

1 MOHRES Main User Interface

MOHRES

Site System Type Load Type

Inputs01P... Standalone Fixed

Analysis

WT Rotor Radius (m) 7

PV Panel Area (m²) 60

No of Batteries 40

Nominal Diesel Generator Size (Watt) 5000

Nominal Fuel Cell Size (Watt) 10000

Nominal Electrolyser Capacity (Watt) 10000

Deterministic Analysis Stochastic Analysis

Design

Design Method Deterministic: Storage Sizin...

Optimisation Method GA Single Obj Constrained

Start Design

NaN = System Cost (\$)

100 = Levelised Cost of Energy (cent/kWh)

NaN = Total Blackout Duration (h)

NaN = Average Blackout Duration (h)

NaN = Maximum Blackout Duration (h)

0 = Unmet Load (Wh)

NaN = MTBF (h)

NaN = Penetration (%)

NaN = CO2 Emission (kg)

NaN = Excess Power (Wh)

10 = Exhaustive Search: grid size

100 = GA/PS: max generation/iteration

20 = GA/PS: population size

0.3 = GA: Pc

0.9 = GA: Pm

0.2 = Margin of safety (-) (storage sizing)

1 = Autonomy period (day) (battery sizing)

Set/Edit Design, Optimisation and Analysis Parameters

Saved Results

Saved Optimisation Results CS1_PVB_01.mat

Saved Solutions CS1a_MC.mat

Site Data & System Type

- Demand load and renewable resources data
- System type
- Demand load type

Analysis

- System Size
- