

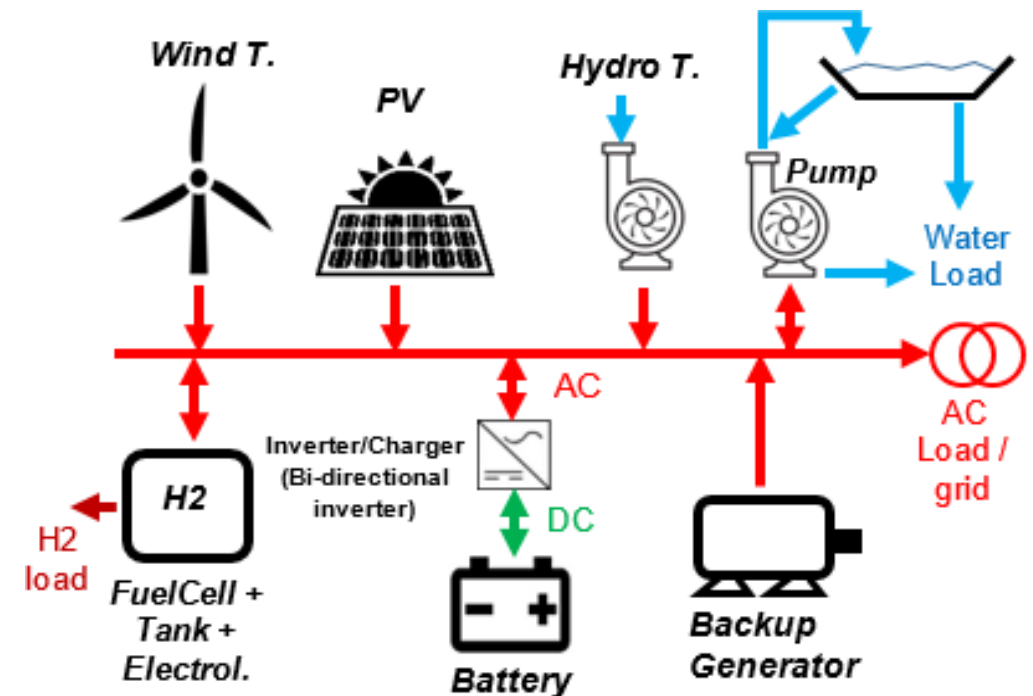
# MHOGA software

## MegaWatt Hybrid Optimization by Genetic Algorithms

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# Overview

- Simulation and optimization software
- Off-grid or grid-connected generating systems
- Possible load:
  - AC
  - DC
  - H<sub>2</sub> 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<sub>2</sub> tank – fuel cell
  - Fossil fuel generators
- Sell / Buy electricity to the AC grid
- Sell H<sub>2</sub> generated by electrolyzer (Green H<sub>2</sub>)



# 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)
    - Sell generated green H<sub>2</sub> 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:**

Obtain random values for: PURCHASE E. price inc. Average (%):  Std. dev. (%):

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

Show in the simulation during one year:

☒ Average year

☐ Year number:

Annual increase in electricity and H<sub>2</sub> price: ☐ Fixed  
(if fixed, same values as price inflations of LOAD/AC GRID)  
AC grid Electricity: Purchase:  %; Sell:  %  
H<sub>2</sub> sold:  %

Annual increase in load consumption: ☐ Fixed  
AC:  %; DC:  %  
H<sub>2</sub>:  %; 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

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

Year	Purch.E.	Sell E.	Sell H <sub>2</sub>	Inc. AC	Inc. DC	Inc. H <sub>2</sub>	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 supply 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<sub>2</sub> emissions
  - NPC - Unmet load
  - NPC - CO<sub>2</sub> 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 —>

☒ Min. NPC  
☐ Min. LCOH  
☐ Min. Payback period  
☐ Max. IRR savings vs AC only

☒ Max. NPV  
☐ Min. LCOE  
☐ Min. LCOH  
☐ Max. Cap.F. min. LCOE  
☐ Max. IRR  
☐ Min. Payback period

☒ Cost - CO<sub>2</sub> Emis. ☐ Triple  
☐ Cost - Unmet load ☐ Another

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

# Optimization

- 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 or lowest LCOH or...)
- If too many combinations -> optimization time can be too high, inadmissible → Use **Genetic Algorithms** metaheuristic 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 green H<sub>2</sub> generation
- **Frequency containment reserve (FCR) service**

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:**

<input type="checkbox"/> Pmin_gen	<input type="checkbox"/> Pmin_FC	<input type="checkbox"/> H2TANKstp
<input type="checkbox"/> P1_gen	<input type="checkbox"/> P1_FC	<input type="checkbox"/> P2
<input type="checkbox"/> SOCstp_gen	<input type="checkbox"/> SOCstp_FC	<input type="checkbox"/> SOCmin
<input type="checkbox"/> Pcritical_gen	<input type="checkbox"/> Pcritical_FC	<input type="checkbox"/> Plim_charge

