# MHOGA software

## **M**egaWatt **H**ybrid **O**ptimization by **G**enetic **A**lgorithms

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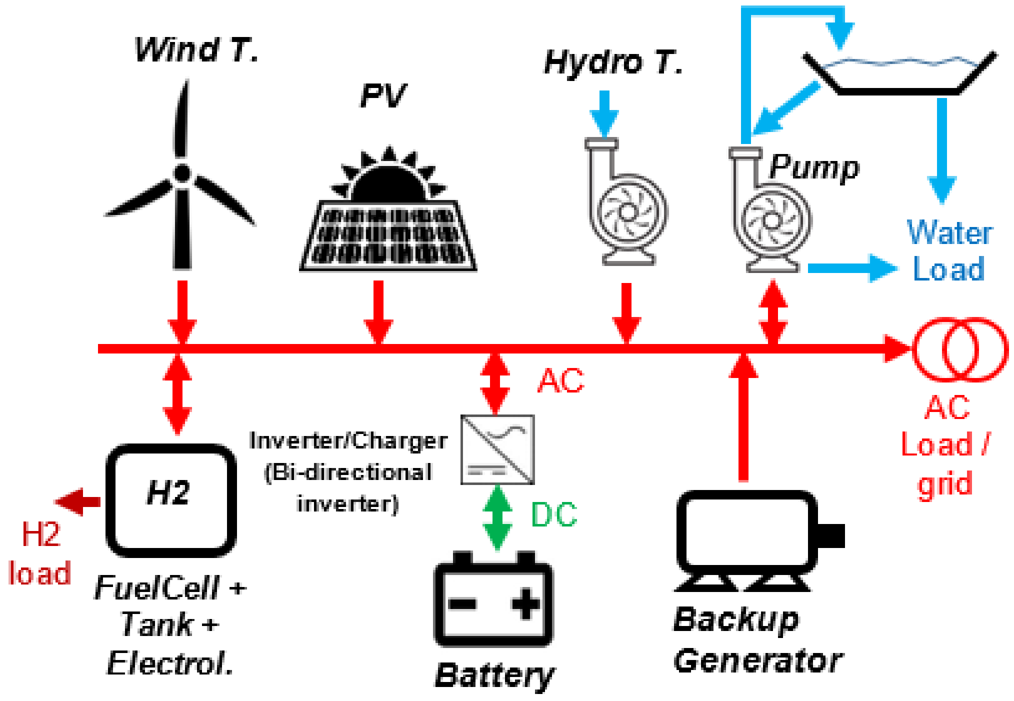
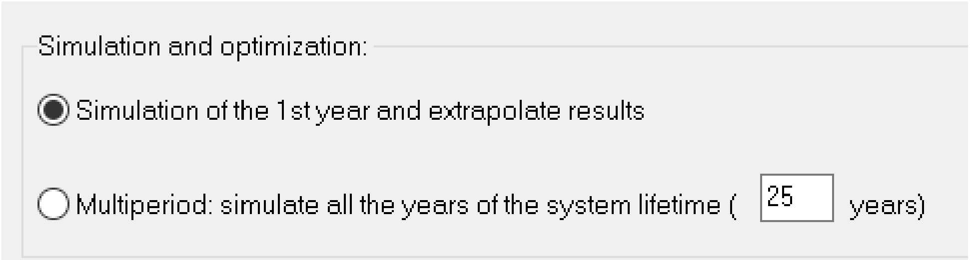
# Overview

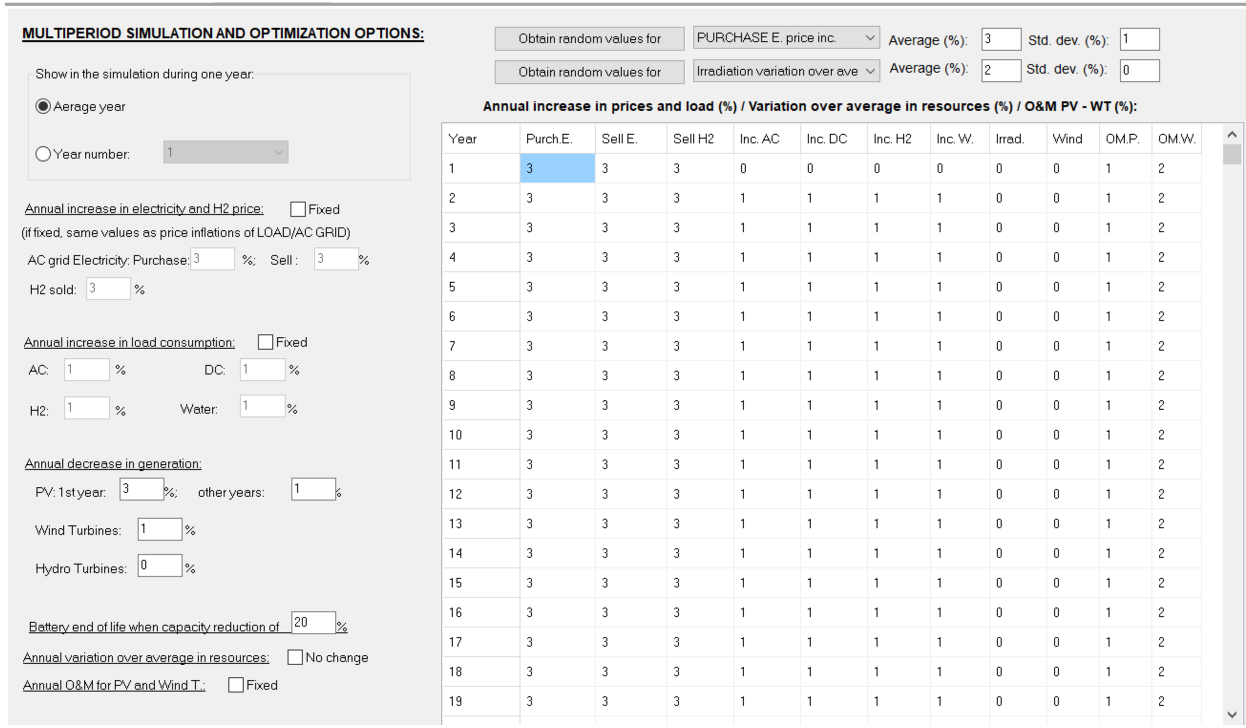
- Simulation and optimization software
- Off-grid or grid-connected generating systems
- Possible load:
  - AC
  - DC
  - $H_2$ for external use
  - Pumped water
- Possible components:
  - Renewable sources: PV, Wind, Hydro
  - Storage:
    - Lead-acid, Li-ion or other types of batteries
    - Pumped Hydro Storage (PHS)
    - Hydrogen: Electrolyzer – $H_2$ tank – fuel cell
  - Fossil fuel generators
- Sell / Buy electricity to the AC grid
- Sell $H_2$ generated by electrolyzer (Green $H_2$)



# Simulation

- Each combination of components and control strategies is simulated during:
  - 1 typical year (steps from 1 min. to 1 h)
  - All the system lifetime (25 years typically), considering anual changes in:
    - Electricity price (buy / sell to the AC grid)
    - Sell generated green $H_2$ price
    - PV, wind resources
    - PV, wind, hydro generation
    - Battery capacity
    - O&M for PV or Wind



MULTIPERIOD SIMULATION AND OPTIMIZATION OPTIONS:

Show in the simulation during one year:
Aerage year
Year number: 1

Annual increase in electricity and H2 price: Fixed
(if fixed, same values as price inflations of LOAD/AC GRID)
AC grid Electricity: Purchase: 3 %; Sell : 3 %
H2 sold: 3 %

Annual increase in load consumption: Fixed
AC: 1 % DC: 1 %
H2: 1 % Water: 1 %

Annual decrease in generation:
PV: 1st year: 3 %; other years: 1 %
Wind Turbines: 1 %
Hydro Turbines: 0 %

