

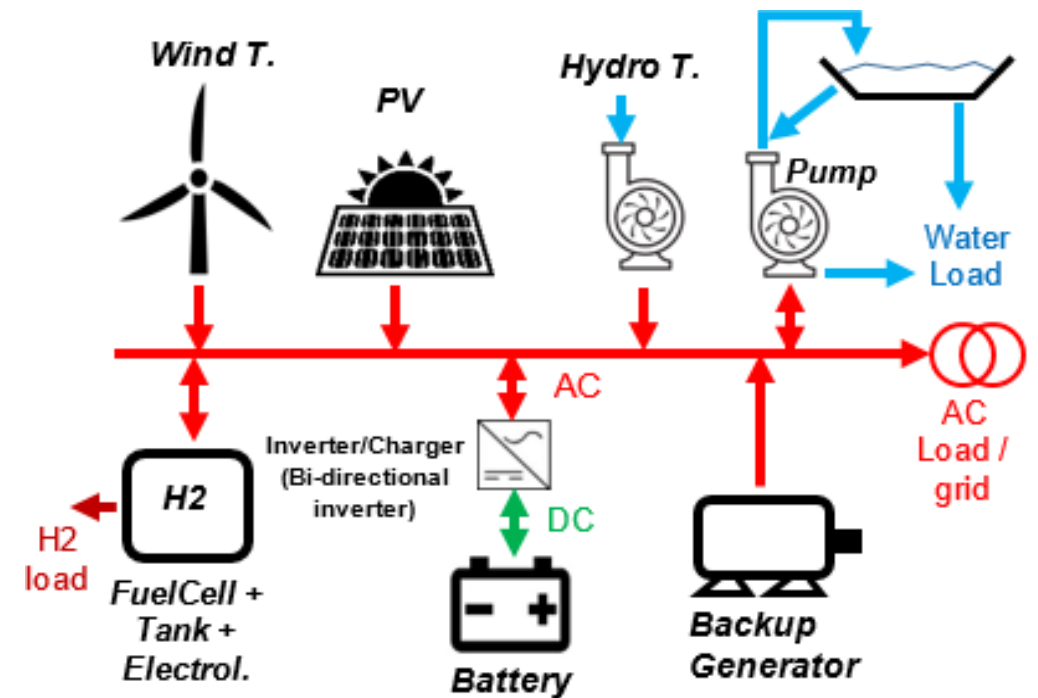
MHOGA software

MegaWatt Hybrid Optimization by Genetic Algorithms

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Overview (I)

- Simulation and optimization software
- Off-grid or grid-connected systems
- Possible load:
 - AC
 - DC
 - H₂ for external use
 - Pumped water
- Possible components:
 - Renewable sources: PV, Wind, Hydro
 - Storage:
 - Lead-acid and li-ion batteries
 - Pumped Hydro Storage (PHS)
 - Electrolyzer – H₂ tank – fuel cell
 - Backup generators
 - Electrolyzer – H₂ tank – fuel cell
- Sell / Buy electricity to the AC grid
- Sell H₂ generated by electrolyzer (Green H₂)



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 annual changes in:
 - Electricity price (buy / sell to the AC grid)
 - Generated green H₂ price
 - PV, wind resources
 - PV, wind, hydro generation
 - Battery capacity
 - O&M for PV or Wind

Simulation and optimization:

☒ Simulation of the 1st year and extrapolate results

☐ Multiperiod: simulate all the years of the system lifetime (years)

MULTIPERIOD SIMULATION AND OPTIMIZATION OPTIONS:

Show in the simulation during one year:

☒ Average year

☐ Year number:

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

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

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

Battery end of life when capacity reduction of %

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 (%): Std. dev. (%):

Obtain random values for: Irradiation variation over ave Average (%): Std. dev. (%):

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

Year	Purch.E.	Sell E.	Sell H ₂	Inc. AC	Inc. DC	Inc. H ₂	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 (I)

- Mono-objective:
 - Minimize NPC (off-grid or grid-connected systems to supply load)
 - Maximize NPV (grid-connected power generating systems)
- Multi-objective:
 - NPC - CO₂ emissions
 - NPC - Unmet load
 - NPC - CO₂ emissions - Unmet load

Economic optimization:

☐ Minimize Net Present Cost (NPC), usually for off-grid systems and high load on-grid

☒ Maximize Net Present Value (NPV), usually for low load or no-load on-grid systems

☒ Max. NPV

☐ Min. LCOE

☒ Cost - CO₂ Emis. ☐ Triple

☐ Cost - Unmet load ☐ Another

☒ Display only non-domin. % over min. NPC.

Max. non-domin.:

Optimization (II)

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

Control strategies

- For off-grid systems:
 - Load following
 - Cycle charging
 - Control variables
- Energy arbitrage: 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 generating green H₂

CONTROL STRATEGY AND VARIABLES TO OPTIMIZE

Global strategy:

☒ Load Following

☐ Cycle Charging ☒ Continue up to SOC stp

☐ Try Both

Variables to optimize relative to the global strategy:

☐ Pmin_gen

☐ Pmin_FC

☐ H2TANKstp

☐ P1_gen

☐ P1_FC

☐ P2

☐ SOCstp_gen

☐ SOCstp_FC

☐ SOCmin

☐ Pcritical_gen

☐ Pcritical_FC

☐ Plim_charge

ENERGY ARBITRAGE: System with batteries and grid connected

☐ Batteries are charged by the AC grid // discharged if: ☒ (also for Elyzer.-> H2)
☒ (Sell price)

☒ Optimize strategy of grid-connected batteries:

☒ 3 variables: X1(dif.), X2(%), X3(%).