ENERGY ARBITRAGE: System with batteries and grid connected

☒ Batt. charged by the AC grid // discharged if: ☒ (also for Elyzer.-> H2) ☐ Elyzer. full load

Price E<=  €/kWh // Price E>=  €/kWh ☐ D-% ☒ (Compare with Sell price)

☐ Optimize strategy of grid-connected batteries:

☒ Batteries can inject electricity to the AC grid

☐ 1 day at low SOC-> charge battery with AC grid

☐ When batteries are off, compensate autodisch.

☐ FCR (use 1 min time step)

# 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

## ECONOMIC DATA:

Nominal interest rate (capital cost):	<input type="text" value="7"/>	%	Annual real discount ratel (%):	<input type="text" value="4.9"/>	%
(nominal discount rate)					
Annual inflation rate (O&M...):	<input type="text" value="2"/>	%	<input checked="" type="checkbox"/> In LCOE / LCOH include real disc. rate in Energy		
Study period (system lifetime):	<input type="text" value="25"/>	years	<input checked="" type="checkbox"/> In maximize NPV systems use Inf. sell / H2		
			<input type="checkbox"/> In max. NPV, LCOE calculated with Esell+Eload		
<input checked="" type="checkbox"/> At the end of the study period consider the residual cost of the components					
Currency	<input type="text" value="Euro (€)"/>		<input checked="" type="checkbox"/> Discounted Payback period		
			Consider loan: <input type="checkbox"/> for payback <input type="checkbox"/> for IRR		
Installation cost and variable initial cost:	<input type="text" value="0"/>	M€ Fix +	<input type="text" value="25"/>	% of initial cost	
Corporate taxes (%)	<input type="text" value="0"/>		<input checked="" type="checkbox"/> If in a year costs > incomes, taxes = 0 that year		
			<input checked="" type="checkbox"/> Negative taxes accumulate and are offset later when taxes > 0		

## Loan (constant quota, French system):

Amount of loan:	<input type="text" value="100"/>	%
of the initial cost of investment		
Loan Interest:	<input type="text" value="7"/>	%
Duration of loan:	<input type="text" value="25"/>	years

☐ Capacity Market

Data

# 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

Average: 100

Std. dev.: 10

X: hours of duration of PHS

1

Y: hours of duration of PHS

9

From year: 1

To year: 25

Year	Price (€/MWh/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 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