Battery end of life when capacity reduction of 20 %
Annual variation over average in resources: No change
Annual O&M for PV and Wind T.: Fixed

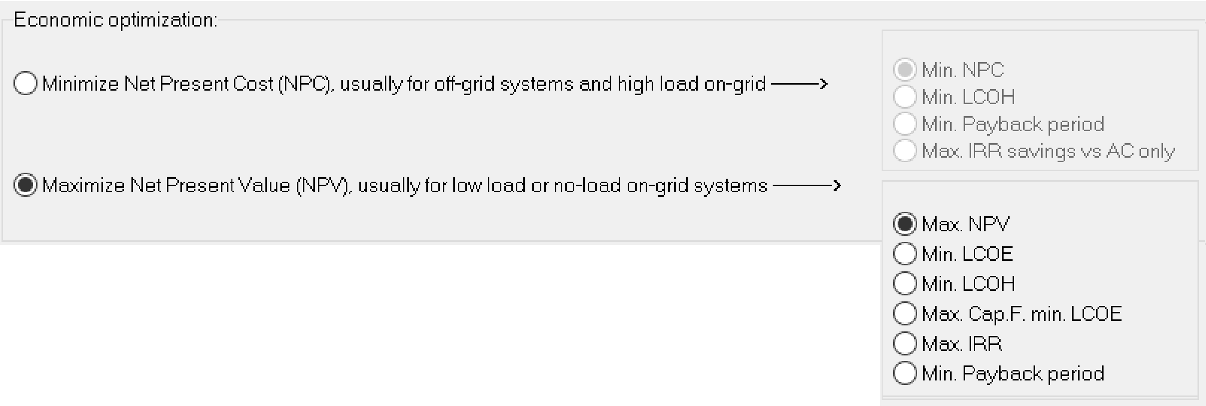
Obtain random values for PURCHASE E. price inc. Average (%): 3 Std. dev. (%): 1
Obtain random values for Irradiation variation over ave Average (%): 2 Std. dev. (%): 0

Annual increase in prices and load (%) / Variation over average in resources (%) / O&M PV - WT (%):

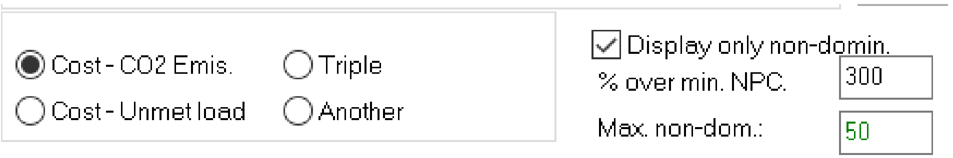
| Year | Purch.E. | Sell E. | Sell H2 | Inc. AC | Inc. DC | Inc. H2 | Inc. W. | Irrad. | Wind | OM.P. | OM.W. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 2 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 4 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 5 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 6 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 7 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 8 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 9 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 10 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 11 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 12 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 13 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 14 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 15 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 16 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 17 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 18 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |
| 19 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 2 |

# Optimization

- Mono-objective:
  - Minimize NPC (off-grid or grid-connected systems to suppply load).
    - Also option of minimization of LCOH or minimization of payback-time or maximization of IRR savings compared to system of only AC grid
  - Maximize NPV (grid-connected power generating systems)
    - Also option of minimization of LCOE or LCOH or Cap. Factor and LCOE or maximization of IRR or minimization of payback-time.




- Multi-objective:
  - NPC - $CO_2$ emissions
  - NPC - Unmet load
  - NPC - $CO_2$ emissions - Unmet load



# Optimization

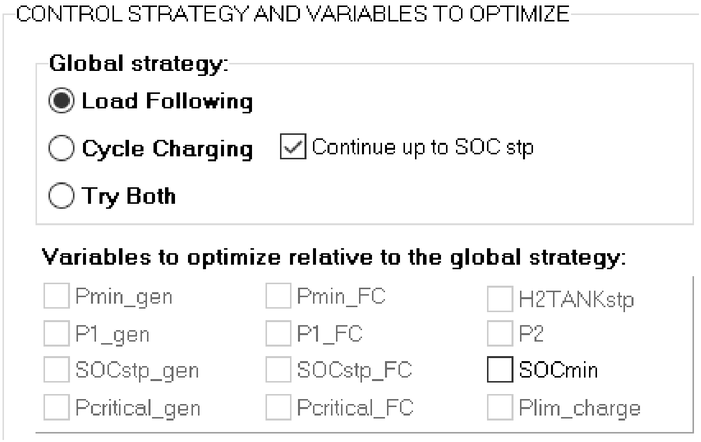
- The software simulates and evaluates all the posible combinations of components and control strategies $\rightarrow$ obtains the optimal one (lowest NPC or highest NPV or lowes LCOE or lowest LCOH or…)
- If too many combinations -> optimization time can be too high, inadmissible $\rightarrow$ Use **Genetic Algorithms** metaheuristic technique $\rightarrow$ optimize in reasonable time

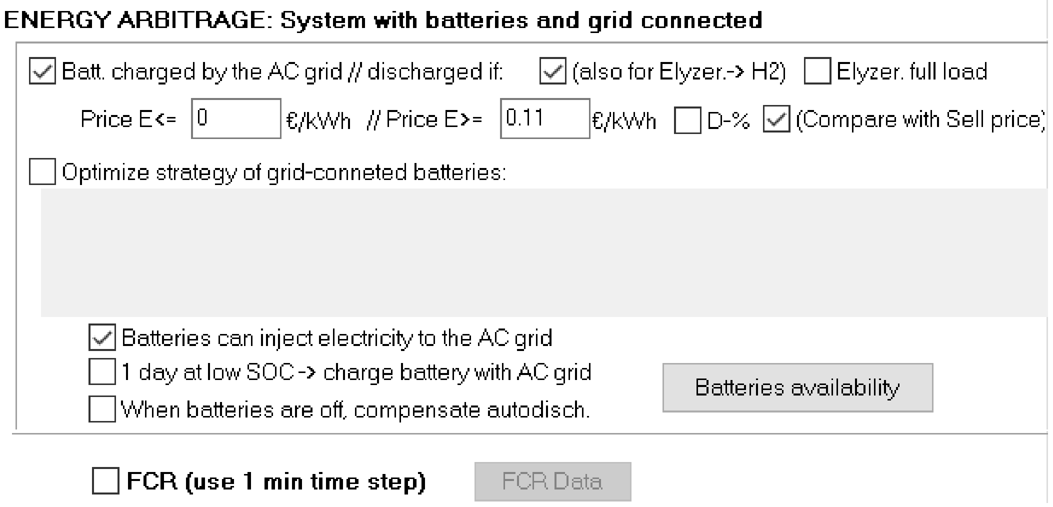
# Control strategies

- **For off-grid systems**:
  - Load following
  - Cycle charging
  - Control variables

- **Energy arbitraje**: For grid-connected power generating systems
  - Fix / optimize max. electricity price to charge batteries and min. electricity price to discharge batteries -> optimal storage management
  - Also for PHS
  - Also for green $H_2$ generation

