. 60º (kWh/day)	Rad. 75º (kWh/day)	Rad. 90º (kWh/day)	Slope Opt. (*)	Rad. Slope	Opt. (kWh/c	der
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		
Мау	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 (lixed PV modules) is 63 ° Optimal slope for the whole year (no load, fix modules) is 34 °											

This optimal slope is updated automatically in the irradiation screen.

#1: PV panels slope	(*)	; PV pa
#2: PV panels slope	(#):[60	; PV pai
PV gen. #1 : 100	2	Groun
	-•	

We download hourly data from PVGIS, year 2015:

Get data from local DB	Download from:	PVGIS - Year 2015 Renewable Ninja (year 2019)				
Download NASA data	✓ Hourly Irradiation					
	Hourly Temper	ature for: 🔽 PV 🔽 Wind T. 🔲 Batt.				
n File ,	🔽 Hourly Wind Sp	peed				
	01	Cancel				

Obtaining:

SOLAR RESOURCE	- D X
Latitude (*) (+N, -S): 41.66 Get data from local DB Longitude (*) (+E, -W): -0.86 Download hourly data Locate on map Update coord Download NASA monthly d	#1: PV panels slope (*): 34 ; PV panels Azimuth (*): 0 #2: PV panels slope (*): 60 PV panels Azimuth (*): 0 PV gen. #1: 100 % Ground Reflectance: 02 Import Alb Gr. Optimal Slope#1 Optimal Slope #1
Monthly Average Import from File FROM PVGIS year 2015	Steps Wour (kWh/m2) Minutes- each hour in 1 row (tilt, in kW/m2) Minutes- 1 per row (tilt surf. in kW/m2) Import
Data Source for Monthly Average Daily Irradiation: Radiation Horizz Irradiation PV Tracking Syste av. till s. PV Tracking Syste January 472 Wybrow Factor F(I) for the	Image: No Tracking Calculation Method for Hourly Iradiation: Image: No Tracking Liu & Jordan Dack albedo Collares-Pereira & Rabl
Februray 5.01 kWh/m2) (Durusoy 2020): 0.33
Monthl March 5.36 kWh/m2 7-1	Y AVERAGE DAILY IRRADIATION, TILTED SURFACE Official hour advances:
April 6.68 kWh/m2 6-	2 h to solar hour
May 6.94 kWh/m2 5-	From day 30
June 7.18 kWh/m2 4-	
July 7.15 kWh/m2 2-	To day 20 of month 10
August 6.96 kWh/m2 1-	Winter:
September 6.13 kWh/m2 J F	M A M J J A S O N D Official hour advances:
October 5.06 kWh/m2	MONTH 1 h to solar hour
November 3.72 kWh/m2	Honzontal M lited
December 2.81 kWh/m2 Force 0 cloudy of	onsecutive days (only difuse irradiation) in month January
SHADOWS	Daily Average Irradiation (Tilt Surf.): 5.61 W/h/m2
Sacla factor (v.b.)	Total Annual Irradiation (Tilt Surf.): 2048.21 KWh/m2
Veriability minutes: correlation factor: 0.9 etd. dov: 0.2	Annual Irr. Back surface / Direct for CPV: 470.18 kWh/m2 / 1440.55 kWh/m2
	Import block (nouny, and Import block (nouny, and
OK Calculate	Graph in steps of 60 v min. Export G. tilted Export G. horiz.

 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:

👔 Load and options of Selling / Purchasing Energy from the Ad	C grid	- 🗆 X
Data source: O Monthly Average Load Profile Import File (kW, tH2/h, c	lam3/h)	Hours AC DC H2 Water Minutes- each hour in 1 row Minutes- 1 per row Import
AC LOAD (kW) DC LOAD (kW) H2 LOAD (tH2/h)	WATER (dam3/day) FROM WATER TANK	PURCHASE / SELL E
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) ✓ Fixed Buy Price (€/kWh) 0.15 Hourly Price Annual Inflation (%): Emission (kgCO2/kWh): 0.4 Fixed Pmax (kW) Fixed Cost P (€/kWlyr) 100 Options Access Charge Price (€/kWh) 0 Hourly Values Access Charge Price (€/kWh) ✓ Fixed Access price (€/kWh) ✓ Fixed Back-up price (€/kWh) ✓ Fixed Back-up price (€/kWh) ✓ Fixed Back-up price (€/kWh) ✓ Hourly Price (Will be added to the E purchessed) Add negative gen. charge	✓ Sell Excess Energy to AC grid ✓ Fixed Sell Price (€/kWh) □ Pr. sell = pr. buyx □ Annual Inflation (%): 3 Max. Power(kW) 30 = Prmax buy Energy Generation Charge (Transfer Charge) P ✓ Fixed Transfer price (€/kWh) 0 Self-consumption and Net Mettering: No net mettering Cost of net metering service (€/kWh) 0 Buy-back: Export E is paid at (€/kWh)	AC GRID AVAILABILITY Hourly Price Priority to supply E not covered by renewables: Storage/Generator AC Grid Stor /Gen. priority if Pr.buyE >= 0 Sell surplus H2 in tank (difference on the year and at the beginning) Price (C/AWh) Hourty Price Sell surplus H2 in tank (difference on the year and at the beginning) Price (C/AWh) Hourty Price Sell surplus Y
Total tax for electricity costs (buy + charges) (%):	Total tax for electricity sold (%): 0	Losses in wire and transformer (%): 0

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	66.34	1.92	0	14.37	75	14.53	0.0692	SIMULATE	REPORT	COST
2	63.916	2.24	0	13.12	87.5	13.45	0.0747	SIMULATE	REPORT	COST
3	63.884	1.92	0	13.97	76.875	14.53	0.0712	SIMULATE	REPORT	COST
4	63.135	2.35	0	12.41	99.375	14.64	0.0797	SIMULATE	REPORT	COST
5	63.066	1.92	0	13.83	77.5	14.53	0.0719	SIMULATE	REPORT	COST
6	63.021	1.6	0	15.44	62.5	15.35	0.0655	SIMULATE	REPORT	COST
7	61.461	2.24	0	12.78	89.375	13.45	0.0766	SIMULATE	REPORT	COST
8	61.173	2.35	0	12.27	98.75	14.4	0.0803	SIMULATE	REPORT	COST
9	60.642	2.24	0	12.67	90	13.45	0.0772	SIMULATE	REPORT	COST
<										>
COMP	ONENTS: PV gen: PV10	(10 kWp_dc)x 6 (100%	PV#1: slope 34º, e	/ (vzimuth ۵۹	/ Unmet load = 0	% // Total N	let Present Value (NPV) = 66.34 k€.	. IRR = 14.4%.	^
STRA (only fi	TEGY: There is no load c 'om renewable, not from g	onsumption -> no cont rid) if price of E. (sell) is	ol strategy related s lower than 0 €/KW	to the load /h; disch. (lo	consumption sup bad + injecting to t	oply. Arb.: Co the grid) if pr	ontrol variables for ice E. (sell) higher	grid-connected than 0.11 €/KWh	batteries: char	ge V

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:

<u>A</u>	В	C I) E	F G	н	1	J K	L	M	N	0	P	Q	R	S
roject: I	ligh1-multi2.khc	. Solution # 1													
SULTS	DURING THE YE	ARS OF THE SYSTEM LIFE	TIME, MULTIPERIOD S	IMULATION.											
ists and	rincomes are ca	sit flow of each year (no	c present value)												
aar		Cum Inf Rurch E/%	Cum Inf. Sell El	%) Cum In	f Sell (12/%)	AC load(%)	DC load/	0	H2 load(%)	Wa	ter load(%)	le.	rad (%)		Mind(%)
cui	1	3	4 28	, og Cum. m	3	100	De loud.	" 100	100		100		-1 93		avinu(/a)
	2	6.09	6.85		6.09	100		101	100		101		-1.93		
	3	9.27	9.92		9.27	102.01	10	01	102 01		102.01		1.95		
	4	12.55	12.05		12.55	103.03	10	1.03	103.03		103.03		-2.01		
	5	15.93	16.07		15.93	104.05	10	106	104.05		104.06		-0.5		
	6	19.41	10.07		19.11	105.1	10	15.1	105.1		105.1		0.06		
	7	22.99	27.13		22.99	106.15	10	15	106.15		106.15		-4.18		
	8	26.68	31.34		26.68	107.21	10	1 21	107.21		107.21		0.86		
	9	30.48	33.23		30.48	108.29	10	29	108.29		108.29		0.05		
	10	34.39	39.89		34 39	109.37	10	37	109.37		109.37		0.03		
	11	38.42	42.59		38.42	110.46	11	146	110.46		110.46		-0.3		
	12	42.58	46.92		42.58	111.57	11	57	111.57		111.57		1 79		
	13	46.85	52.1		46.85	112.68	11	68	112.68		112.68		1.58		
	14	51.26	57.50		51.26	113.81	11	1.81	113.81		113.81		0.68		
	15	55.8	62.64		55.9	114.95	11	1.05	114.95		114.95		0.00		
	16	60.47	68.2		60.47	116.1	1	6.1	116.1		116.1		-0.17		
	17	65.28	71.62		65.28	117.26	11	1.26	117.26		117.26		-0.17		
	19	70.24	74.71		70.24	119.42	11	1.43	118.43		118.42		1.02		
	10	75.25	77.71		75.25	110.45	11	1.61	110.45		110.45		-0.02		
	20	80.61	81.34		80.61	120.81	11	1.81	120.81		120.81		-4.03		
	21	86.03	87.59		86.03	122.02	12	1.02	122.02		122.02		-2.31		
	22	01.61	07.09		01.61	122.02	12	1.24	122.02		122.02		0.44		
	22	97.36	92.50		97.36	124.47	12	47	123.24		124.47		-0.58		
	24	102.28	109.12	1	03.28	125.72	12	72	125.72		125.72		0.19		
	25	100.20	117.00		00.20	126.07	12	07	126.97		126.07		0.91		
	multi2	E)	117.04			100.0		:	4		170.37				



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:

MIN. AND MAX. No COMPONEN	NTS IN PARALLEL:
Bateries in parallel: Min. 1	Max. 1
PV gen. in parallel: Min. 0	Max. 8
Wind T. in parallel: Min. 1	Max. 1
AC Gen. in parallel: Min. 1	Max. 1

We optimize again:

[_	-				
#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs A				
1	63.135	2.35	0	12.41	99.375	14.64	0.0797	SIMULATE	REPORT	COST				
2	61.173	2.35	0	12.27	98.75	14.4	0.0803	SIMULATE	REPORT	COST				
3	60.209	2.35	0	12.05	101.875	14.69	0.0819	SIMULATE	REPORT	COST				
4	59.751	2.67	0	11.53	111.875	13.67	0.0843	SIMULATE	REPORT	COST				
5	59.746	2.03	0	12.91	86.875	15.3	0.0778	SIMULATE	REPORT	COST				
6	6 58.779 2.03 0 12.84 86.25 15.15 0.0779 SIMULATE REPORT COS													
7	58.405	2.67	0	11.45	111.25	13.46	0.0846	SIMULATE	REPORT	COST				
8	57.219	2.67	0	11.25	114.375	13.73	0.0861	SIMULATE	REPORT	COST				
9	56.553	2.03	0	12.46	89.375	15.32	0.0804	SIMULATE	REPORT	COSI				
										*				
<										>				
COMP	ONENTS: PV gen: PV10	(10 kWp. dc)x 7 (100%	PV#1: slope 34% a	izimuth 0≗) /	// Batteries Bat48k	(Wh (1 kAh))	1s x1n // Bat Inv	/erter Inv-Ch10k	W of 10 kVA //	Unmet 🔥				
load =	0 % // Total Net Present \	/alue (NPV) = 63.135 k	€, IRR = 12.4%.		,		terripitt maxim							
STRA	TEGY: There is no load c	onsumption -> no conti	rol strategy related	to the load	consumption sup	oply. SOC m	in.: 10 %. Arb.: Con	trol variables for	r grid-connecte	d				
batteri	es: charge (only from rene	ewable, not from grid) if	price of E. (sell) is	lower than	0€/kWh; disch. (li	oad + injecti	ng to the grid) if pri	ce E. (sell) highe	er than 0.11 €/k\	Nh				

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 PDF tab. In the third tab, the PDF (probability density function) graphs, by default, are not shown. To show them, go to the OPTIONS (main menu of the software, Project -> OPTIONS) and check the box "In the simulation window, show the probability density function (PDF) of the main results":

In the simulation window, show the probability density function (PDF) of the main results

When this option is selected, we see something like the following figure in the third tab of the simulation screen: probability density functions of the power (or energy for the battery) of the components.



We can see the most of the time the PV generating power is 0 (night time), same for export power, battery bank charge, discharge, energy in battery bank (SOC minimum the most of the time) and sold power to AC grid. It is because PV generation is 0 during no irradiation hours. If we uncheck (upper right area) "**Show PDF first col.**", we will see all the columns except the first one, which is the one of 0. We can see the PV generation PDF curve for the daytime hours of the year, and also the rest of the PDF curves without the first column.



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.

\widetilde{M} Load and options of Selling / Purchasing Energy from the A	C grid	- 🗆 ×
Data source: O Monthly Average Load Profile Import File (kW, tH2/h,	dam3/h)	O Hours AC DC H2 Water Minutes-each hourin 1 row Import Export
AC LOAD (kW) DC LOAD (kW) H2 LOAD (tH2/h)	WATER (dam3/day) FROM WATER TANK	PURCHASE / SELL E
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Fixed Buy Price (¢,/kWh) 0.15 Hourly Price Annual Inflation (%): Emission (kgC02/kWh): 3 0.4 Emissions data ✓ Fixed Prmax (kW) Fixed Cost P (¢,/kW/yr) 100 Options 0 Hourly Values Access Charge Price (¢,/kWh) ✓ Fixed Access price (¢,/kWh) ✓ Fixed Back-up price (¢,/kWh) ✓ Add negative gen. charge (Will be added to the E purchased) Add negative gen. charge	Sell Excess Energy to AC grid Fixed Sell Price (¢/kWh) Pr. sell = pr. buyx Annuel Inflation (%): Max Power(kW) Charge (Transfer Charge) P Fixed Transfer price (¢/kWh) Self-consumption and Net/Mettering: No net mettering Cost of net mettering service (¢/kWh) Buy-back: Export E is paid at (¢/kWh)	AC GRID AVAILABILITY Hourly Price Priority to supply E not covered by renewables: (*) Storage/Generator StorAge/Generator StorAge/Generator CGRID AVAILABILITY Priority to supply E not covered by renewables: (*) Storage/Generator StorAge/Generator StorAge/Generator StorAgen/Generator Price (C/kg) Hourly Price Sell only V
Total tax for electricity costs (buy + charges) (%):	Total tax for electricity sold (%):	Losses in wire and transformer (%): 0

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.

When iHOGA imports a file, the decimal spacing of the values of the file must ALWAYS BE DOT (.). If you open the downloaded file, you will see the dot as the decimal spacing. Even if your computer uses comma as decimal spacing, in the files that iHOGA will import the DECIMAL SPACING MUST BE DOT (.).

Frouny, all days the same From file (8760 bourt-walues)		Graph 🖾 D.max-mi
Houny Periods	Import hourly Price	E PDF

After importing the file, you can click in the button "Graph" and see the hourly sell price:



In all the graphs, you can **zoom** in the graph (draw a window with your mouse over the area to be enlarged: click from top left to bottom right); later you can undo the zoom (click and drag from bottom right to top left).

We can see that average hourly price is 0.06 €/kWh, its maximum is 0.329 and its minimum 0.001 €/kWh.

Click "Back".

With the button "**PDF**" it shows the probability density function (PDF) of the price, showing also (below the graph) the mean and standard deviation (and, with these values, it shows in green the Gaussian curve). Next figure shows an example, where most of the time price is near 0, and also there is a lot of hours with price around $0.06 \notin kWh$; the Gaussian curve does not fit well in this case (that is, the original data does not follow a Gaussian normal PDF).



Click "OK".

With the button "**D.max-min**" it shows, for each day, the difference between the maximum price and the minimum price of that day. This graph is interesting to see the daily price difference (max.-min.), important for arbitrage energy cases (for example, charging batteries at low price hours and discharging during hours at high price hours). Showing 365 days display, se can see many days, in this example of prices, the difference is higher than $0.2 \notin$ /kWh, which could make profitable (in some cases) the energy arbitrage:



With the button "**PDF Dm-m**" it shows the probability density function (PDF) of the previous graph (values of difference between the maximum price and the minimum price of that day), showing also the mean and standard deviation (and, with these values, it shows in green the Gaussian curve). In next figure we can see that, in this case, the most of the values (difference between max. and min. price for each day) is around 0.18 €/kWh, and the PDF curve is not very different from a Gaussian PDF curve.



Click "**OK**" to return to the options of selling electricity to the AC grid.

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:

1	ŧ	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs 🔨
	1	-8.044	2.35	0	0	99.375	14.3	0.0816	SIMULATE	REPORT	COST
		04 4 3 9	0.05		10.07	00.35		0.0000	OB U U ATE	DEDODT	0007

And the NPV now is negative, 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€:

N PV GENERATORS									— (
Add PV Gen. Zero Add PV Gen. family PHOTOVOLTAIC GENERATOR	e data:	~ ~	K (•	▶ +	-				
Name I PV10-	Power(kWp_dc) 10	Cost(k€) 5	C.O&M(%/yr)	Life(years) 25	NOCT(°C) 43	Power T. coef.(%/*C) -0.4	BIFACIALITY(0-1)	CPV NO	Emissions(kgCO2/ 800	'kWp)

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 positive, i.e., profitable system.

#		Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	In∨estment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs 🔨
	1	40.688	2.35	0	13.22	55.625	14.3	0.0465	SIMULATE	REPORT	COST

Maybe the optimal control strategy is not the one that was set. In the main screen, CONTROL STRATEGIES tab, "(**Compare with 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.

Global strategy: ■ ● Load Following ■ ○ Cycle Charging □ Continue up to SOC stp ■ ○ Try Both ■	Elyzer. full load npare with Sell price
Cycle Charging Continue up to SOC stp Try Both O Try Both	Elyzer. full load
○ Cycle Charging ○ Continue up to SOC stp ○ Try Both ✓ Optimize strategy of grid-conneted batteries: ● 3 variables: X1(dif), X2(%), X1:min, 0.029 max, 0.3251 €/k	mpare with Sell price
○ Try Both ○ Optimize strategy of grid-conneted batteries: ● 3 variables: X1(dif), X2(%), X1:min, 0.029 max, 0.3251 €//	
● 3 variables: X1(dif.), X2(%), X3(%), X1:min, 0.029 max, 0.3251 €/	1
Variables to optimize relative to the global strategy:	/kWh
Pmin_gen Pmin_FC H2TANKstp Q variables: price E. min. and max Min > 0.0008 ; Max< 0.3615 6/h	/kWh 🗌 PrCh <pr< th=""></pr<>
P1_gen P1_FC P2	
SOCstp_gen SOCstp_FC SOCmin I dev stlow SOC-2 charge battary with 4C grid	
Pcritical_gen H2TANKstp Plim_charge Batteries are off, compensate autodisch.	ability

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 (to avoid spending too much time following this guide), 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:

Ň	INVERTER/CHARGERS														-		×
	Add from Database	e from family:	ro		•	•				M	ء •	• •	ı +	- 4	· ~	% ୯]
	GENERAL DATA									EF	FICIE	NCY (%) vs.	OUTP	UT POV	VER (%)	->
Д	Name	Power(kVA)	Lifespan (yr	Cost (k€)	lmax_ch_DC(kA)	Ef_charger(%)	Vdcmin(V)	Vdcmax(V)	Pmax_ren(kW)	0%	2%	3%	4%	5%	10%	20%	:0:
Þ	Inv-Ch10kW	10	15	2	0.25	98	48	48	1E15	10	30	50	70	85	93	92	L .
l			J														
~																	
					MIN. AND MAX	. No COMPO	NENTS IN	PARALLEL									
					Bateries in paral	lel: Min. 1	Max.	1									
					PV gen. in paral	lel: Min. 6	Max.	8									
					Wind T. in paral	lel: Min. 📘	Max.	1									
					AC Gen. in para	lel: Min. 📘	Max.	1									

Now the optimizing time will be several minutes. Save and calculate. We get:

#	Total NPV (k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	IRR(%)	Investment(k€)	Cap.F(%)	LCOE(€/kWh)	Simulate	Report	Costs ^
1	42.069	2.35	0	13.4	55.625	14.1	0.0473	SIMULATE	REPORT	COST
2	40.418	2.67	0	12.52	61.875	13.05	0.0496	SIMULATE	REPORT	COST
3	40.018	2.03	0	13.96	49.375	14.93	0.0463	SIMULATE	REPORT	COST
	_									~
<										>
COMF Unme	PONENTS: PV gen: PV10- t load = 0 % // Total Net Pr	(10 kWp_dc)x 7 (100% esent Value (NPV) = 4	5 PV#1: slope 34⁰, 2.069 k€, IRR = 13.	azimuth 0º) 4%.	// Batteries Bat48	kWh (1 kAh)	::1s.x1p.// Bat.In	verter Inv-Ch10k	W of 10 kVA //	^
STRA batteri	TEGY: There is no load c es: X1=0.029(sell) €/kWh; >	onsumption -> no cont K2=20%; X3=40%. Disc	rol strategy related charge: load + inje	to the load cting to the	consumption sup grid	ply. SOC m	in.: 10 %. Arb.: Con	trol variables fo	r grid-connecte	d

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. the 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 (that is, when there is surplus power which cannot be injected to the grid) and the turbine will run when the sell electricity

price is high. Let's suppose that the water reservoir maximum capacity is 80 dam³ and the elevation head is 31 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 only be considered if we had just a turbine that generates power with the available water flow, that is, run-of-the-river hydro; this is not our case as we are using PHS in this project).