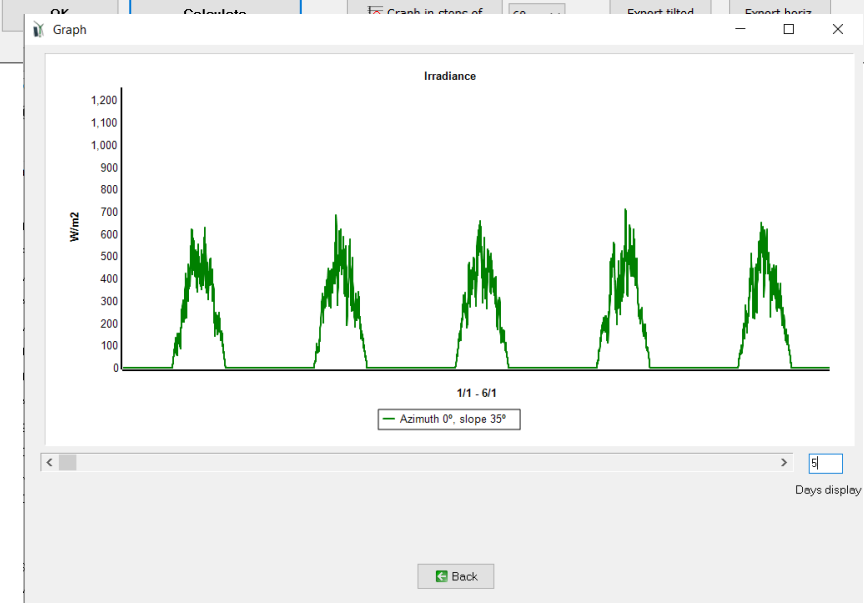
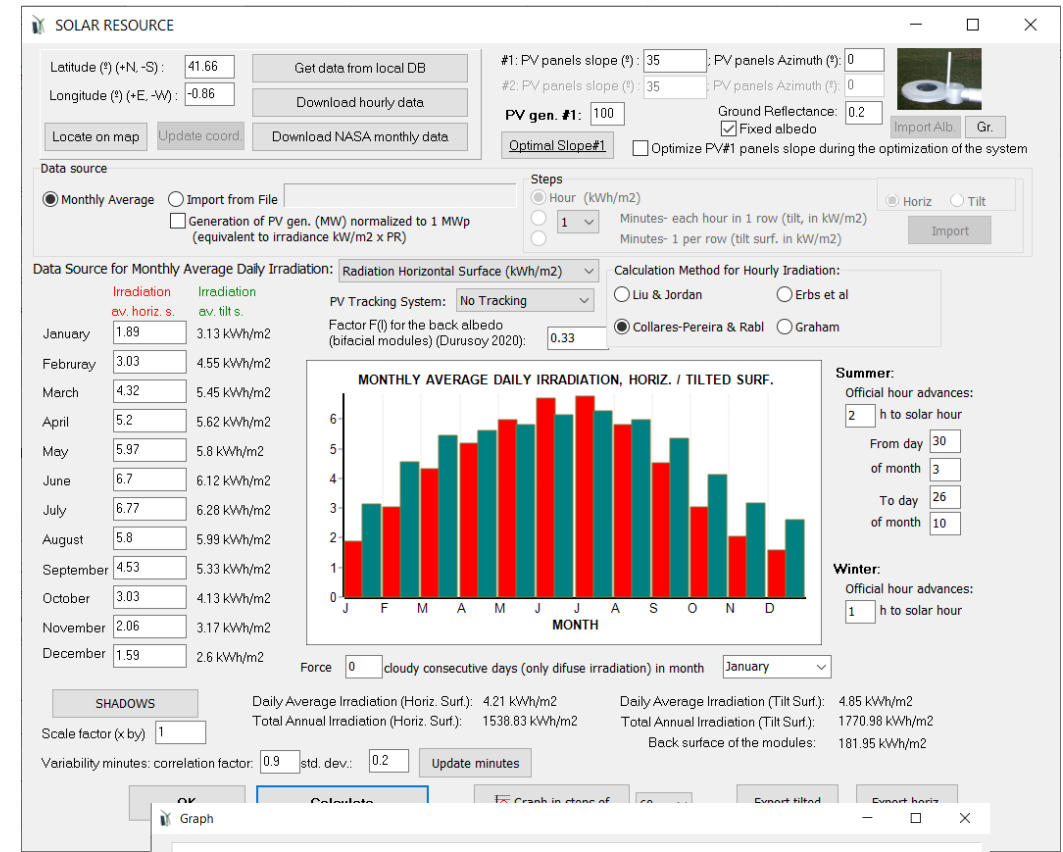
WINTER periods distribution:

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



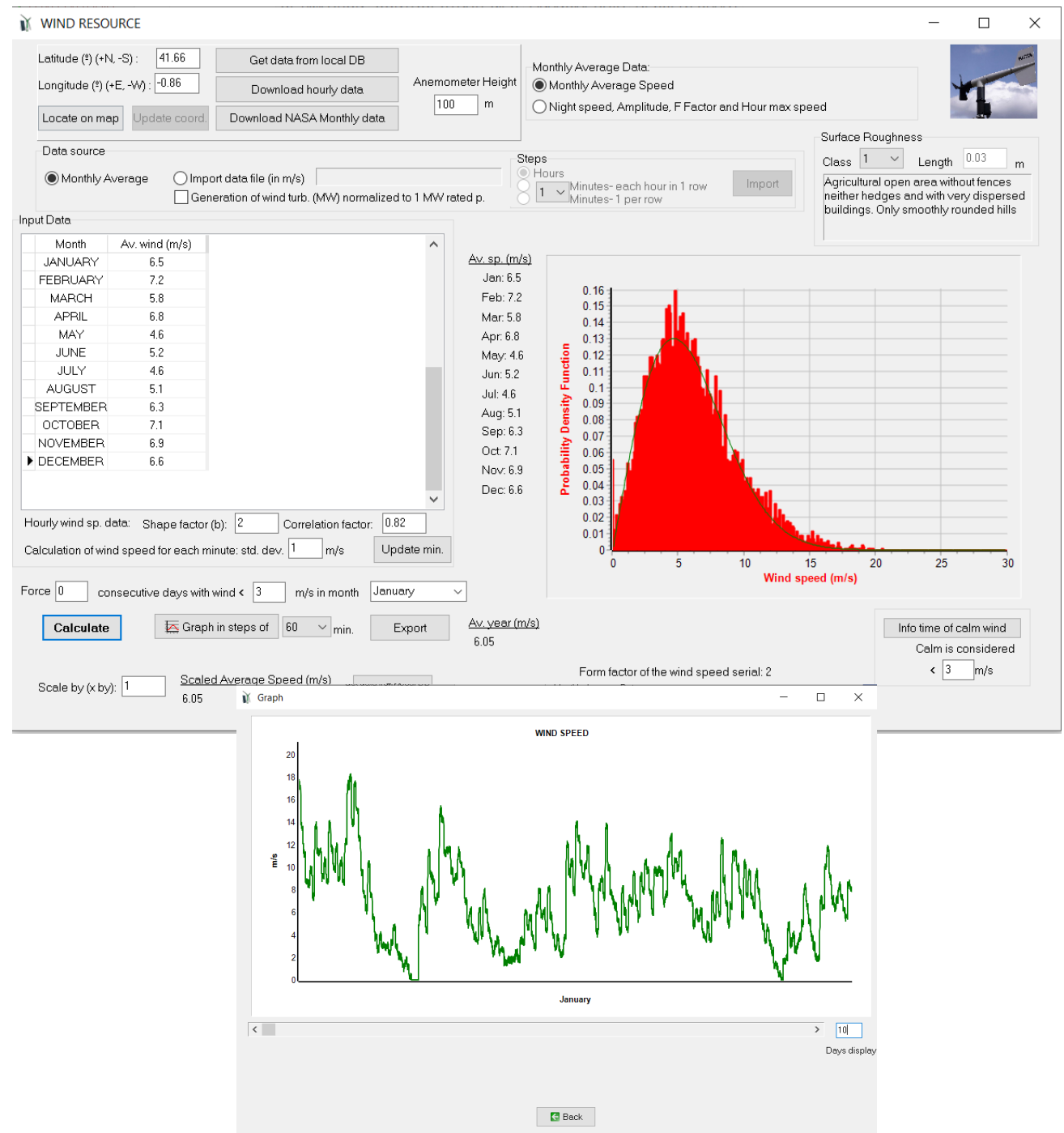
# Irradiation

- 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



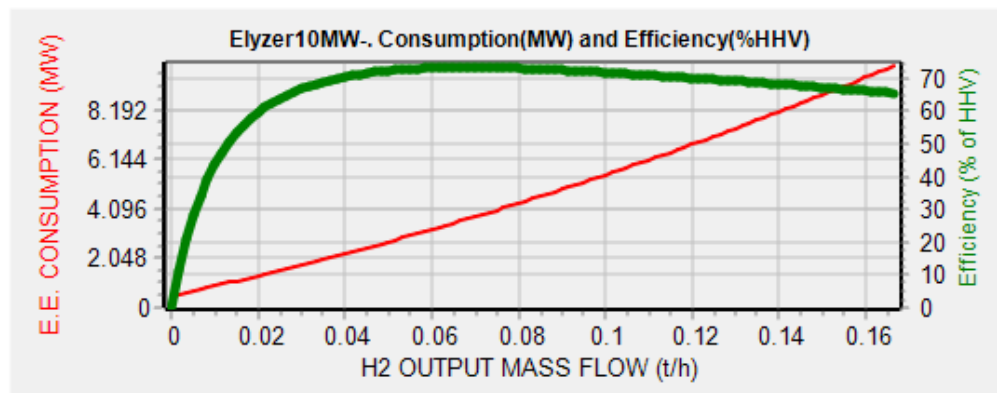
# Models for components

- 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

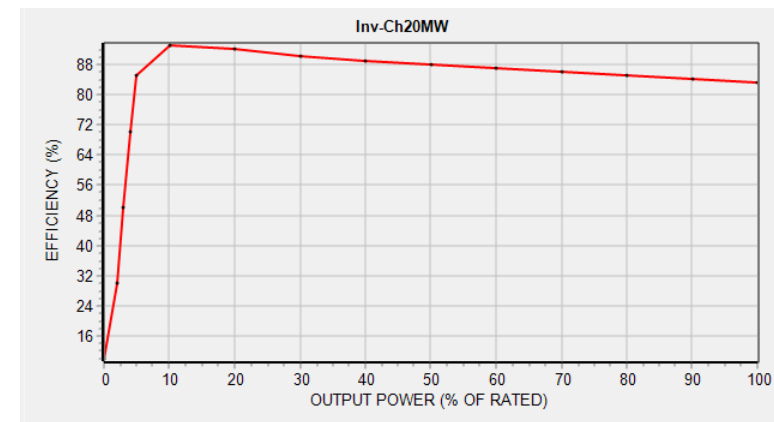
Temp. J 18 F 18 M 20 A 20 M 20 J 22 Mean (°C) 20  
 Bat. (°C) J 22 A 22 S 22 O 20 N 18 D 18  
☒ Except Schiffer model, consider Tmean>=Tfloat life  ☒ Mon. ☐ Hour  
 Float life reduces 50% for every 10 °C increase   
☒ Cycle life depends on T   
☒ Capacity depends on T