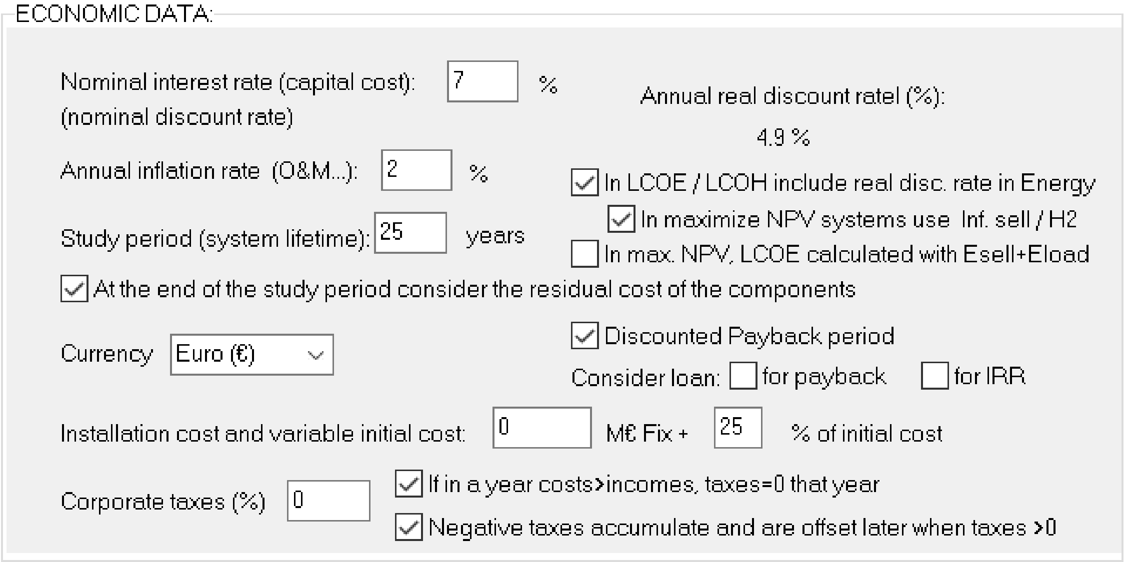
- **Frequency containment reserve** (FCR) service

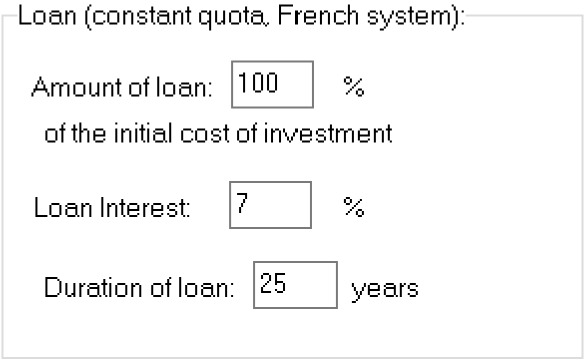


# Economic and financial data

- Default currency (€) can be changed to $ or any other
- Nominal interest rate
- Annual general inflation rate for O&M, etc.
- Annual specific inflation rates for:
    - Electricity sell Price
    - Electricity buy Price
    - H2 sell Price
    - Backup generator fuel Price
    - Change in components prices to calculate replacing costs
- Corporate Taxes
- Loan
- **Capacity market** expected incomes
- After simulating → calculation of NPC/NPV, LCOE, IRR, payback time… for each combination




# Capacity market data

**CAPACITY MARKET :**

In the 1st column you must enter the price of the Capacity market for the different years (referred to its year).

In the rest of columns you must enter the de-rating factor of the different technologies.

Obtain random values for | Price Capacity Market

X: hours of duration of battery: 1 | Y: hours of duration of battery: 9

X: hours of duration of PHS: 1 | Y: hours of duration of PHS: 9

Average: 100 | Std. dev.: 10

From year: 1 | To year: 25

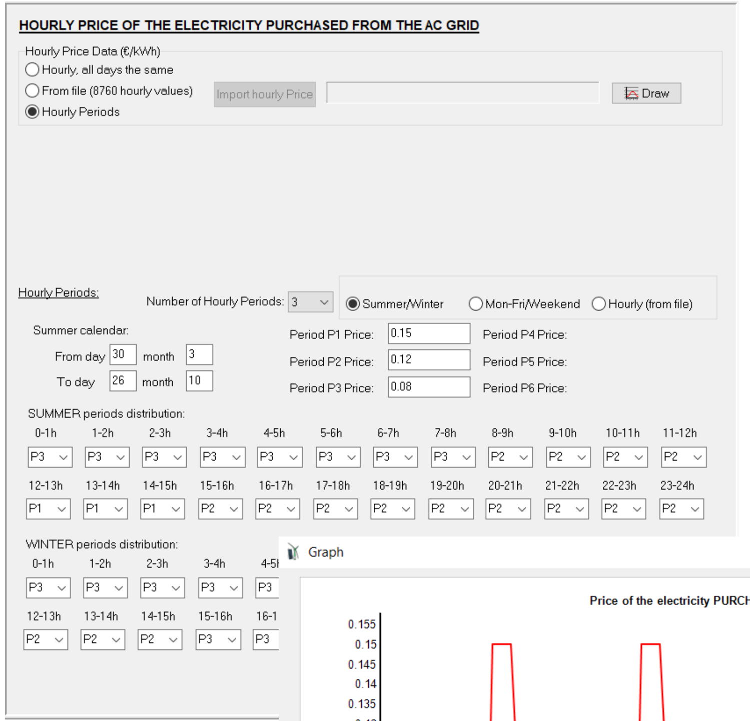
| Year | Price (€/MW/yr) | PV(%) | Wind(%) | Hydro(%) | Diesel(%) | F.C.(%) | Bat_X_h(%) | Bat_Y_h(%) | PHS_X_h(% | PHS_Y_h(% |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 2 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 3 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 4 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 5 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 6 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 7 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 8 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 9 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 10 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 11 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |
| 12 | 10000 | 5 | 10 | 95 | 90 | 90 | 10 | 90 | 10 | 90 |

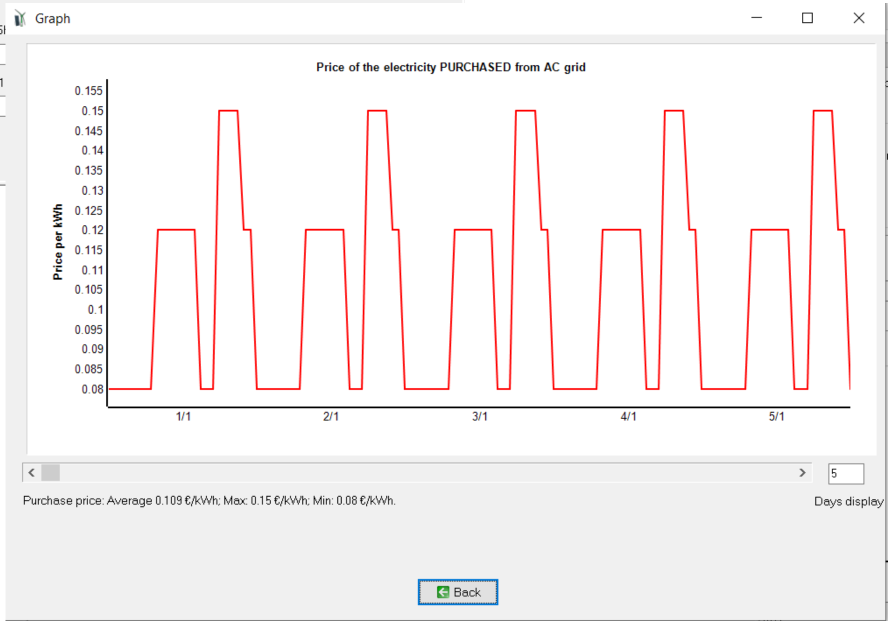
# Load and Resources

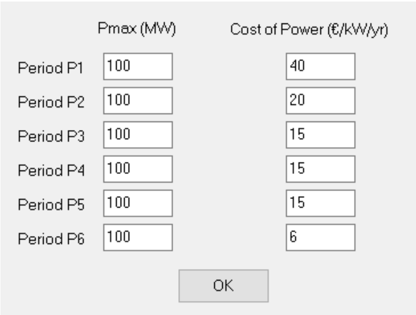
- AC, DC, H2 and water pumping load can be defined in monthly average hourly vales or it can be imported in several minutes or hourly basis.
- Irradiation, wind speed and tempertaure can be:
  - Hourly values downloaded from 3 different databases (PVGIS, NASA, RENEWABLES NINJA)
  - Obtained synthetically from monthly average data
  - Imported the whole year, in steps from 1 min. to 1 h.
  - Import PV / wind generation in steps from 1 min. to 1 h.
- Water for hydro in hourly or monthly average values
- Hourly values converted to minute values using autorregresive functions
- Wind and/or PV generation from a real wind turbine / PV in hourly or minutes steps can be imported and used as input for the wind turbines / PV generation.
- Wind turbines with 16 power vs wind speed curves, one for each wind direction sector (from 0º to 337.5º in steps of 22.5º) can be defined. This way the wind generation will depend not only on the wind speed but also on the wind direction.