X1:min. 0.029 max. 0.3251 €/kWh

☐ 2 variables: price E. min. and max.

Min.> 0.0008 ; Max< 0.3615 €/kWh

☒ Batteries can inject electricity to the AC grid

☐ 1 day at low SOC-> charge battery v

☐ When batteries are off, compensate autodisch.

Batteries availability

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
- Loan
- Corporate Taxes
- After simulating -> calculation of NPC/NPV, LCOE, IRR for each combination

ECONOMIC DATA:

Nominal interest rate (capital cost): %
(nominal discount rate)

Annual real discount rate (%):
4.9 %

Annual inflation rate (O&M...): %

Study period (system lifetime): years

☒ In LCOE / LCOH include real disc. rate in Energy
☐ In maximize NPV systems use Inf. sell / H2

☒ At the end of the study period consider the residual cost of the components

Currency:

Installation cost and variable initial cost: M€ Fix + % of initial cost

Corporate taxes (%) ☐ If in a year costs > incomes, taxes = 0 that year
☐ Negative taxes accumulate and are offset later when taxes > 0

Loan (constant quota, French system):

Amount of loan: %
of the initial cost of investment

Loan Interest: %

Duration of loan: years

Load and Resources

- AC, DC, H2 and water pumping load can be defined in monthly average hourly values or it can be imported in several minutes or hourly basis.
- Irradiation, wind speed and temperature 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 autoregressive 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 0° to 337.5° in steps of 22.5°) 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

	Pmax (MW)	Cost of Power (£/kW/yr)
Period P1	<input type="text" value="100"/>	<input type="text" value="40"/>
Period P2	<input type="text" value="100"/>	<input type="text" value="20"/>
Period P3	<input type="text" value="100"/>	<input type="text" value="15"/>
Period P4	<input type="text" value="100"/>	<input type="text" value="15"/>
Period P5	<input type="text" value="100"/>	<input type="text" value="15"/>
Period P6	<input type="text" value="100"/>	<input type="text" value="6"/>

OK

Self-consumption and Net Metering:

☒ No net metering

☐ Net Metering, 1 year rolling credit

☐ Net Metering, no rolling credit

☐ Net Billing, 1 year rolling credit

☐ Net Billing, no rolling credit

☐ Net Metering, 1 year, PERIODS

☐ Net Metering, PERIODS

HOURLY PRICE OF THE ELECTRICITY PURCHASED FROM THE AC GRID

Hourly Price Data (£/kWh)

☐ Hourly, all days the same

☐ From file (8760 hourly values)

☒ Hourly Periods

Hourly Periods: Number of Hourly Periods: ☒ Summer/Winter ☐ Mon-Fri/Weekend ☐ Hourly (from file)

Summer calendar: From day month To day month

Period P1 Price: Period P4 Price:

Period P2 Price: Period P5 Price:

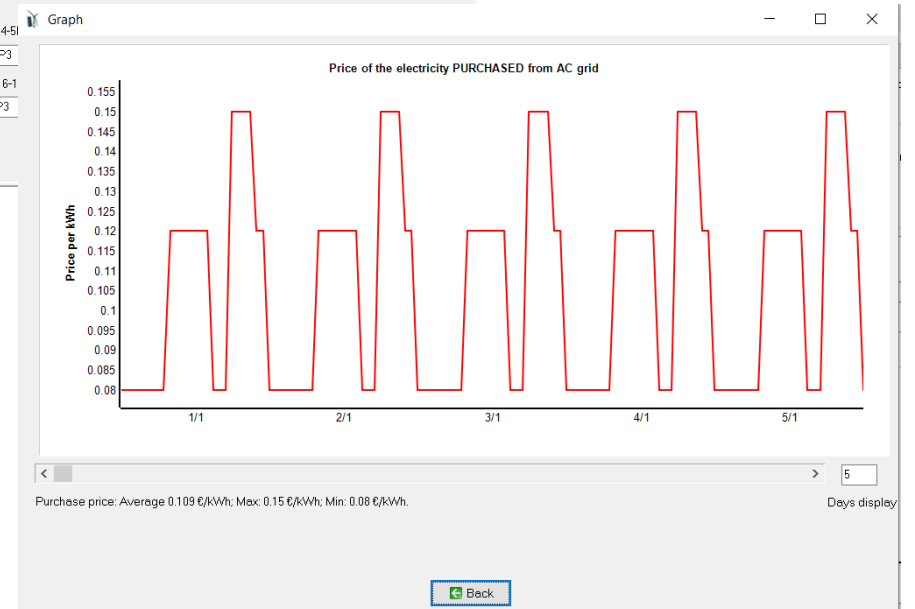
Period P3 Price: Period P6 Price:

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
P3	P3	P3	P3	P3	P3	P3	P3	P2	P2	P2	P2
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	P1	P1	P2	P2	P2	P2	P2	P2	P2	P2	P2