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)  
☐ Full equivalent cycles  
☒ Rainflow (cycle counting)

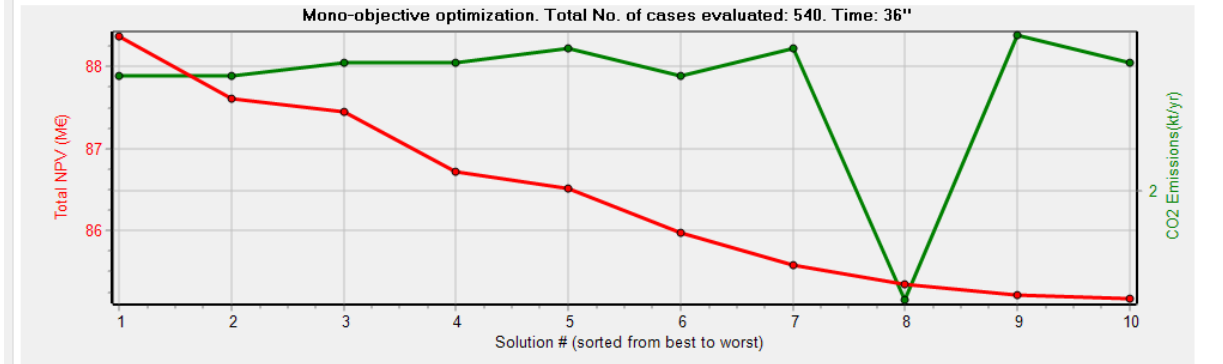


Nominal H2 mass flow = 0.166 t/h; It is needed at least 0.5 MW to generate H2



# Optimization results

- Combinations sorted from best to worst (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	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
2	87.618	2.17	0	15.41	85.625	0.07	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
3	87.452	2.19	0	15.3	86.875	0.0707	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
4	86.723	2.19	0	15.19	87.5	0.0712	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
5	86.52	2.21	0	15.07	88.75	0.0718	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
6	85.972	2.17	0	15.17	86.875	0.0712	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
7	85.573	2.21	0	14.94	89.375	0.0725	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
8	85.35	1.84	0	16.54	72.5	0.0653	<a href="#">SIMULATE...</a>	REPORT...	COSTS...
9	85.215	2.23	0	14.81	90.625	0.0731	<a href="#">SIMULATE...</a>	REPORT...	COSTS...

COMPONENTS: PV gen: PV10 (10 MWp) x 6 (100% PV#1: slope 35°, azimuth 0°) // Batteries Bat5MWh (5 kWh): 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%.