Now, in the main screen, click in "! HYDRO TURB" button.

₩ HYDRO TURBINES	- 🗆 X
Add from Database Zero V	•
	EFF. TURBINE (%) vs. FLOW (% of F max.)
Name Pnom kW/ Max.flow(m3/s) Min. height (m) Max.flow(m3/s) Idespan (vr) C. O. Tur10kW 10 0.04 25 3 25 30	&M (%/yr) 0% 10% 20% 30% 40% 50% 60% 70% 60% 90% 100% 1 0 0 60 80 90
Check that reversible pump/turbines are suitable for an available head of 27.9 - 34.1 m. Available head of 27.9 - 34.1 m. Available head of 27.9 - 34.1 m. Available head of pump-turbine or pump and turbine different machines).	Tur10kW, F=0.04m3/s, Pnom=10kW; Pmax (max, height 35m)=10.9kW
In that case, data from HYDRO resource will not be considered. Water tank and pumping data (elevation head, friction losses, pumping efficiency and pump minimum load) considered will be the ones shown in the LOAD/AC GRID window (Water tab). Water will be pumped from reservoir when there is renewable energy or when settled by the control strategy: turbine will generate electricity when water consumption or when settled by control strategy IN PHS: Reversible Pump-Turbine, data here. Same height and friction losses (data in LOAD/AC grid, water)	96 88 72 (%) 64 50 56
Supply load with turb. when load > 50 % P. turb. and Water T.> 30 %	
Multiplier Gearbox Efficiency: 98 % Electrical Generator Efficiency: 90 %	U 10 20 30 40 50 60 70 80 90 100 % MAX.FLOW
Emissions CO2 equiv. (manufacturing) 5 g CO2 equiv. / KWh generated	

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 "PHS: Reversible Pump-Turbine, data here...."

PHS: Reversible Pump-Turbine, data here. Same height and friction losses (data in LOAD/AC grid, water)

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 \in . Then, change the name of the machine (for example "Tur10kW-M") and later change the cost to 70 k \in .



Check that reversible pump/lurbines are suitable for an available head of 27.9 - 34.1 m. Available head must be between Min. height and Max. height of the turbine

We can see that this machine the maximum flow is $0.04 \text{ m}^3/\text{s}$, and the minimum and maximum height are 25 and 35 m. In our case the available head will be 31 m, which, + 10% losses implies a max. pumping head of 34.1 m, while when turbine runs the min. head is 31 m -10% losses, 27.9 m. As our turbine has 25 m for min. height and 35 for max. height, 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.density.g.height_max.Total_Efficiency =

 $=0.04m^{3}/s \cdot 1000kg/m^{3} \cdot 9,81m/s^{2} \cdot 35m \cdot 0.9 \cdot 0.98 \cdot 0.9 = 10902 W = 10.9 kW$

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 dam³), the capacity at the beginning of the simulation (let's suppose it is at 50%, that is, 40 dam³), the elevation head (31 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.

\widetilde{M} Load and options of Selling / Purchasing Energy from the AC grid	- 🗆 X
Data source:	Hours AC DC H2 Water
O Monthly Average () Load Profile O Import File (kW, tH2/h, dam3/h)	Minutes- each hour in 1 row Import Export
AC LOAD (kW) DC LOAD (kW) H2 LOAD (tH2/h) WATER (dam3/day	FROM WATER TANK PURCHASE / SELL E
DAILY WATER CONSUMPTION (dam3/day);	
January 0 (0 MWh/day) July 0 (0 MWh/day) 0 h	1h 2h 3h 4h 5h 6h 7h 8h 9h 10h 11h
February 0 (0 MWh/day) August 0 (0 MWh/day) 2	2 2 2 2 2 10 5 5 3 3 4 DEFINE ~
March 0 (0 MWh/day) September 0 (0 MWh/day) 12 h	13h 14h 15h 16h 17h 18h 19h 20h 21h 22h 23h Total
April 0 (0 MWh/day) October 0 (0 MWh/day)	
May 0 (0 MWh/day) November 0 (0 MWh/day)	HOURLY WATER CONSUMPTION (% OF THE DAY)
June 0 (0 MWh/day) December 0 (0 MWh/day)	
Scale factor for Monday - Friday: 1 For the Weekend: 1	0 6 18 Variability minutes (%): 90
WATER TANK:	hour
Water tank capacity: 80 dam3; min. (%); 0 ELECTRICAL	<u>_PUMP:</u>
Capacity at the begin ing of the simulation (%: 50 Inlet Hydro res. Pump electric	cal rated power: 0 KW Pump minimum power: 0 % of rated
	Pump power = hydro turb. power) Priority to pump if surplus P > 0 % P. pump.
Elevation head + evident lift: 1 m Extra pump	fficiency 80 % Var Pump eff.
Friction Losses: 10 %	

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·density·g·height·(1+friction_losses)/Efficiency =

 $=80000m^{3} \cdot 1000kg/m^{3} \cdot 9.81m/s^{2} \cdot 31m \cdot (1+0.1)/0.8 = 3.34521 \cdot 10^{10} J = 9.2922 MWh$

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):

MIN. AND MAX. No COMPONE	NTS IN PARALLEL:
Bateries in parallel: Min. 0	Max. 1
PV gen. in parallel: Min. 7	Max. 7
Wind T. in parallel: Min. 1	Max. 1
AC Gen. in parallel: Min. 1	Max. 1

Click in CALCULATE, and, after several minutes (control strategy is optimized), we obtain 2 results of combinations of components:

#	Total NPV (kf)	Emission (tCO2Av)	Linmet(MM/hAv)	IBB(%)	Investment(kf)	Can E(%)	LCOE(#JAMb)	Simulato	Benort	Coete A
π	тощини т (ко)		Chine((www.yy)	11 (70)	investment(Ko)	Oup.(76)	LOOL(QKWII)	omulae		COata M
1	-35.907	2.28		0	133.75	12.15	0.1084	SIMULATE	REPORT	COST
2	-38.103	2.38	0	0	143.125	12.22	0.1169	SIMULATE	REPORT	COS1
<										>
COMF kVA // STRA batter	ONENTS: PV gen: PV10- Unmet load = 0 % // Tota TEGY: There is no load c es: X1=0.029(sell) €/KWh; X	(10 KWp_dc)x 7 (100% I Net Present Value (N onsumption -> no cont X2=20%; X3=40%, Disc	5 PV#1: slope 34º, PV) = -35.907 k€, II rol strategy related charge: load + inje	azimuth 0º) RR = 0%. I to the loac cting to the	// Hydro Turb. Af I consumption sup grid	C Tur10kW-M oply. Arb.: Co	√ of 10 kW, 0.04 m ontrol ∨ariables for	3/s // Bat. Inverti grid-connected	er Inv-Ch10kW hdro turb./pum	of 10 ^
										\sim

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 uncheck "Inverter/cha", as the electrolyzer has its own rectifier defined in its screen.