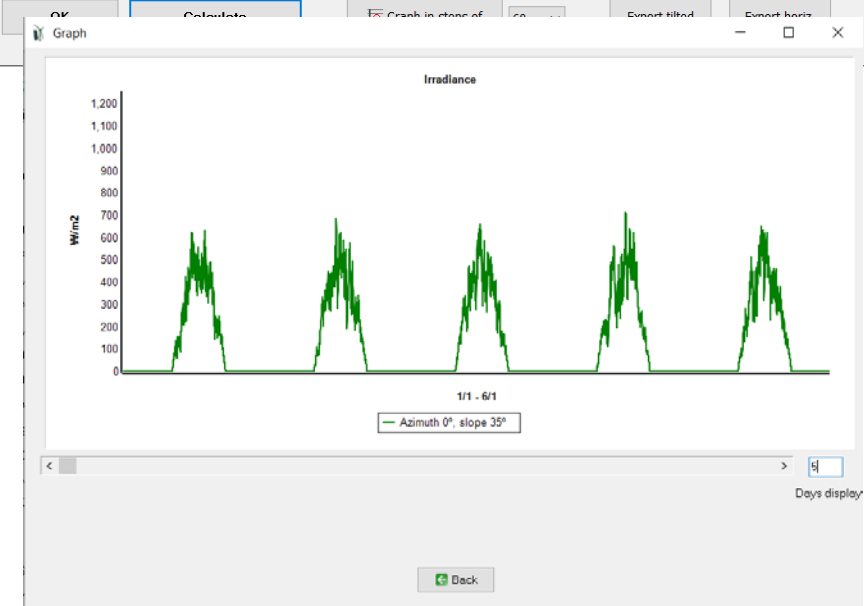
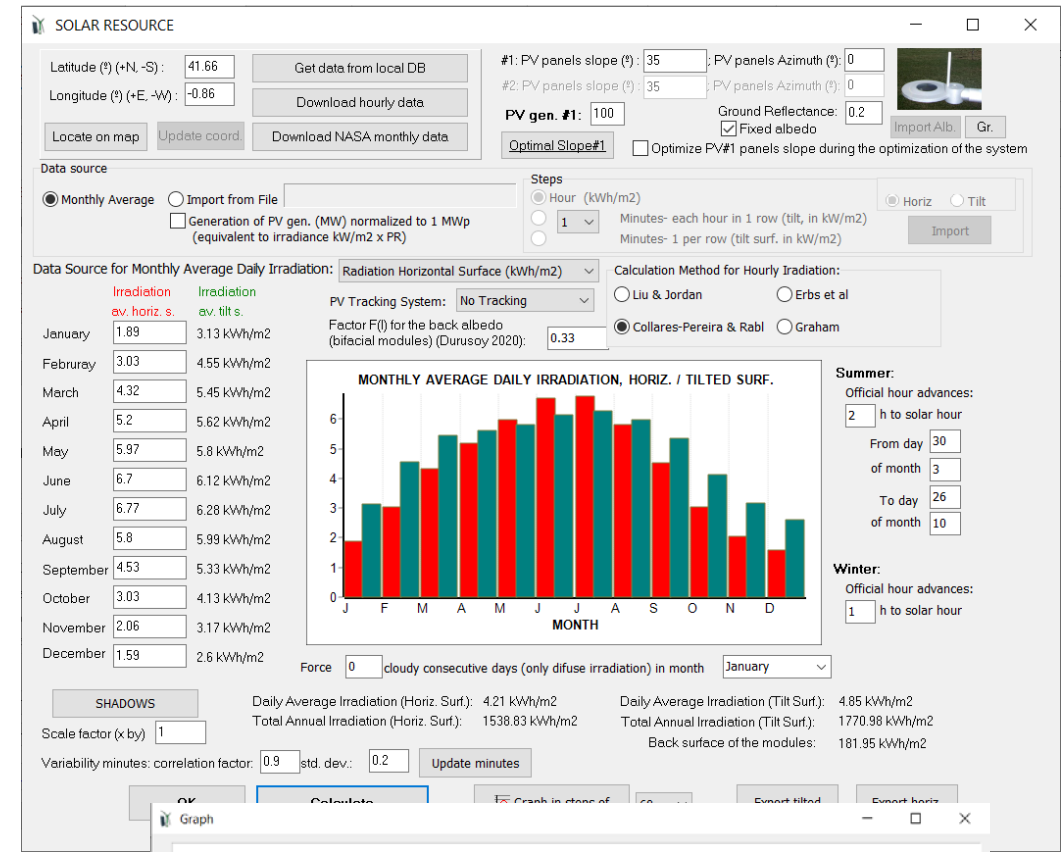
WINTER periods distribution:

0-1h	1-2h	2-3h	3-4h	4-5h
P3	P3	P3	P3	P3
12-13h	13-14h	14-15h	15-16h	16-17h
P2	P2	P2	P3	P3