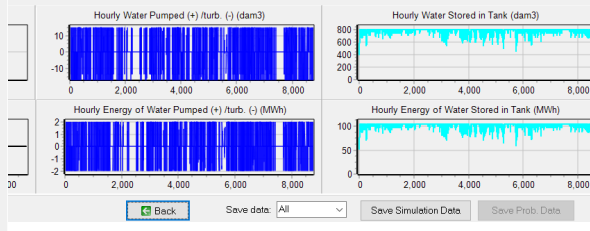
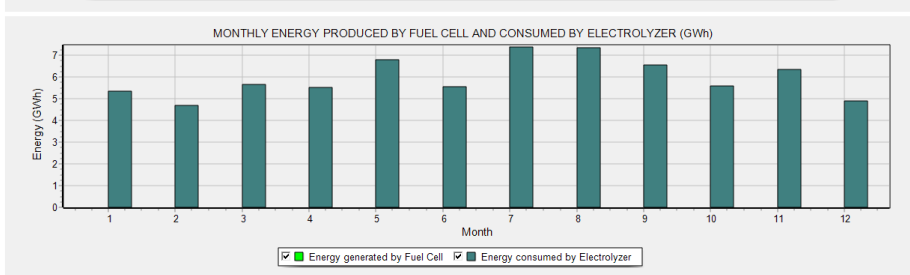
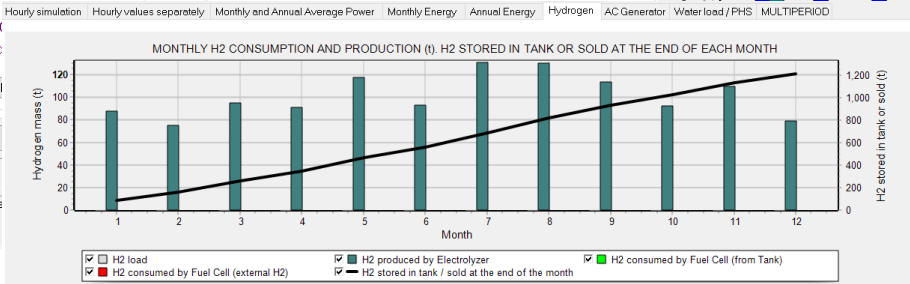
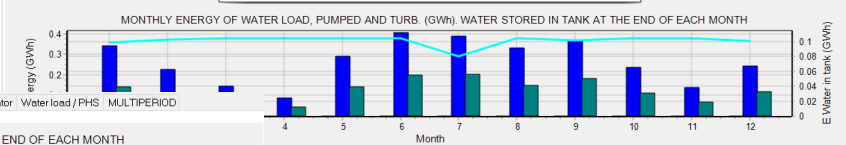
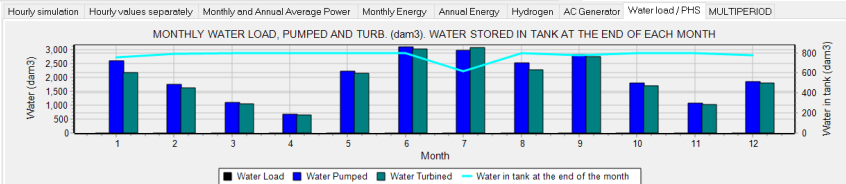
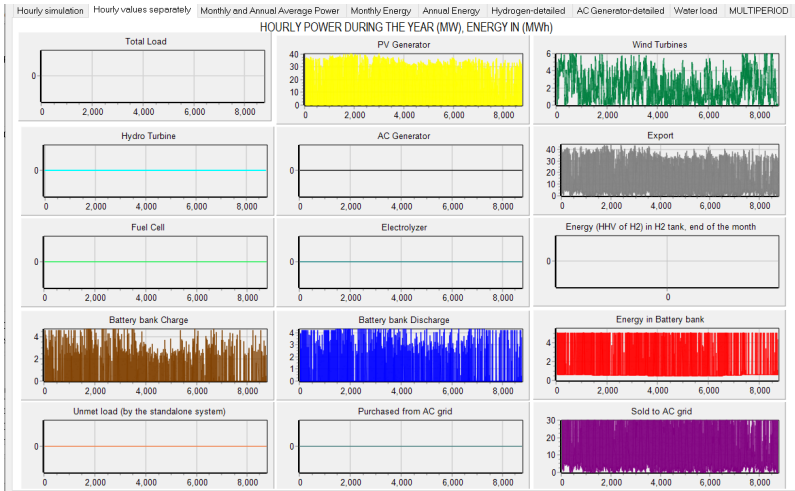
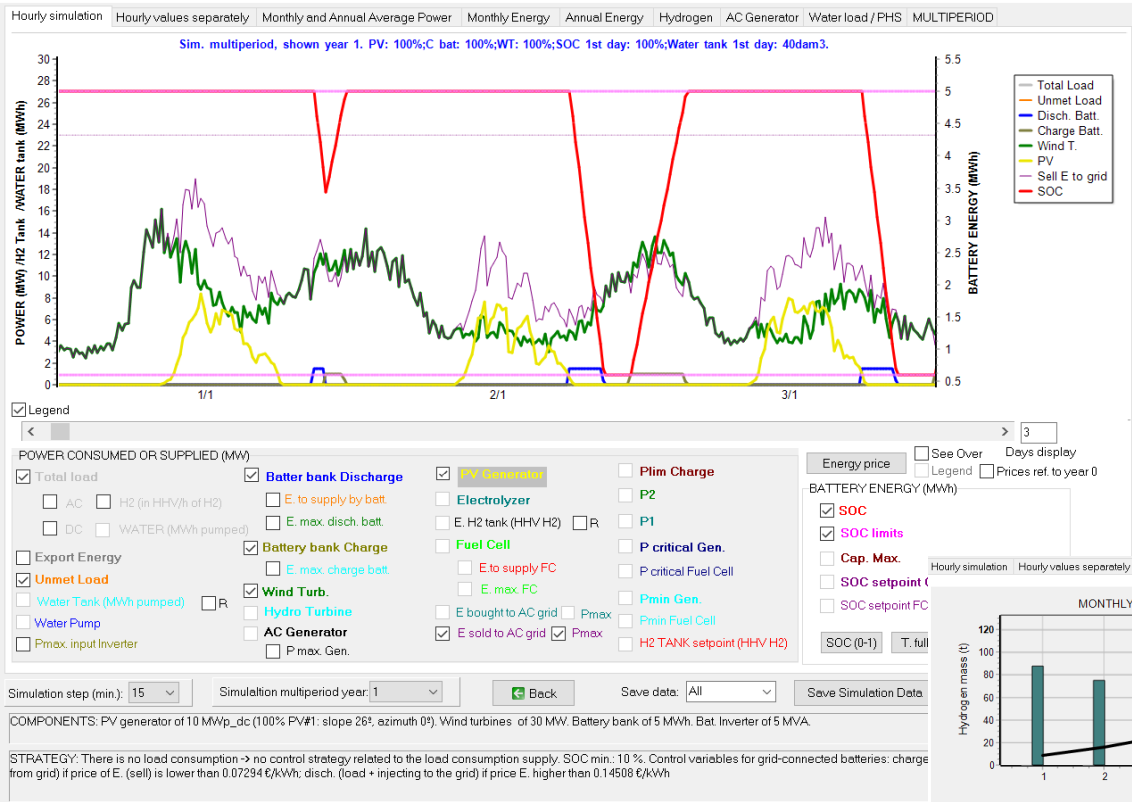
STRATEGY: There is no load consumption -> no control strategy related to the load consumption supply. SOC min.: 10 %. Control variables for for grid-connected batteries: charge batt. (only from renewable, not from grid) if price of E. (sell) is lower than 0 €/kWh; disch. batt. (load + injecting to the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