COMPONENTS	
✓ PV Gen.	
Wind Turbines	
Hydro T.	
Battery bank	
Backup Gen.	
Inverter/char.	
✓ H2 (F.C Elyzer.)	

And then click in the button "H2 (F.C. – Elyzer.)":

ctrolyzers	H2 Tank									
				Generation of	H2 by electri	cal energy	Data to mo	dify the consu	mption and effici	ency curv
Add from I	Database	Zero	~		N N	-	Curves cha	ange in H2 mass	flow limit (% of rat	ed): 100
					P PI	•			Factor_efficien	y: 0.45
_	Name	P. Nom(kW)	Acq. cost (kf)	C D8M(RAR)	Lifesnen (ur)		B (WW/ka/b)	P min (%)		
E	Elvzer5kW	5	20	2500	20	40	10	20		
(M) 4.096 3.072 2.048 1.024 U 0	Elyzer5k	W. Consumption(kW) (0.06 0.0	4V) 80 40 8 0.1	Poww Wate Stac Cold Lifeti @y	er consumption in er cost (€/kg_H2): < replacement co start time (min): [me and O&M cos ears and €/yr lours and €/h	stand+by: 10 0 st (% of acq. cost 20 : Each sts data:	% of nominal p : 40 cold start equiv. t Elec	o extra ageing (min) tricity DC	ability : 100
ominal H2 n Equ Cor	nass flow = 0.1 k ivalent CO2 em mpression ele	g/h; It is needed at leases in the second seco	g fuel cells and ele	ate H2 actrolyzers): 330 ity ner kn H2);	kg CO2 e 0	quiv. / kW rated p	ower	H ₂	н ₂ о	
nnual Inflatio	n Rate for Fuel (Cells, Electroi y.co.co	-10 %	max expe	Variation of Fue cted 90% reduc	I Cells, Electrolyz	ers and H2 Tanks st. introduce "-90?	s Cost (e.g., for ar ś"):	-90 %	
				Limit is reached	d in 21.9 years					

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 $5 \cdot 0.1 = 0.5$ 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)>

trolyzer	5 H2 Tank									
Add fro	ım Database	Zero	~	Generatio	on of H2 by el	ectrical energy				
				I 4 🕨	▶ + =	▲ ✓ × (•			
	Name	Pot. Nom(kW)	Acq. cost (k€)	I ⊲ ► C. O&M (€/yr)	▶ 🕈 = Lifespan (yr)	▲ ✓ × (B (KW/kg/h)	Pot. min. (%)	^	
E	Name Ilyzer5kW	Pot. Nom(kW) 5	Acq. cost (k€) 20	 I C. O&M (€/yr) 2500 	Lifespan (yr)	▲ ✓ × (A (kW/kg/h) 40	B (kW/kg/h) 10	Pot. min. (%) 20	^	

In the bottom right corner of the screen, click in "**Inverter and rectifier data**" button, the next window appears:

ELECTROLYZER: Efficiency of the rea	ctifier of the	electroly	zer: 90	%		
FUEL CELL:						
Efficiency of the inv	verter of the	Fuel Cel	l (%) vs O	utput pow	er (% of ra	ited):
0% 2%	3%	4%	5%	10%	20%	30%
0 30	50	70	85	93	92	90
40% 50%	60%	70%	80%	90%	_100%	
89 88	87	86	85	84	83	
		OK				
0% 2% 0 30 40% 50% 89 88	3% 50 60% 87	4% 70 70% 86 OK	5% 85 85 85	10% 93 90% 84	20% 92 100% 83	30% 90

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 (set this value):

Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): 330 Leg 000 uv. / KW rated power Compression electrical consumption (KWh electricity per kg H2): FUEL CELL FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an H2 Tanks C	Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): 330 Ltg corruption (kWh electrolyzers): 330 Ltg corrupt	Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): ³³⁰ Compression electrical consumption (KWh electricity per kg H2): Electrolyzer + H2 TANK FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and -10 % Max Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an -90 % Limit is reached in 21.9 years Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data	Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): ³³⁰ Compression electrical consumption (kWh electricity per kg H2): FUEL CELL ELECTROLYZER + H2 TANK Annual Inflation Rate for Fuel Cells, Electrolyzers and -10 % Max Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce "-90%"): Limit is reached in 21.9 years Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data OK	Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): 330Ho goes uiv. / KW rated power Compression electrical consumption (KWh electricity per kg H2): 5ELECTROLYZER + H2 TANK Annual Inflation Rate for Fuel Cells, Electrolyzers and -10 % Max Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an H2 Tank Cost :								
Compression electrical consumption (KWh electricity per kg H2): FUEL CELL FUEL CELL FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an H2 Tanks Cost (e.g	Compression electrical consumption (kWh electricity per kg H2): Image: Compression electrical consumption (kWh electricity per kg H2): Image: Compression electrical consumption electricity per kg H2): Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an H2 Tanks Cost (e.g., for an H2 Tanks Cost (e.g., for an expected 30% reduction on current cost introduce "-90%"): -90 % Limit is reached in 21.9 years Limit is reached in 21.9 years -90 %	Compression electrical consumption (kWh electricity per kg H2): Image: Second seco	Compression electrical consumption (kWh electricity per kg H2): Image: State of the state	Compression electrical consumption (kWh electricity per kg H2): ELECTROLYZER + H2 TANK Annual Inflation Rate for Fuel Cells, Electrolyzers and 10 % Max Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce "90%"): Limit is reached in 21.9 years Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Kerter and rectifier data Ker	Equivalent CO2 emissions (manufacturing fuel cells and electrolyzers): 330 🔁 the CO2 emissions (manufacturing fuel cells and electrolyzers): 330							
FUEL CELL FUEL CELL FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an H2 Tanks	FUEL CELL Image: Control of the con	Image: State of the state	FUEL CELL Image: Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce "-90%"): Limit is reached in 21.9 years	FUEL CELL FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H0 N Tank Cost Max. Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce "-90%"): Limit is reached in 21.9 years Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data OK	Compression electrical consumption (KWh electricity per kg H2)							
FUEL CELL FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tank Cost -10 % Max Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce *90%"):	Image: Product of State for Fuel Cells, Electrolyzers and H2 Telectrolyzers	Image: PUEL CELL Image: PUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and P12 Tanks Cost (e.g., for an P12 Tanks Cost (e.g.	□ FUEL CELL □ FUEL CELL Annual Inflation Rate for Fuel Cells, Electrolyzers and H10 Max. Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce "-90%"): Limit is reached in 21.9 years	Image: Production of Fuel Cells, Electrolyzers and Production on current cost, introduce "-90%"): Image: Production of Fuel Cells, Electrolyzers and Production of Fuel Cells, Electrolyzers and Production on current cost, introduce "-90%"): Image: Production of Fuel Cells, Electrolyzers and Production on current cost, introduce "-90%"): Image: Production of Fuel Cells, Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data								
Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce "-90%"):	Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce "-90%"): Limit is reached in 21.9 years	Annual Inflation Rate for Fuel Cells, Electrolyzers and 10 % Max. Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce **90% "): Limit is reached in 21.9 years	Annual Inflation Rate for Fuel Cells, Electrolyzers and 10 % Max. Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce *90%*): Limit is reached in 21.9 years Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Newtown of their inverter and rectifier respectivelly) Newtown of their inverter and rectifier respectivelly Newtown of their inverter and rectifier respectivelity Newtown of their inverter and rect	Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost introduce *.90%"): Limit is reached in 21.9 years								
		Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data	Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data OK	Fuel Cell and Electrolyzer are connected to AC bus (by means of their inverter and rectifier respectivelly) Inverter and rectifier data OK	Annual Inflation Rate for Fuel Cells, Electrolyzers and H2 Tank Cost: Max. Variation of Fuel Cells, Electrolyzers and H2 Tanks Cost (e.g., for an expected 90% reduction on current cost, introduce "-90%"): -90 %							

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 \in /kWh) and the sell price also the default value (0.12 \in /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 \in /kW.