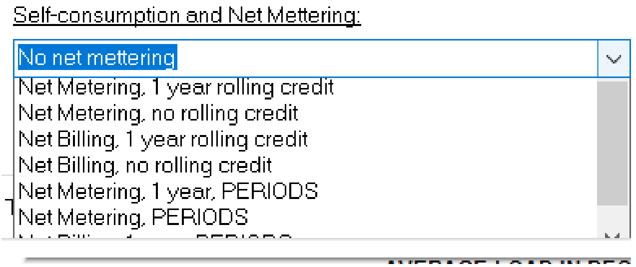
# Purchase / sell electricity to AC grid

- Different prices for purchase and sell electricity
- Fixed values or hourly, imported or by periods (TOU, RTP)
- Hourly periods also for maximum Power available from / to the AC grid
- Options for net metering / net billing



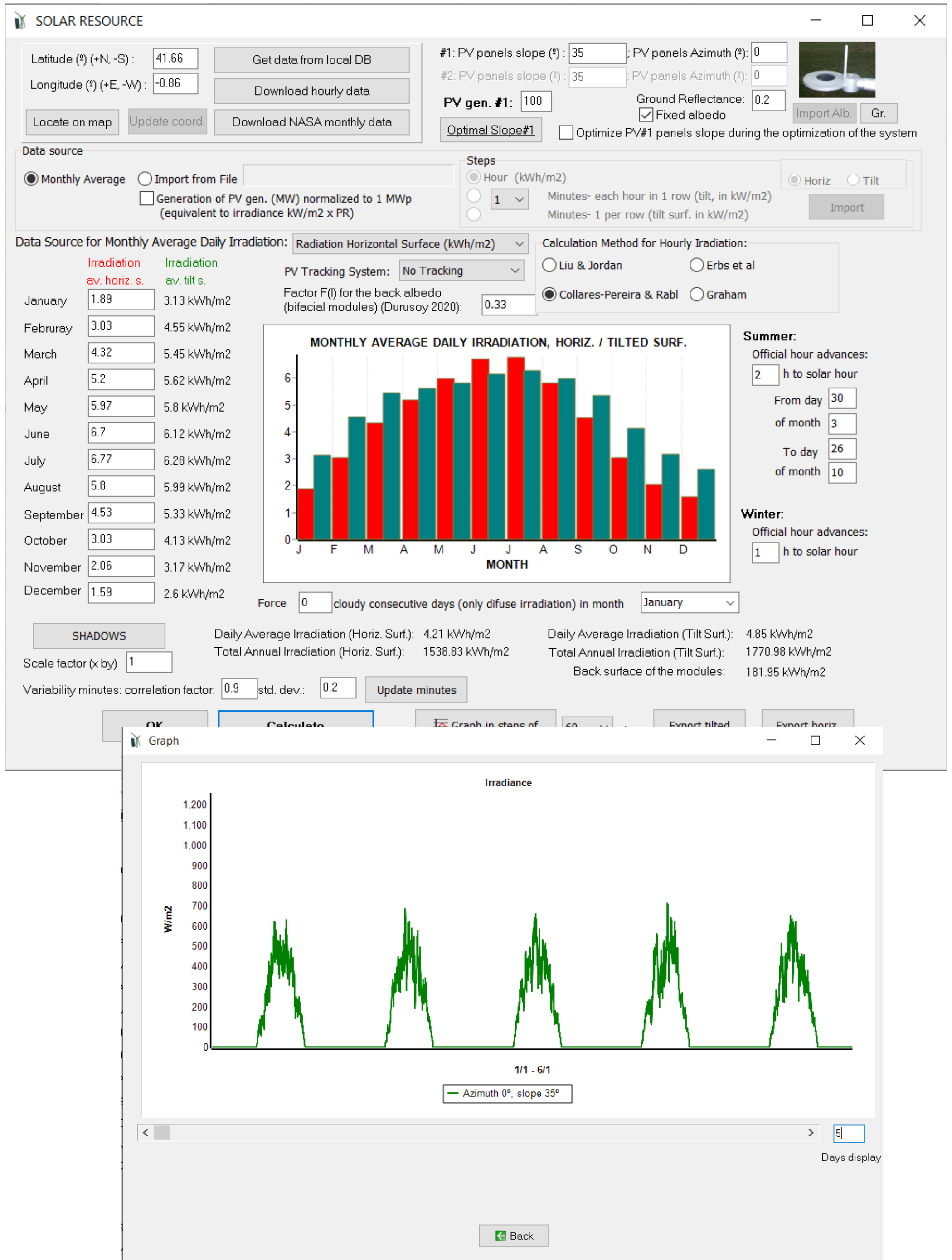



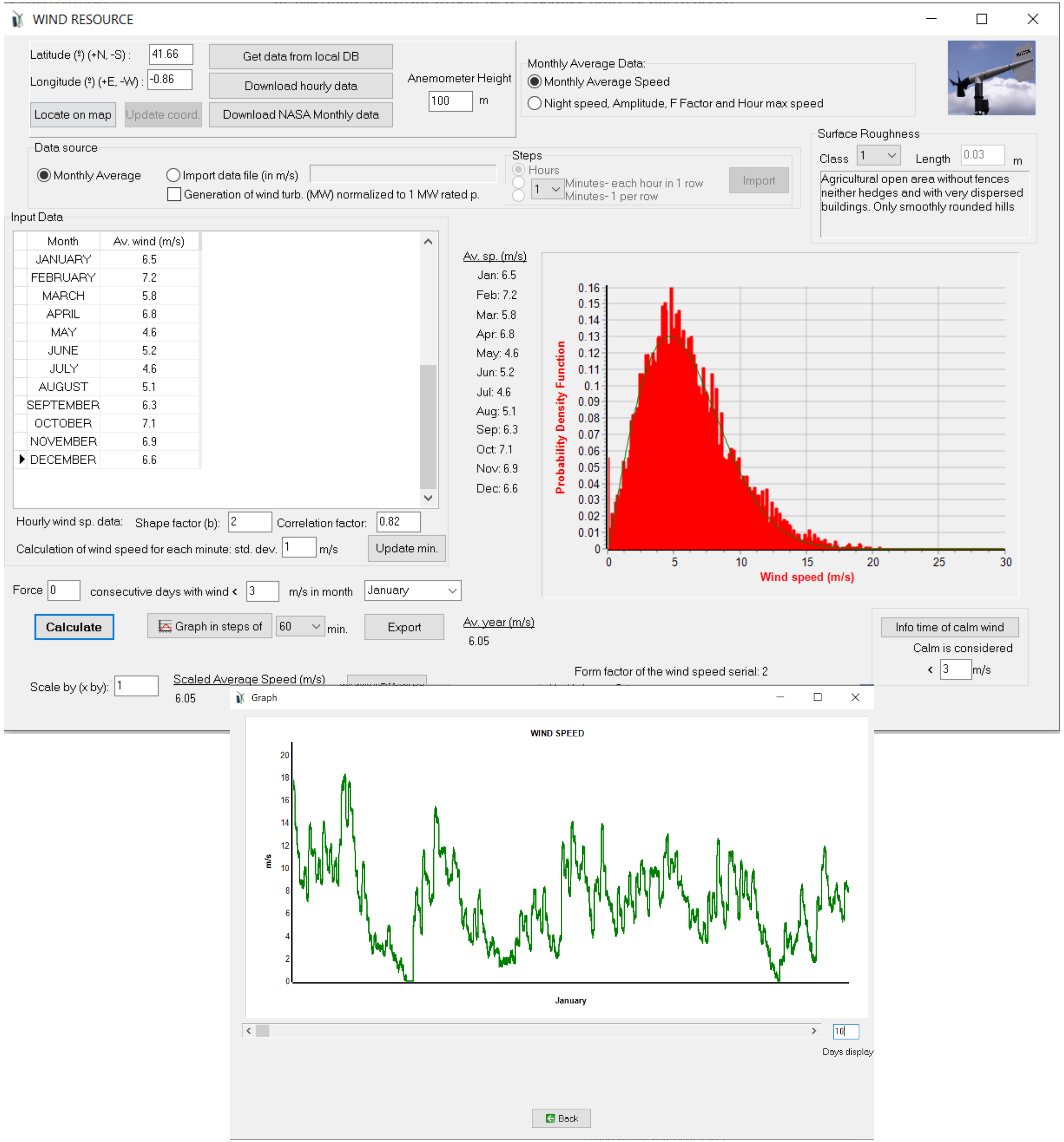
# Irradiation

- Irradiation over any surface, fixed (tilt, azimuth) or 1 or 2 axis tracking
- PV generator can be divided in two zones with different tilt and azimuth.
- Irradaition over the back surface is calculated → PV bifacial modules can be considered
- CPV can be considered (direct irradiation)



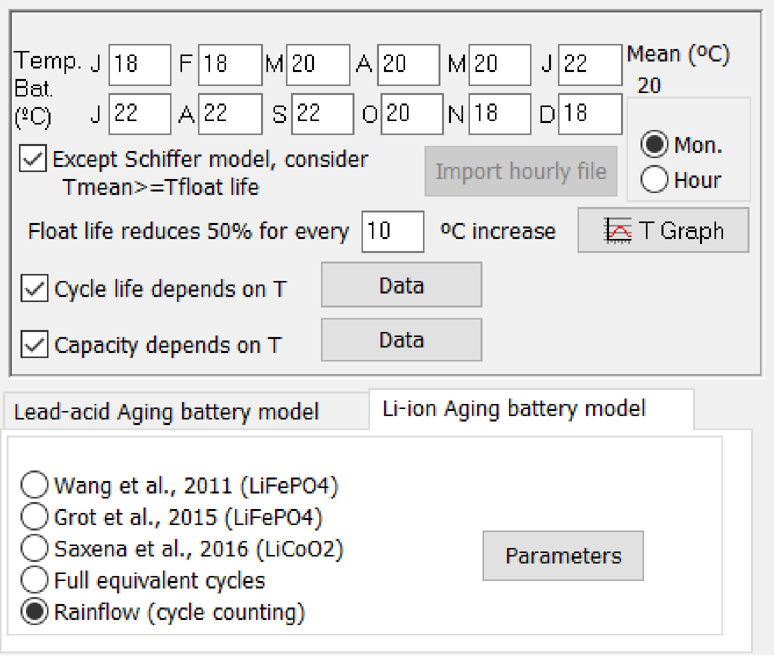
# Wind speed

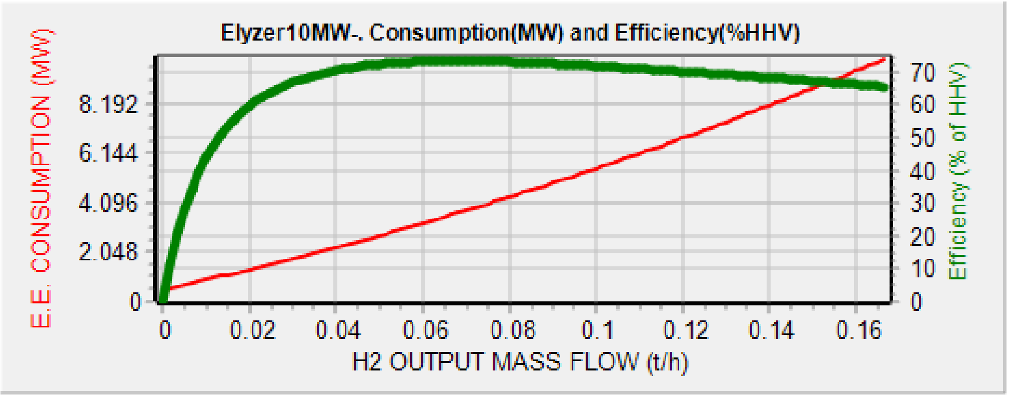