See best

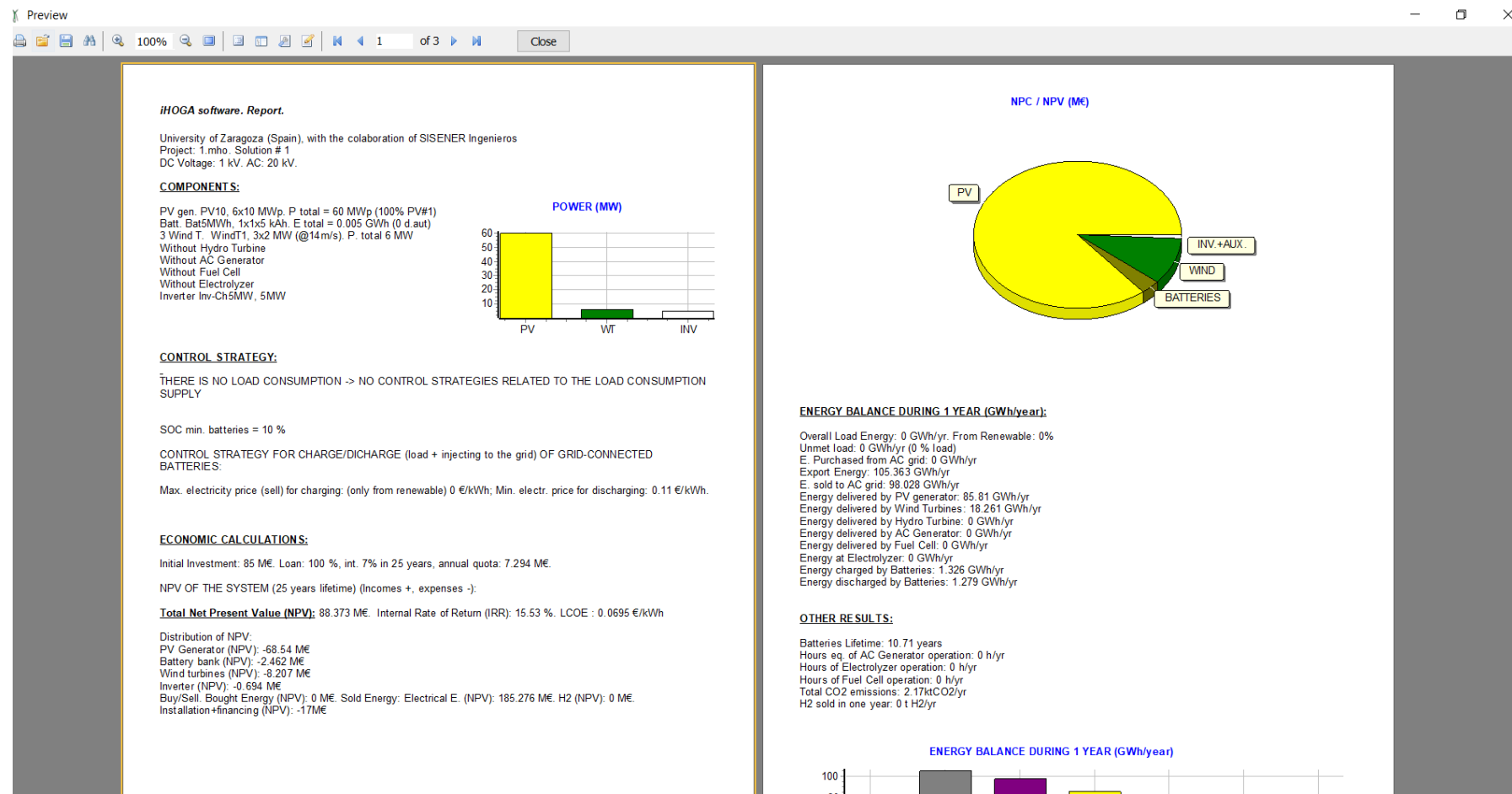
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Save Excel table