Also click on "Sell surplus H2 in tank..." to indicate we want to sell the H2 produced, and leave the default price of $10 \notin$ kg and annual inflation of 3% for that price.

Load and options of Selling / Purchasing Energy from the AC Data source: OMonthly Average O Load Profile O Import File (kW, 1H2/h, d	am3/h)	- C X
AC LOAD (kW) DC LOAD (kW) H2 LOAD (tH2/h)	WATER (dam3/day) FROM WATER TANK	PURCHASE / SELL E
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Fixed Buy Price (¢/kWh) 0.15 ourly Price Annual Inflation (%): Emission (kgCO2/kWh): 3 0.4 Emissions data ✓ Fixed Prmax (kW) Fixed CostP (¢/kWh) 3 0ptions 40 Horky Values Accessor Charge Drice (¢/kWh) ✓ Fixed Access price (¢/kWh) Ø Fixed Access price (¢/kWh) ✓ Fixed Access price (¢/kWh) Ø Hourly Price Back-up Charge Price (¢/kWh) Ø Hourly Price (Will be added to the E purchased) Add negative gen. charge	Sell Excess Energy to AC grid Fixed Sell Price (£/kWh) Pr. sell = pr. buy x Annual Inflation (%): 3 Max. Power(kW) 30 =Pmax buy Energy. Generation Charge (Transfer Charge) Pr Fixed Transfer price (£/kWh) U Self-consumption and Net Mettering: No net mettering Cost of net metering service (£/kWh) U Buy-back: Export E is paid at (£/kWh) U	AC GRID AVAILABILITY Hourly Price
Total tax for electricity costs (buy + charges) (%):	Total tax for electricity sold (%):	Losses in wire and transformer (%): 0

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.

V PARAMETERS OF THE OPTIMIZATION
MAIN ALGORITHM (OPTIMIZATION OF COMPONENTS)
OPTIMIZATION METHOD:
⊖ GENETIC ALGORITHMS
GENETIC ALGORITHM:
Generations: 15 Population: 10
Crossover rate: 90 % Mutation rate: 1 % Mutation Uniform
STOPPING CRITERION:
Stop execution of main algorithm if after 15 generations
it cannot improve 1 % in 5 consecutive generations
EVALUATE ALL COMBINATIONS:
Display best: 18

OK, save and then CALCULATE.

The optimal system is the same as the one of project "High1-multi-2", but with a lower NPV due to the extra cost of the contracted 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	64.442	1.92	0	14.18	75	14.53	0.0707	SIMULATE	REPORT	COST			
2	62.018	2.24	0	12.94	87.5	13.45	0.0762	SIMULATE	REPORT	COST			
3	61.123	1.6	0	15.2	62.5	15.35	0.0673	SIMULATE	REPORT	COST			
4	56.712	2.56	0	11.78	100	12.41	0.0823	SIMULATE	REPORT	COST			
5	50.409	1.28	0	15.5	50	15.57	0.0667	SIMULATE	REPORT	COST			
6	37.346	0.96	0	15.4	37.5	15.57	0.0675	SIMULATE	REPORT	COST			
7	24.264	0.64	0	15.21	25	15.57	0.0689	SIMULATE	REPORT	COST			
8	11.183	0.32	0	14.61	12.5	15.57	0.0733	SIMULATE	REPORT	COST			
9	11.044	3.27	0	6.07	112.5	13.19	0.1296	SIMULATE	REPORT	COST			
<										>	Ý		
COMP	COMPONENTS: PV gen: PV10 (10 kWp_dc)x 6 (100% PV#1: slope 34%, azimuth 0%) // Unmet load = 0 % // Total Net Present Value (NPV) = 64.442 k€, IRR = 14.2%.												
STRA (only fi	TEGY: There is no load co om renewable, not from g	onsumption -> no cont rid) if price of E. (sell) i:	rol strategy related s lower than 0 €/kW	to the load /h; disch. (lo	consumption sup bad + injecting to t	oply. Arb.: Co he grid) if pr	ontrol variables for ice E. (sell) higher	grid-connected than 0.11 €/kWh	batteries: char	ge	~		

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 0.1107 tons, that means that the H2 sold during each year is that value (annual average value of the 25 years).

P. PV (kWp_dc)	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	1×0	0	0 0	0
7x10	34	0	1x0	0	1×0	0	0 0	0
5×10	34	0	1x0	0	1x0	0	0 0	0
8×10	34	0	1×0	0	1x0	0	0 0	0
4x10	34	0	1×0	0	1×0	0	0 0	0
3x10	34	0	1×0	0	1x0	0	0 0	0
2x10	34	0	1×0	0	1x0	0	0 0	0
1x10	34	0	1×0	0	1x0	0	0 0	0
7x10	34	0	1×0	0	1x0	0	0 5	0.1107
<								, *

Solution number 9 NPV is 5.225 k€, much lower than the optimal solution, therefore in this case it is not optimal generating H2 with the excess energy.

9 11.044 3.27 0 6.07 112.5 13.19 0.1296 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 (click "R" in the checkbox next to "E H2 tank (HHV H2)" to see the energy of the hydrogen tank in the right axis):



The hydrogen tab, for 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:

Simulation and optimization:	
◯ Simulation of the 1st year and extrapolate results	
Multiperiod: simulate all the years of the system lifetime (25 years) Option:	3
Economic optimization:	
Minimize Net Present Cost (NPC), usually for off-grid systems and high load on-grid>	Min. NPC
	Min. LCOH
Maximize Net Present Value (NPV), usually for low load or no-load on-grid systems	Max. NPV
DC renewable include own charger and controller	O Min. LCOE O Min. LCOH Max. Cap.F. min. LCOE Max. IPP
When saving the project, update all the results of the table to the present conditions	U MIDC IFIT
Number of decimal places in results of costs 3 ~	
Number of decimal places in results of energy 3 V	
OK	

In the LOAD/ AC GRID screen, we add AC load, residential load of 100 kWh/day:

Load profile:	Zero 💌
	Zero
	Residential 100kWh/day
* anability	VILLAGE 100kWh/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.