- Monthly average converted to hourly and minute basis
- Or download or import hourly or minute basis data



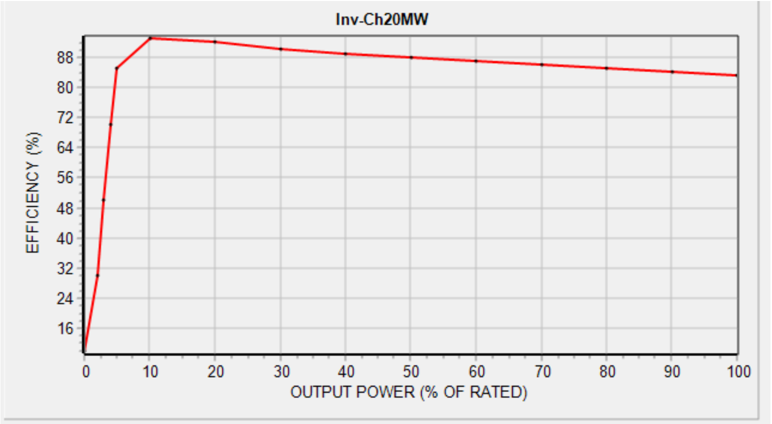
# Models for components

- Accurate models for all the components
- Advanced ageing battery models, for lead-acid and for Li-ion
- Inverter and inverter-charger efficiency dependant on output power
- Variable consumption and efficiency for backup generator, electrolyzer and fuel cell



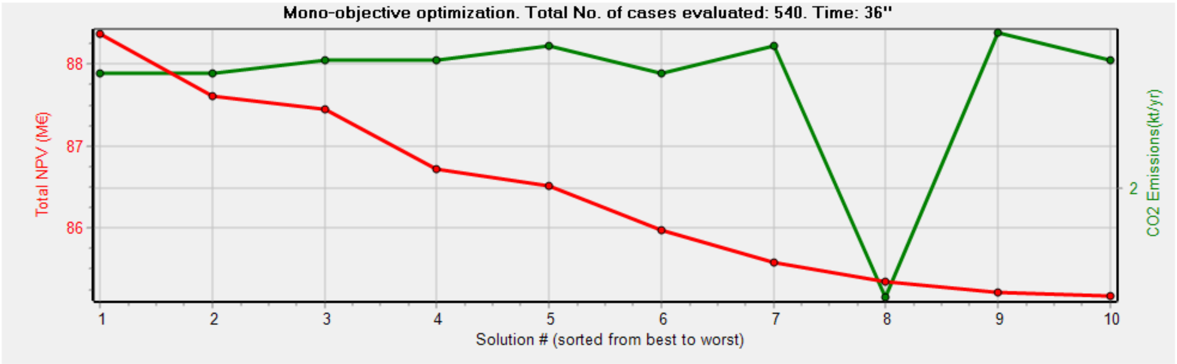




Nominal H2 mass flow = 0.166 t/h; It is needed at least 0.5 MW to generate H2



# Optimization results

- Combinations sorted from best to worst (or best of each generation of the GA)
- Simulation of each combination
- General report of each combination
- Costs report of each combination