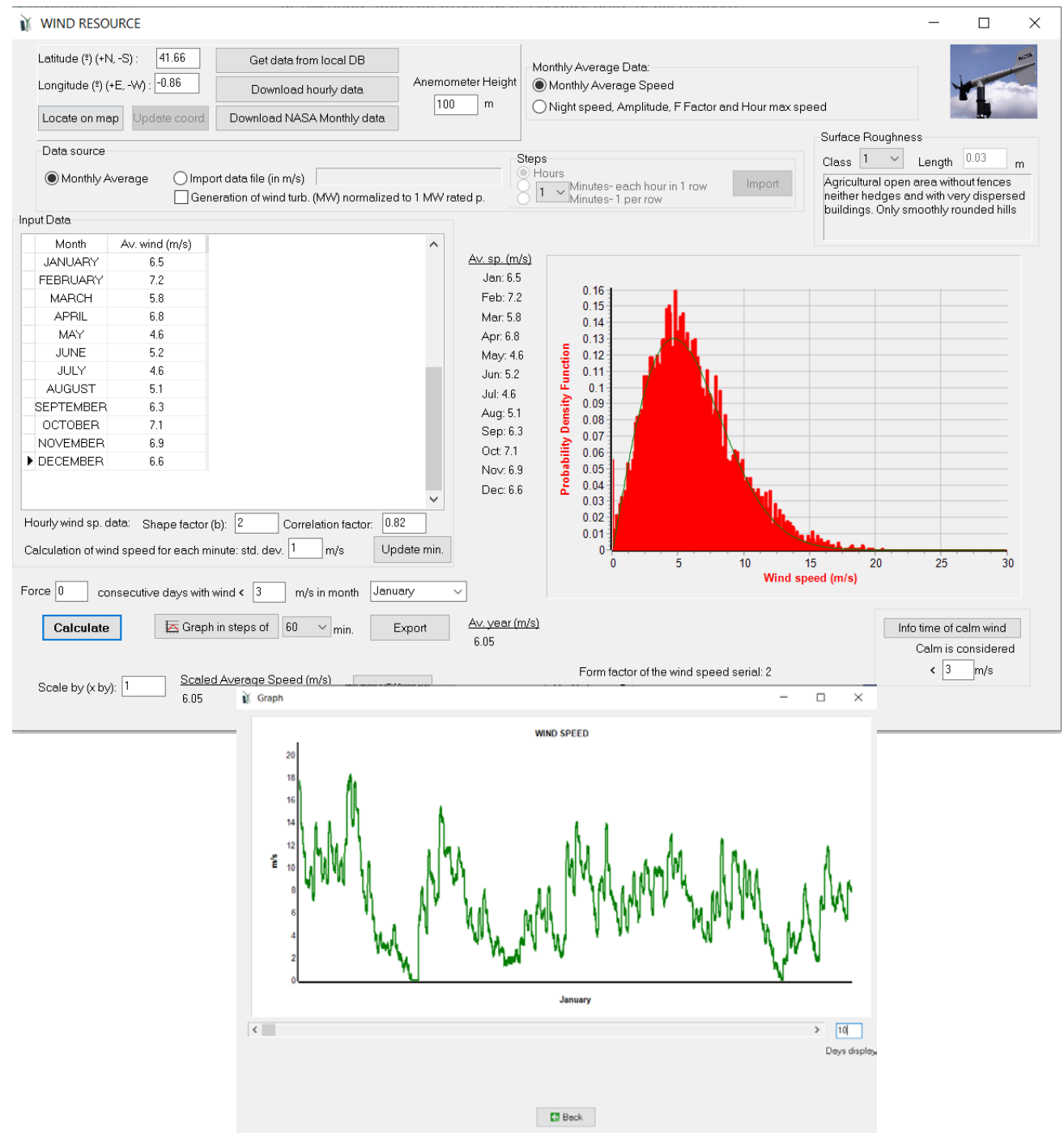
Irradiation

- 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.
- Irradiation over the back surface is calculated -> PV bifacial modules can be considered
- CPV can be considered (direct irradiation)



Wind speed

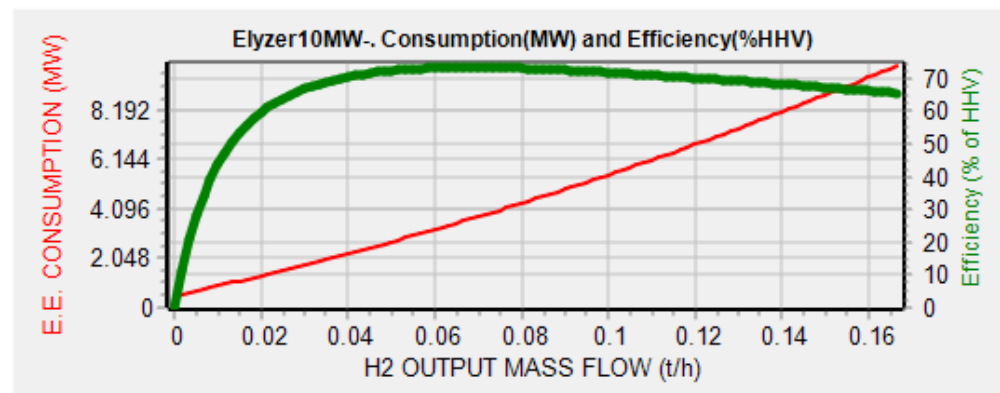
- Monthly average converted to hourly and minute basis
- Or download or import hourly or minute basis data



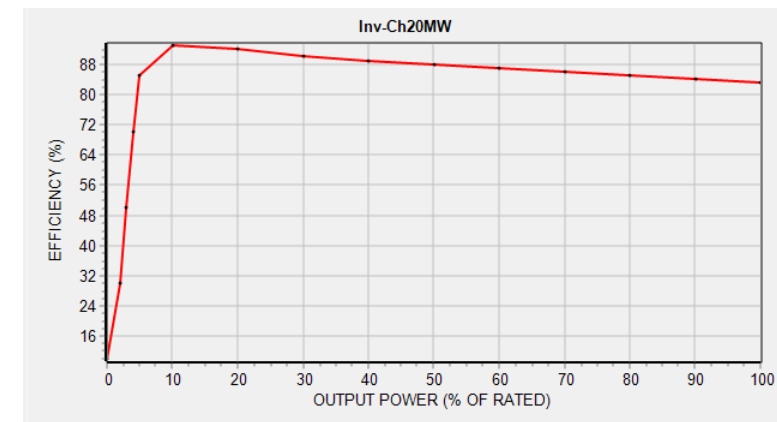
Models for components

- 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

Temp. J 18 F 18 M 20 A 20 M 20 J 22 Mean (°C) 20
 Bat. (°C) J 22 A 22 S 22 O 20 N 18 D 18
☒ Except Schiffer model, consider Tmean>=Tfloat life
☒ Cycle life depends on T
☒ Capacity depends on T
 Float life reduces 50% for every 10 °C increase
☒ Mon. ☐ Hour
 Lead-acid Aging battery model
☐ Wang et al., 2011 (LiFePO4)
☐ Grot et al., 2015 (LiFePO4)
☐ Saxena et al., 2016 (LiCoO2)
☐ Full equivalent cycles
☒ Rainflow (cycle counting)