# Optimization results



# Optimization results





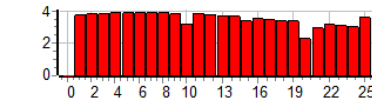
# Optimization results

Project: 1.mho. Solution # 1

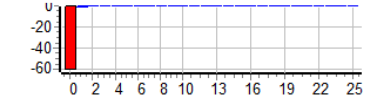
Distribution of Incomes (+) and costs (-), NPV, during the years. RED: acqu. costs, replac. costs and incomes for final sale. BLUE: O&M. Currency: M€.

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.

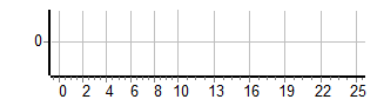
TOTAL NPV: 88.373 M€



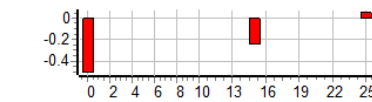
Total Cost of PV Generator (NPV): -68.54 M€



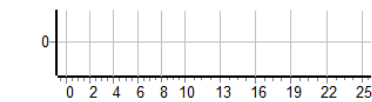
Total Cost of Hydro (NPV): 0 M€



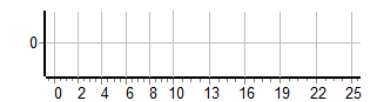
Total Cost of Inverter (NPV): -0.694 M€



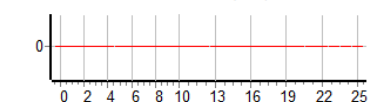
Total Cost of Electrolyzer (NPV): 0 M€



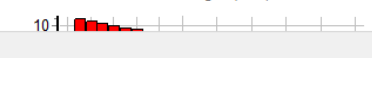
Total Cost of H2 Tank (NPV): 0 M€



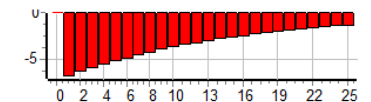
Total Cost of External Fuel for FC (NPV): 0 M€



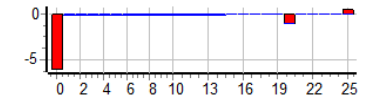
Total Incomes of E sold to AC grid (NPV): 185.276 M€



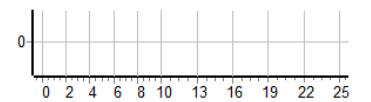
Financial Cost (NPV): initial payment + annual quotas: -85 M€



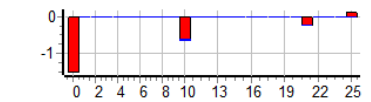
Total Cost of Wind Turbines group (NPV): -8.207 M€



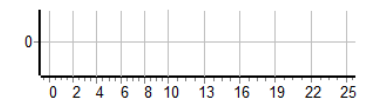
Total Cost of AC Generator (NPV): 0 M€



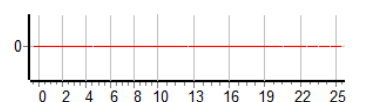
Total Cost of Batteries Bank (NPV): -2.462 M€



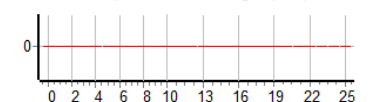
Total Cost of Fuel Cell (NPV): 0 M€



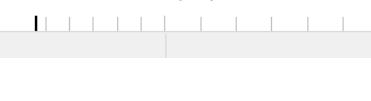
Total Cost of AC Gen. Fuel (NPV): 0 M€



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

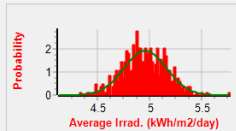
☐ Monte Carlo simulation with stopping rule

☐ Analyze variability of the average value of load

☒ Analyze variability of the average value of irradiation

**IRRADIATION AVERAGE VALUE**

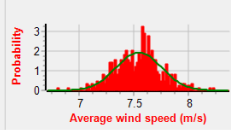
Mean: 4.95 kWh/m2/day  
Standard Deviation: 0.2 kWh/m2/day  
Mean = 4.958, Std. Dev. = 0.206 kWh/m2/day  
Maximum = 5.77, Min. = 4.35 kWh/m2/day  
Hourly variability in the series: 0 %  
Std. deviation for temperature: 1 °C



☒ 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

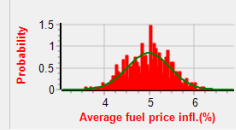


☐ Analyze variability of the average value of water flow

☒ 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!