Show diagram

| No. | Total NPV (M€) | Emission (ktCO2/yr) | Unmet(GWh/yr) | IRR(%) | Investment(M€) | LCOE(€/kWh) | Simulate | Report | Costs |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 88.373 | 2.17 | 0 | 15.53 | 85 | 0.0695 | SIMULATE... | REPORT... | COSTS... |
| 2 | 87.618 | 2.17 | 0 | 15.41 | 85.625 | 0.07 | SIMULATE... | REPORT... | COSTS... |
| 3 | 87.452 | 2.19 | 0 | 15.3 | 86.875 | 0.0707 | SIMULATE... | REPORT... | COSTS... |
| 4 | 86.723 | 2.19 | 0 | 15.19 | 87.5 | 0.0712 | SIMULATE... | REPORT... | COSTS... |
| 5 | 86.52 | 2.21 | 0 | 15.07 | 88.75 | 0.0718 | SIMULATE... | REPORT... | COSTS... |
| 6 | 85.972 | 2.17 | 0 | 15.17 | 86.875 | 0.0712 | SIMULATE... | REPORT... | COSTS... |
| 7 | 85.573 | 2.21 | 0 | 14.94 | 89.375 | 0.0725 | SIMULATE... | REPORT... | COSTS... |
| 8 | 85.35 | 1.84 | 0 | 16.54 | 72.5 | 0.0653 | SIMULATE... | REPORT... | COSTS... |
| 9 | 85.215 | 2.23 | 0 | 14.81 | 90.625 | 0.0731 | SIMULATE... | REPORT... | COSTS... |

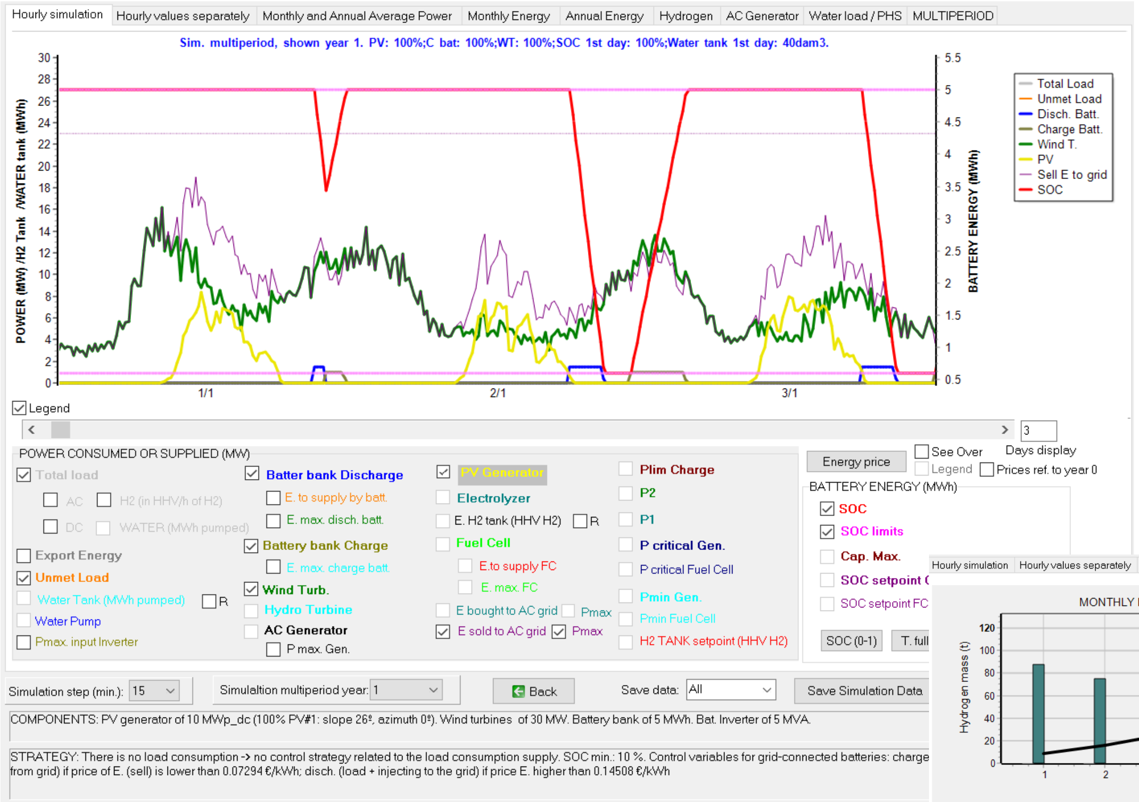
COMPONENTS: PV gen: PV10 (10 MWp)x 6 (100% PV#1: slope 35º, azimuth 0º) // Batteries Bat5MWh (5 kAh): 1s. x 1p. // 3 Wind Turb. WindT1 (2 MW at 14 m/s) // Inverter Inv-Ch5MW of 5 MVA // Unmet load = 0 % // Total Net Present Value (NPV) = 88.373 M€, IRR = 15.5%.

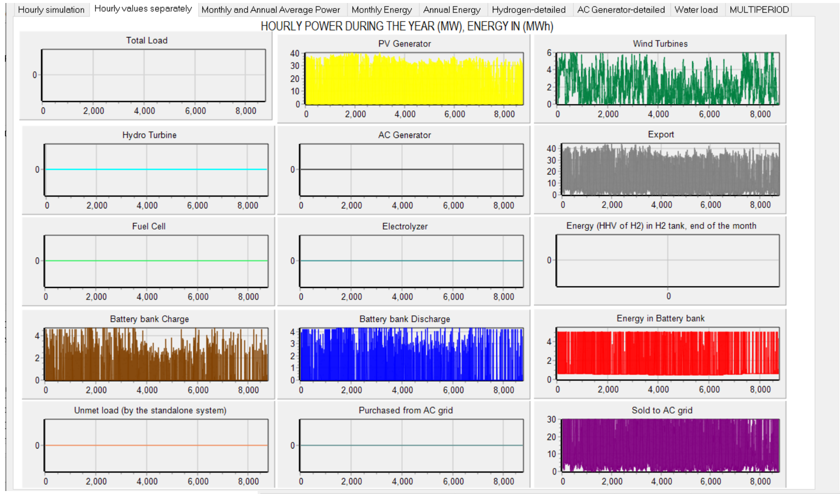
STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. SOC min.: 10 %. Control variables for for grid-connected batteries: charge batt. (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. batt. (load + injecting to the grid) if price E. (sell) higher than 0.11 €/kWh