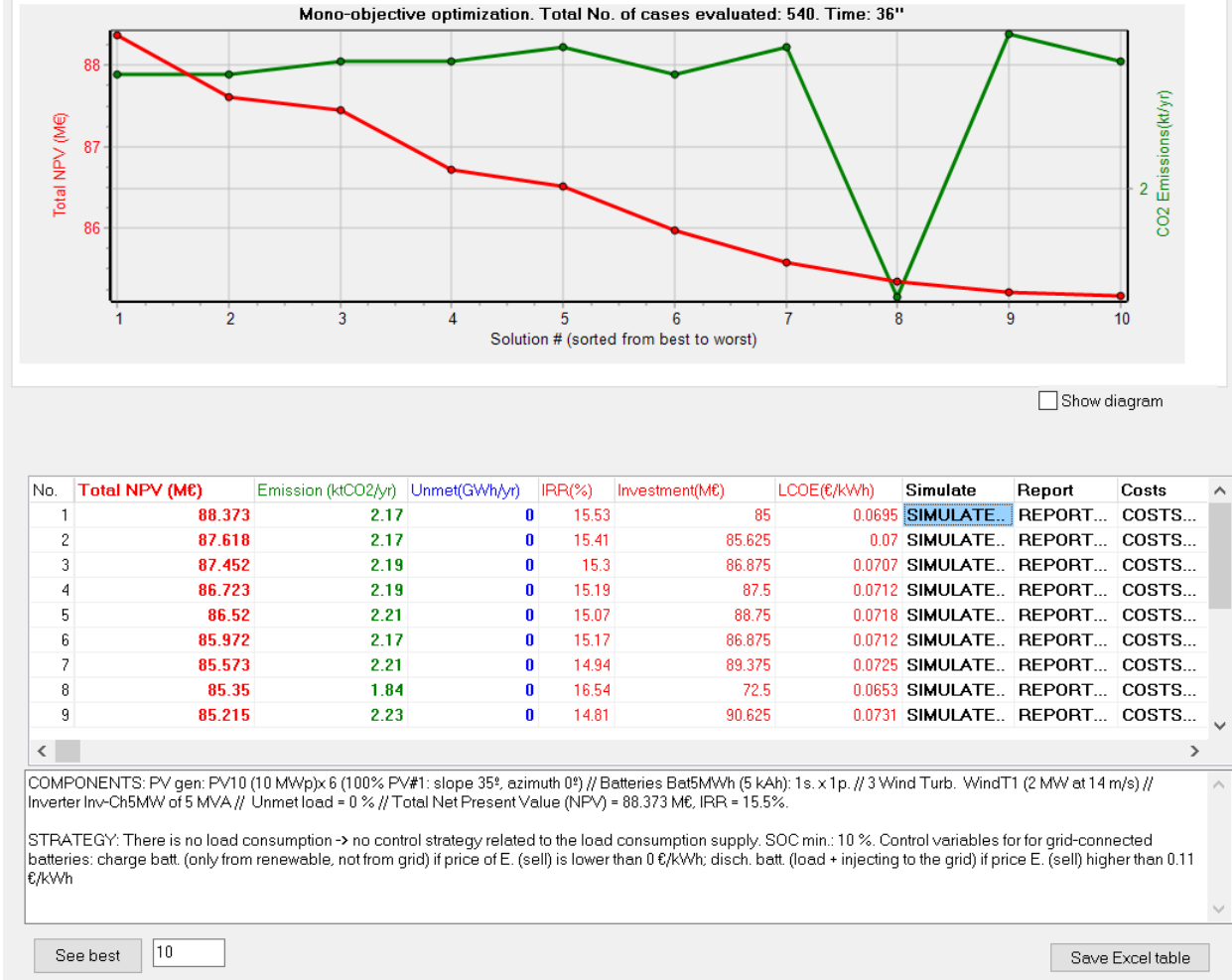


Nominal H2 mass flow = 0.166 t/h; It is needed at least 0.5 MW to generate H2

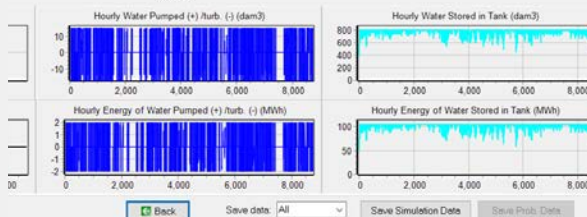
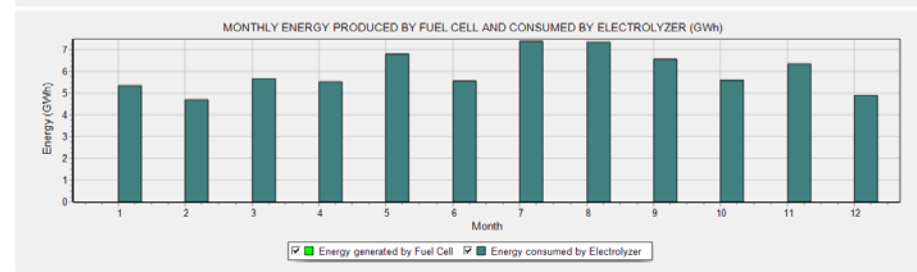