Data source: O Monthly Average O Load Profile O Import File (KW, tH2/h, dar	n3/h)	Hours AC DC H2 Water		
CLOAD (kW) DC LOAD (kW) H2 LOAD (tH2/h)	WATER (dam3/day) FROM WATER TANK	PURCHASE / SELL E		
Purchase from AC grid Unmet Load (Non Served Energy by Stand-alone system) Fixed By Price (c/kWh) 0.15 Hourly Price Annual Inflation (%): Emission (kgC02/kWh): 3 0.4 Fixed By Price (C/kWh) Emissions data Fixed Reve (W) Fixed Cost P (c/kWk/yr) 100 Options Price (C/kWh) Hourly Values Access Charge Price (c/kWh) Hourly Price Back-up Charge Price (c/kWh) Hourly Price Will be added to the E purchased) Add negative gen. charge	Sell Excess Energy to AC grid Fixed Sell Price (6/kWh) Pr. sell = pr. buy x Annual Inflation (%): Max. Power(kW) Dut Prmax buy Energy Generation Charge (rionser crionge) Price Fixed Transfer price (6/kWh) Fixed Transfer price (6/kWh) Self-consumption and Net Mettering: No net mettering Cost of net metering service (6/kWh) Buy-back: Export E is paid at (6/kWh)	AC GRID AVAILABILITY ourly Price Image: Storage/Generator AC GRID AVAILABILITY Image: Storage/Generator AC Grid Image: Storage/Generator Image: Storage/Generator Image: Storage: Storage Image: Storage: Storage: Storage Image: Storage: Storage: Storage: Storage Image: Storage: Storage: Storage: Storage: Storage Image: Storage: Storage: Storage: Storage: Storage Image: Storage: Storage: Storage: Storage: Storage: Storage Image: Storage:		

Then click on "**Hourly Price**" button close to the buy price. Select **Hourly Periods** and accept all the default values (3 periods):

HOURLY PRICE OF THE ELECTRICITY PURCHASED FROM THE AC GRID					
Hourly Price Data (€/kWh)					
C Hourly, all days the same The sam					
Hourly Periods: Number of Hourly Periods: 3 - 6 Summer/Winter C Mon-Fri/Weekend C Hourly (from file)					
Summer calendar: Period P1 Price: 0.15					
From day 30 month 3 Period P2 Price: 0.12					
To day 26 month 10 Period P3 Price: 0.08					
SUMMER periods distribution:					
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					
WINTER periods distribution:					
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					
OK					

OK and, in the **PURCHASE / SELL E** tab, click "Hourly Values" close to the options of the contracted power Pmax.

Fixed P	max (kW)	Fixed Cost P (€/kW/	yr)
100	Options	0	Hourly Values

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):

Hourly periods same of energy hourly price periods				
	Pmax (kW)	Cost of Power (€/kW/yr)		
Period P1	60	40		
Period P2	80	20		
Period P3	90	15		
Period P4	0	0		
Period P5	0	0		
Period P6	0	0		
		OK		

OK and, in the **PURCHASE / SELL E** tab, click "**Options**" close to the options of the contracted power Pmax.

Fixed Pmax (kW)		Fixed Cost P (€/kW/yr)		
100	Options	D	Hourly Values	

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 optimization, only valid for period P1), or the third option, which will be the one selected **"Not limited: Registered the maximum value (average of....**"

Options for the maximum peak power from the Grid:
Value of Pmax:
C Limited to value shown in Pmax
C Limited to a value optimized between 0 and Pmax. Number of values to consider: 5
Not limited: Registered the maximum value (average of 15
OK

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 "maximeter"):

COST OF THE CONTRACTED POWER:
- If max. power registered is lower than A= 85 % of Pmax-> apply 85 % of cost of Pmax
- If max. power registered is higher than A and lower than B= 105 % of Pmax -> apply 100 % of cost of Pmax
- If max. power registered is higher than B -> apply 100% of cost of Pmax + 2 times diff. betwen registered and B
Pmax is the contracted power
Power registered is the maximum power registered by the meter
ОК

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**:

IZING			
0.5	days auton.		
llel ->	Cn min.		
Max PV gen. parallel -> P min.			
parall	el -> P min.		
paral	lel -> Pmin		
	0.5 Ilel -> parall paral		

We obtain:

-MIN. AND MAX. No CO	MPONENTS IN PARALLEL:

Bateries in parallel: Min.	0	Max.	2
PV gen. in parallel: Min.	0	Max.	6
Wind T. in parallel: Min.	1	Max.	1
AC Gen. in parallel: Min.	1	Max.	1

We calculate:

#	Total Cost (NPC)(k€)	Emission (tCO2/yr)	Unmet(MWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(^
1	72.293	9.56	0	0	INF	0	47.63	0.1393	SIMULATE	REPORT	(
2	74.748	9.56	0	0	INF	0	47.63	0.144	SIMULATE	REPORT	(
3	75.567	9.56	0	0	INF	0	47.63	0.1456	SIMULATE	REPORT	(
4	78.841	9.56	0	0	INF	0	47.63	0.1519	SIMULATE	REPORT	(
5	83.504	9.33	0	0	INF	0	47.03	0.1609	SIMULATE	REPORT	(
6	84.465	9.73	0	0	INF	0.8	47.63	0.1628	SIMULATE	REPORT	(
7	85.96	9.33	0	0	INF	0	47.03	0.1656	SIMULATE	REPORT	C
8	86.778	9.33	0	0	INF	0	47.03	0.1672	SIMULATE	REPORT	(
9	86.866	9.73	0	0	INF	0.8	47.57	0.1674	SIMULATE	REPORT	٢.,
<											×
COMP	ONENTS: PV gen: PV10	(10 kWp_dc)x 6 (100%	PV#1: slope 60º, a	.zimuth 0º) /	/ Unme	et load = 0 % // Total	Cost (N	JPC) = 72.293 k€ (0	.14€/kWh)		^
STRA disch.	TEGY: LOAD FOLLOWIN (load + injecting to the grid	G. Arb.: Control variabl t) if price E. (sell) highe	es for grid-connec r than 0.11 €/KWh	ted batterie	s: char	ge (only from renewa	ble, no	nt from grid) if price	of E. (sell) is low	ver than 0€/KW	'n;
											~

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.

Project: High2.kho. Solution #1

Distribution of costs (+) and incomes (-), NPC, during the years. RED: acquisition costs, replac. costs and incomes for sales. BLUE: O&M. Currency: k€. Total Cost (NPC): 72.293 k€ (0.14 €/kWh). Initial cost of investment: 75 k€. Loan of 100 %, int. 7% in 25 yr., quota: 6.436 k€/yr.



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 6.35 kW for P1, 0 for P2 and 4.78 kW for P3.

	A	В	С	D	E	F	G	н	I	J
43	RESULTS OF T	HE POWER RE	GISTERED AN	D THE POWER	COSTS:					
44										
45	*RESULTS OF	THE MAXIMU	M POWER (kW	/) FROM THE G	RID REGISTER	ED, 1st YEAR:				
46	MONTH	Period P1	Period P2	Period P3						
47	1	8.695	8.464	5.794						
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	5.681						
59	*Actual contr	act power is,	for the differe	ent peridos: 60) kW; 80 kW; 9	0 kW;				
60	*RESULTS OF	THE VALUE OF	F THE POWER	(kW) TO CALC	ULATE THE CO	ST OF THE POV	VER IN THE BI	LL, AND COS	TS (k€), 1st YE	AR:
61	MONTH	Period P1(kW	Cost 1st yr.(k	Period P2(kW	Cost 1st yr.(k	Period P3(kW	Cost 1st yr.(k∉	5)		
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	f the power, 1	st year: 4.635	k€						
75	*If not consid	lering that co	ntract power o	of period P1 <=	power of P2	<= power of P	3			
76	Optimal cont	ract power we	ould be: 6.35 l	W; 0 kW; 4.78	kW; With a to	tal cost of the	power, 1st y	ear: 0.638 k€		
77	*If considering	ng that contra	ct power of pe	eriod P1 <= po	wer of P2 <= p	ower of P3				
78	Optimal cont	ract power we	ould be: 6.35	W; 6.35 kW; 6	.35 kW; With a	a total cost of	the power, 1s	t year: 1.613	k€	

52. High power project, minimization of NPC, multiperiod.

Save the project and then save as with the name "High2-multi".