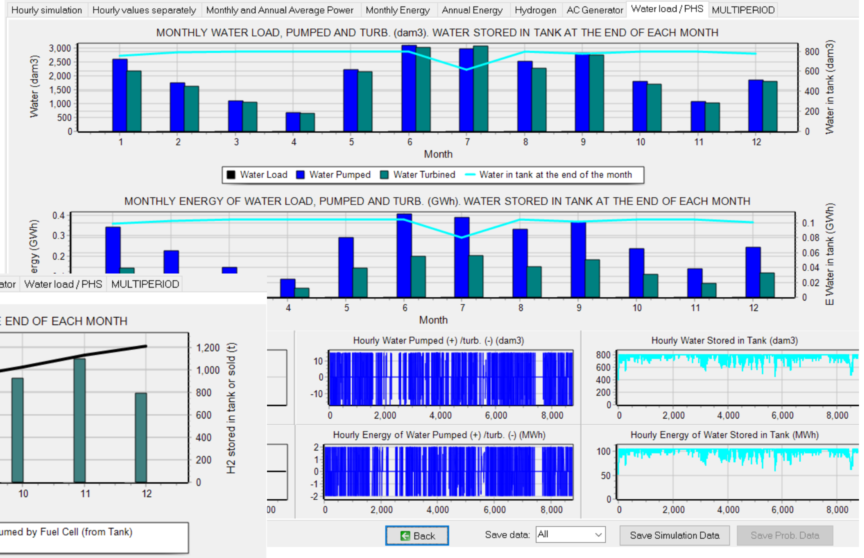
See best 10

Save Excel table

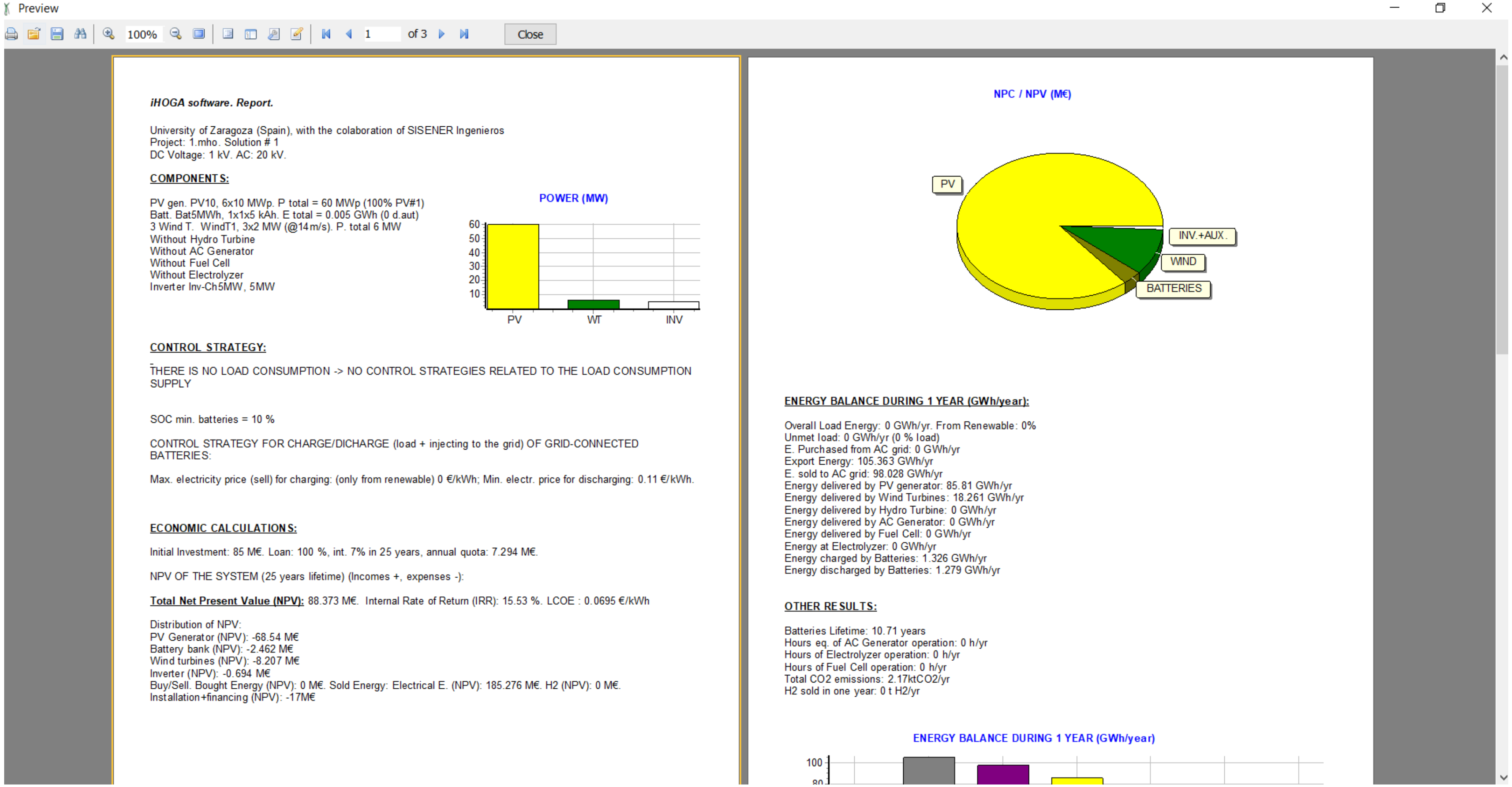
# Optimization results




# Optimization results




*iHOGA software. Report.*

University of Zaragoza (Spain), with the colaboration of SISENER Ingenieros
Project: 1.mho. Solution # 1
DC Voltage: 1 kV. AC: 20 kV.

**COMPONENTS:**

PV gen. PV10, 6x10 MWp. P total = 60 MWp (100% PV#1)
Batt. Bat5MWh, 1x1x5 kAh. E total = 0.005 GWh (0 d.aut)
3 Wind T. WindT1, 3x2 MW (@14m/s). P. total 6 MW
Without Hydro Turbine
Without AC Generator
Without Fuel Cell
Without Electrolyzer
Inverter Inv-Ch5MW, 5MW



**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:

Max. electricity price (sell) for charging: (only from renewable) 0 €/kWh; Min. electr. price for discharging: 0.11 €/kWh.

**ECONOMIC CALCULATIONS:**

Initial Investment: 85 M€. Loan: 100 %, int. 7% in 25 years, annual quota: 7.294 M€.

NPV OF THE SYSTEM (25 years lifetime) (Incomes +, expenses -):

**Total Net Present Value (NPV):** 88.373 M€. Internal Rate of Return (IRR): 15.53 %. LCOE : 0.0695 €/kWh

Distribution of NPV:
PV Generator (NPV): -68.54 M€
Battery bank (NPV): -2.462 M€
Wind turbines (NPV): -8.207 M€
Inverter (NPV): -0.694 M€
Buy/Sell. Bought Energy (NPV): 0 M€. Sold Energy: Electrical E. (NPV): 185.276 M€. H2 (NPV): 0 M€.
Installation+financing (NPV): -17M€



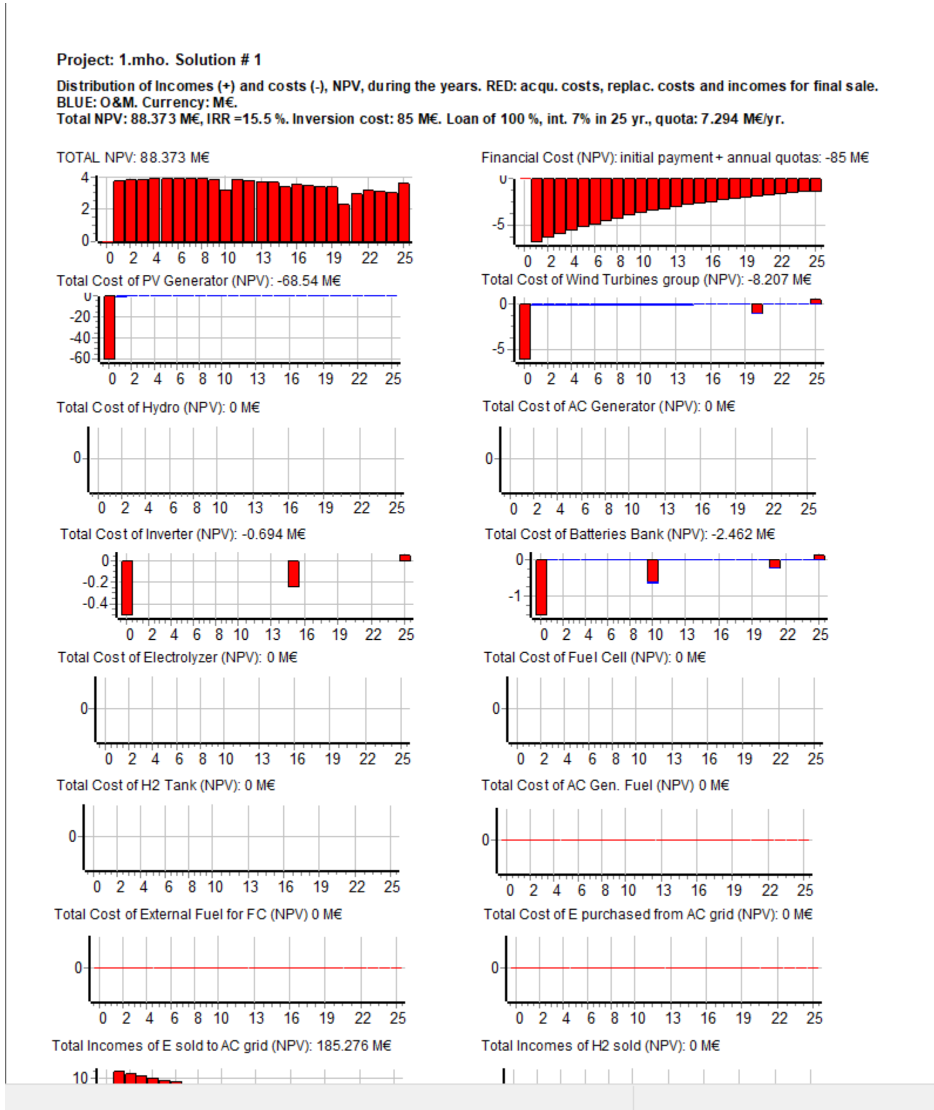
**ENERGY BALANCE DURING 1 YEAR (GWh/year):**