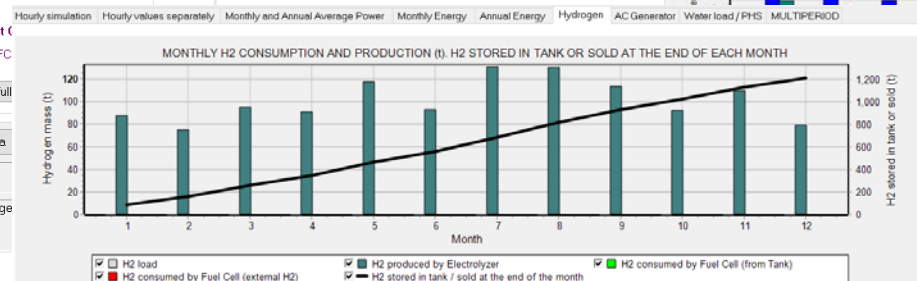
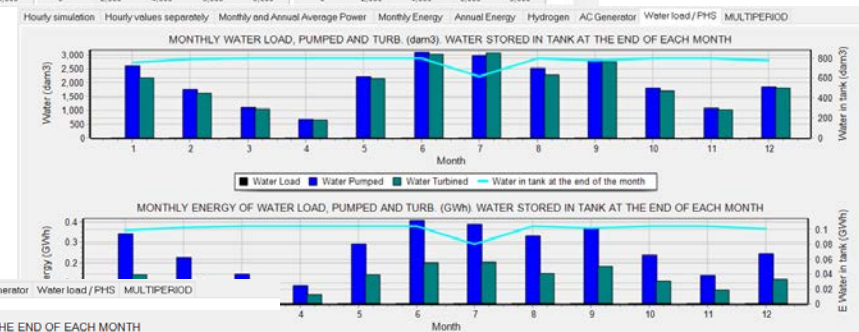
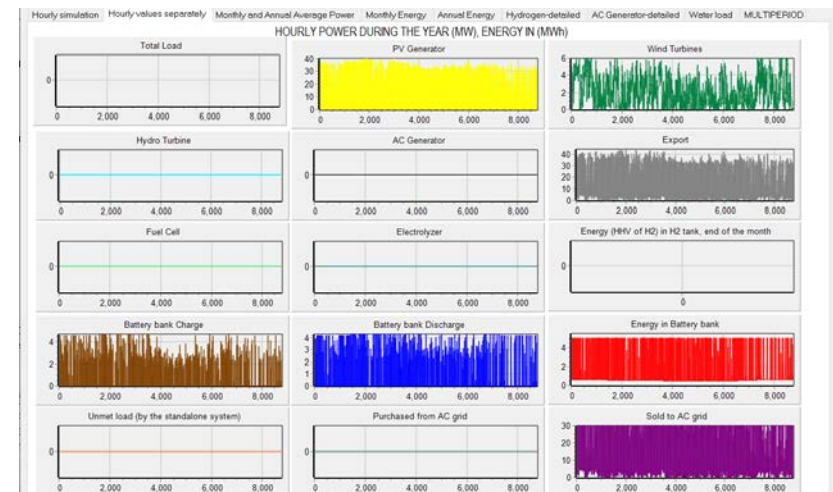
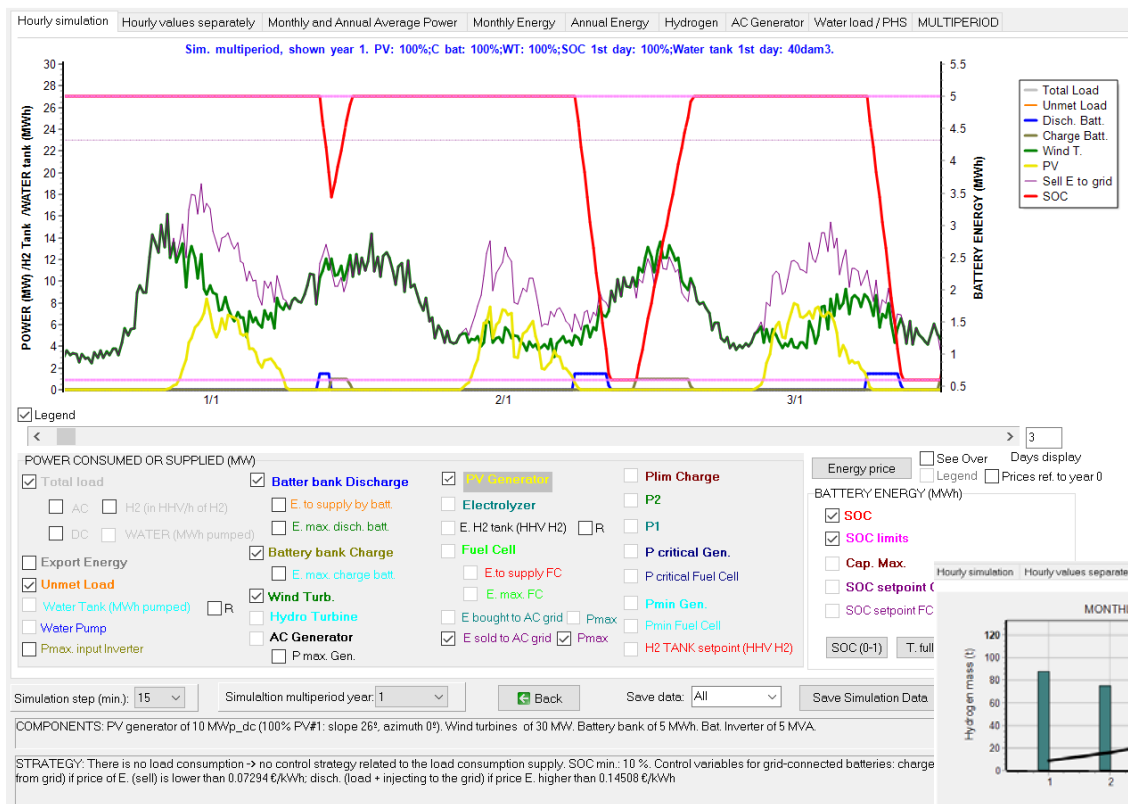