We change to multiperiod (Project->Options):

Simulation and optimization:	
O Simulation of the 1st year and extrapolate results	
 Multiperiod: simulate all the years of the system lifetime (25 years) 	ns

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	(^
	1 96.717	10.75	0	0	INF	0	46.42	0.165	SIMULATE	REPORT	(

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	(^
1	96.717	10.75	0	0	INF	0	46.42	0.165	SIMULATE	REPORT	(
2	99.172	10.75	0	0	INF	0	46.42	0.1692	SIMULATE	REPORT	(
3	99.991	10.75	0	0	INF	0	46.42	0.1706	SIMULATE	REPORT	(
4	103.265	10.75	0	0	INF	0	46.42	0.1761	SIMULATE	REPORT	(
5	105.032	10.54	0	0	INF	0	45.71	0.1792	SIMULATE	REPORT	(
6	107.487	10.54	0	0	INF	0	45.71	0.1833	SIMULATE	REPORT	(
7	108.306	10.54	0	0	INF	0	45.71	0.1847	SIMULATE	REPORT	(
8	108.889	10.85	0	0	INF	0.8	46.42	0.1857	SIMULATE	REPORT	(
9	111.341	10.85	0	0	INF	0.8	46.42	0.1899	SIMULATE	REPORT	(
<											>
COMP	ONENTS: PV gen: PV10	(10 kWp_dc)x 6 (100%	PV#1: slope 60º, a	zimuth 0º) /	/ Unme	et load = 0 % // Total (Cost (N	IPC) = 96.717 k€ (0.	.16€/kWh)		~
STRA' disch.	TEGY: LOAD FOLLOWIN (load + injecting to the grid	G. Arb.: Control variabl 1) if price E. (sell) highe	les for grid-connect r than 0.11 €/KWh	led batterie	s: char	ge (only from renewa	ble, no	t from grid) if price	of E. (sell) is low	ver than 0€/kW	'h: ~

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(I) = 0.33:

Eactor E(I) for the back albedo	
(bifacial modules) (Durusov 2020):	0.33
(bildeldi modales) (balasoy coco).	

Then press CALCULATE. We accept. It calculates and we obtain similar irradiation as before for the front surface. For the back surface, 471.2 kWh/m^2 is the total irradiation of the year.

We could download hourly data from NASA, PVGIS or Renewables Ninja ad the back surface irradiation would remain. However, we will use the default irradiation data (with the back surface irradiation calculated).

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(°C)	Power T. coef.(%/ºC)	BIFACIALITY(0-1) CPV	missions(kgCO2/kW; 🔨
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)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(م
1	79.367	10.57	0	0	INF	0	47.53	0.1354	SIMULATE	REPORT	C
2	81.823	10.57	0	0	INF	0	47.53	0.1396	SIMULATE	REPORT	C
3	82.641	10.57	0	0	INF	0	47.53	0.141	SIMULATE	REPORT	C
4	85.915	10.57	0	0	INF	0	47.53	0.1465	SIMULATE	REPORT	C
5	90.59	10.35	0	0	INF	0	46.89	0.1545	SIMULATE	REPORT	C
6	91.539	10.67	0	0	INF	0.8	47.53	0.1561	SIMULATE	REPORT	C
7	93.045	10.35	0	0	INF	0	46.89	0.1587	SIMULATE	REPORT	C
8	93.864	10.35	0	0	INF	0	46.89	0.1601	SIMULATE	REPORT	C
9	93.992	10.67	0	0	INF	0.8	47.53	0.1603	SIMULATE	REPORT	C
<											> ``
COMP	ONENTS: PV gen: PV108	3IF (10 kWp_dc)x 6 10	0% PV#1: slope 60)º, azimuth ()// U	nmet load = 0 % // To	tal Cos	st (NPC) = 79.367 k	€ (0.14€/kWh)		~
STRA disch.	TEGY: LOAD FOLLOWIN (load + injecting to the grid	G. Arb.: Control variabl d) if price E. (sell) highe	es for grid-connec er than 0.11 €/kWh	ted batterie	s: char	ge (only from renewa	ble, no	t from grid) if price	of E. (sell) is low	ver than 0€/kW	'h;

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 \sim

Now download hourly data from PVGIS, 2015, only irradiation.

Download from:	● PVGIS - Year 2015 ∨
	🔿 Renewable Ninja (year 2019)
	○NASA- Year 2020 ~
Hourly Irradiatio	n
Hourly Tempera	ature for: 🗹 PV 🛛 Wind T. 🗌 Batt.
Hourly Wind Sp	ed
∩k	Cancel

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.): 2780.74 kWh/m2 Annual Irr. Back surface / Direct for CPV: 471.22 kWh/m2 / 2050.47 kWh/m2

Global annual irradiation is 2780.74 kWh/m2 (for the normal PV with 2 axes tracking) while direct is 2050.47 (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).

Name	Power(kWp)	Cost(k€)	C.O&M(%/yr)	Life(years)	NOCT(°C)	Power T. coef.(%/*C)	BIFACIALITY(0-1) CPV	missions(kgCO2/kWj /
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)(V	Ren(%	LCOE(€/kWh)	Simulate	Report	(۸
1	50.062	9.96	0	0	INF	0	51.2	0.0854	SIMULATE	REPORT	(
2	52.517	9.96	0	0	INF	0	51.2	0.0896	SIMULATE	REPORT	(
3	53.336	9.96	0	0	INF	0	51.2	0.091	SIMULATE	REPORT	(
4	56.61	9.96	0	0	INF	0	51.2	0.0966	SIMULATE	REPORT	(
5	62.234	10.07	0	0	INF	0.8	51.2	0.1062	SIMULATE	REPORT	(
6	64.686	10.07	0	0	INF	0.8	51.2	0.1103	SIMULATE	REPORT	(
7	65.505	10.07	0	0	INF	0.8	51.2	0.1117	SIMULATE	REPORT	(
8	66.185	9.79	0	0	INF	0	50.3	0.1129	SIMULATE	REPORT	(
9	68.641	9.79	0	0	INF	0	50.3	0.1171	SIMULATE	REPORT	<u>ر</u>
1											、 [*]
											-
COME	'ONENTS: PV gen: PV10-	T2axes (10 kWp_dc)x	6 Track. Both axis) // Unmet I	oad = I	0 % // Total Cost (NP	C) = 50	.062 k€ (0.09 €/kW	h)		\sim
STRA		G. Arb : Control variab	s for arid-connect	ed hatterie	s: chan	ne (only from renewa	hle no	t from arid) if price	of F (sell) is low	verthan 0 €/k\\	/h:
disch.	(load + injecting to the grid	d) if price E. (sell) highe	erthan 0.11 €/kWh	ou patono	o. onen	ge (only nonnenene	<i>bio</i> , ne	(nonright) in price	012. (001) 10101		
											0