Overall Load Energy: 0 GWh/yr. From Renewable: 0%
Unmet load: 0 GWh/yr (0 % load)
E. Purchased from AC grid: 0 GWh/yr
Export Energy: 105.363 GWh/yr
E. sold to AC grid: 98.028 GWh/yr
Energy delivered by PV generator: 85.81 GWh/yr
Energy delivered by Wind Turbines: 18.261 GWh/yr
Energy delivered by Hydro Turbine: 0 GWh/yr
Energy delivered by AC Generator: 0 GWh/yr
Energy delivered by Fuel Cell: 0 GWh/yr
Energy at Electrolyzer: 0 GWh/yr
Energy charged by Batteries: 1.326 GWh/yr
Energy discharged by Batteries: 1.279 GWh/yr

**OTHER RESULTS:**

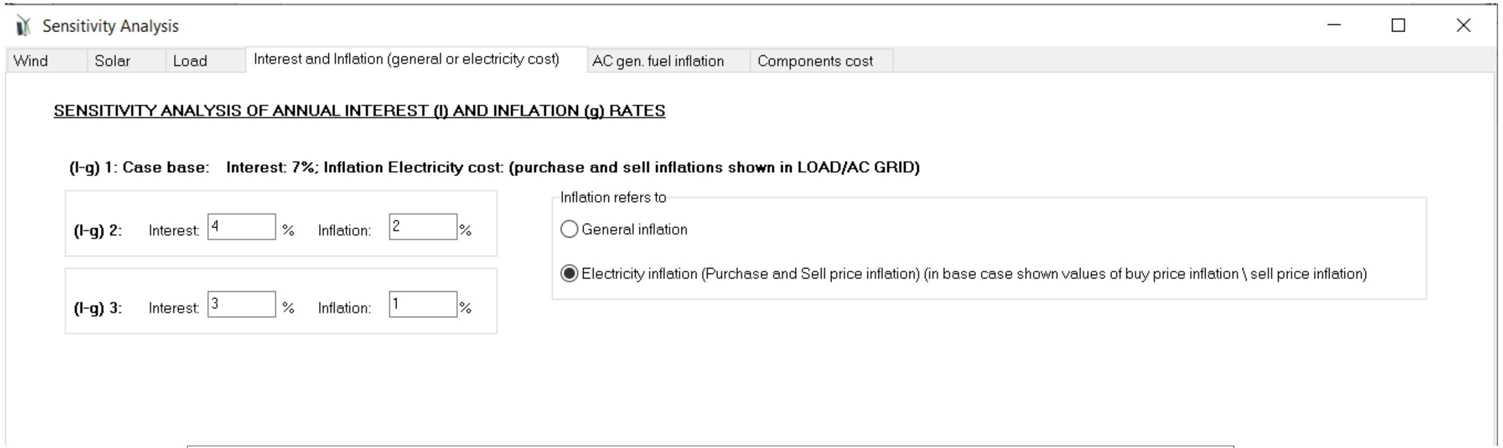
Batteries Lifetime: 10.71 years
Hours eq. of AC Generator operation: 0 h/yr
Hours of Electrolyzer operation: 0 h/yr
Hours of Fuel Cell operation: 0 h/yr
Total CO2 emissions: 2.17ktCO2/yr
H2 sold in one year: 0 t H2/yr

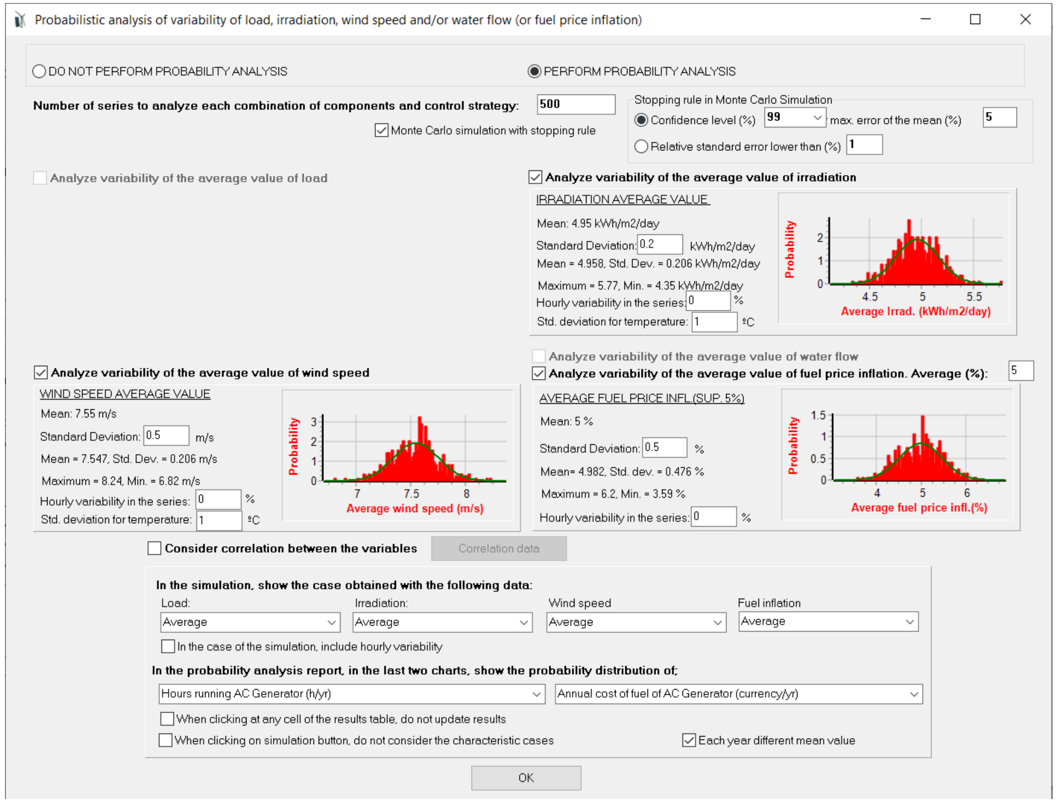
# Optimization results



# Other features

- Sensitivity analysis
- Probability analysis
- ….



# More info

- https://ihoga.unizar.es/en/

- User manual:

https://ihoga.unizar.es/Desc/MHOGA_User_manual.pdf

- Getting started guide:

https://ihoga.unizar.es/Desc/GETTING_STARTED_MHOGA.pdf

Thank you!