Optimization results

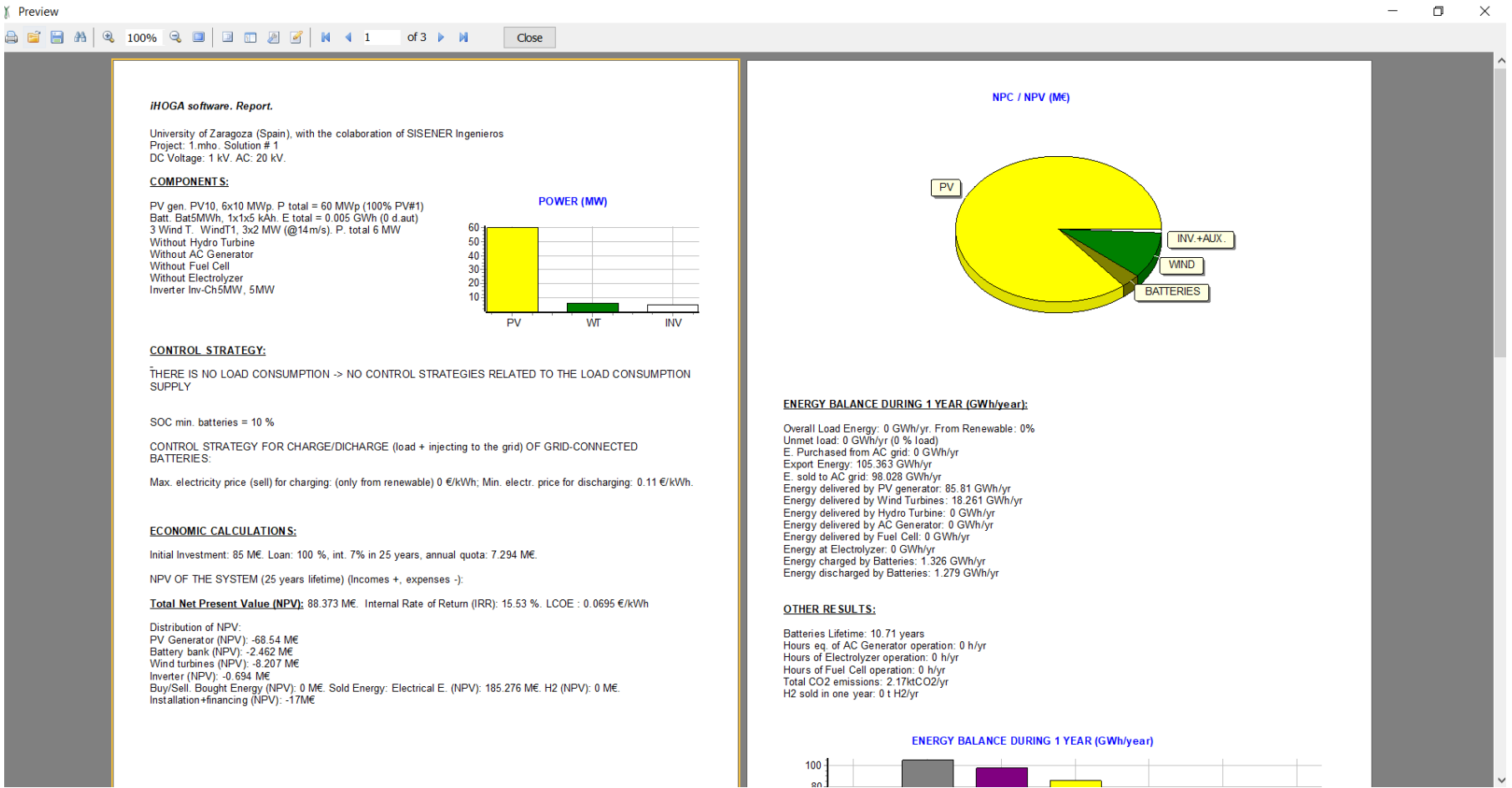
- Combinations sorted from best to worst
- Simulation of each combination
- General report of each combination
- Costs report of each combination



Optimization results



Optimization results



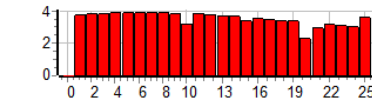
Optimization results

Project: 1.mho. Solution # 1

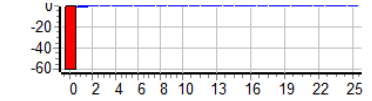
Distribution of Incomes (+) and costs (-), NPV, during the years. RED: acqu. costs, replac. costs and incomes for final sale. BLUE: O&M. Currency: M€.

Total NPV: 88.373 M€, IRR =15.5 %. Inversion cost: 85 M€. Loan of 100 %, int. 7% in 25 yr., quota: 7.294 M€/yr.

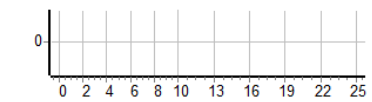
TOTAL NPV: 88.373 M€



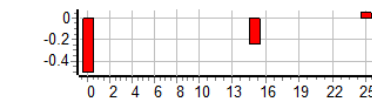
Total Cost of PV Generator (NPV): -68.54 M€



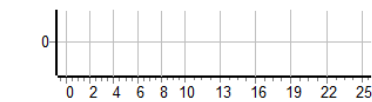
Total Cost of Hydro (NPV): 0 M€



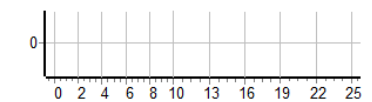
Total Cost of Inverter (NPV): -0.694 M€



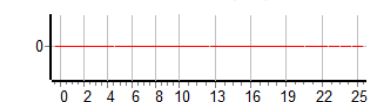
Total Cost of Electrolyzer (NPV): 0 M€



Total Cost of H2 Tank (NPV): 0 M€



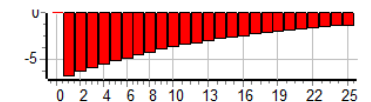
Total Cost of External Fuel for FC (NPV): 0 M€



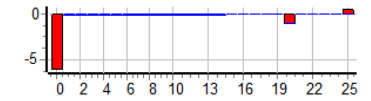
Total Incomes of E sold to AC grid (NPV): 185.276 M€



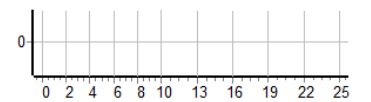
Financial Cost (NPV): initial payment + annual quotas: -85 M€



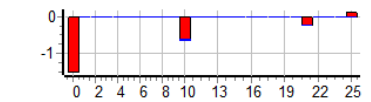
Total Cost of Wind Turbines group (NPV): -8.207 M€



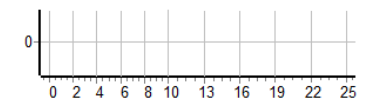
Total Cost of AC Generator (NPV): 0 M€



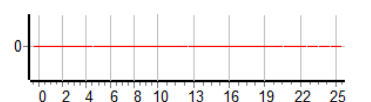
Total Cost of Batteries Bank (NPV): -2.462 M€



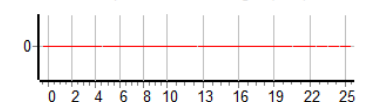
Total Cost of Fuel Cell (NPV): 0 M€



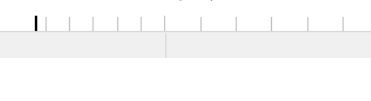
Total Cost of AC Gen. Fuel (NPV): 0 M€



Total Cost of E purchased from AC grid (NPV): 0 M€



Total Incomes of H2 sold (NPV): 0 M€



Other features

- Sensitivity analysis
- Probability analysis
-

Sensitivity Analysis

Wind Solar Load Interest and Inflation (general or electricity cost) AC gen. fuel inflation Components cost

SENSITIVITY ANALYSIS OF ANNUAL INTEREST (I) AND INFLATION (g) RATES

(I-g) 1: Case base: Interest: 7%; Inflation Electricity cost: (purchase and sell inflations shown in LOAD/AC GRID)

(I-g) 2: Interest: 4 % Inflation: 2 %

(I-g) 3: Interest: 3 % Inflation: 1 %

Inflation refers to:

☐ General inflation

☒ Electricity inflation (Purchase and Sell price inflation) (in base case shown values of buy price inflation \ sell price inflation)

Probabilistic analysis of variability of load, irradiation, wind speed and/or water flow (or fuel price inflation)

☐ DO NOT PERFORM PROBABILITY ANALYSIS ☒ PERFORM PROBABILITY ANALYSIS

Number of series to analyze each combination of components and control strategy: 500

Stopping rule in Monte Carlo Simulation:

☒ Confidence level (%) 99 max. error of the mean (%) 5

☐ Relative standard error lower than (%) 1

☐ Monte Carlo simulation with stopping rule

☐ Analyze variability of the average value of load

☒ Analyze variability of the average value of irradiation

IRRADIATION AVERAGE VALUE

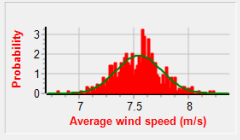
Mean: 4.95 kWh/m2/day
Standard Deviation: 0.2 kWh/m2/day
Mean = 4.958, Std. Dev. = 0.206 kWh/m2/day
Maximum = 5.77, Min. = 4.35 kWh/m2/day
Hourly variability in the series: 0 %
Std. deviation for temperature: 1 °C



☒ Analyze variability of the average value of wind speed

WIND SPEED AVERAGE VALUE

Mean: 7.55 m/s
Standard Deviation: 0.5 m/s
Mean = 7.547, Std. Dev. = 0.206 m/s
Maximum = 8.24, Min. = 6.82 m/s
Hourly variability in the series: 0 %
Std. deviation for temperature: 1 °C

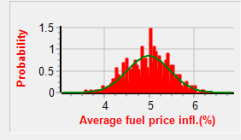


☐ Analyze variability of the average value of water flow

☒ Analyze variability of the average value of fuel price inflation. Average (%): 5

AVERAGE FUEL PRICE INFL. (SUP. 5%)

Mean: 5 %
Standard Deviation: 0.5 %
Mean = 4.982, Std. dev. = 0.476 %
Maximum = 6.2, Min. = 3.59 %
Hourly variability in the series: 0 %



☐ Consider correlation between the variables

Correlation data

In the simulation, show the case obtained with the following data:

Load: Average Irradiation: Average Wind speed: Average Fuel inflation: Average

☐ In the case of the simulation, include hourly variability

In the probability analysis report, in the last two charts, show the probability distribution of:

Hours running AC Generator (h/yr) Annual cost of fuel of AC Generator (currency/yr)

☐ When clicking at any cell of the results table, do not update results

☐ When clicking on simulation button, do not consider the characteristic cases

☒ Each year different mean value

OK

More info

- <https://ihoga.unizar.es/en/>
- User manual:
[https://ihoga.unizar.es/Desc/MHOGA User manual.pdf](https://ihoga.unizar.es/Desc/MHOGA_User_manual.pdf)
- Getting started guide:
[https://ihoga.unizar.es/Desc/GETTING STARTED MHOGA.pdf](https://ihoga.unizar.es/Desc/GETTING_STARTED_MHOGA.pdf)

Thank you!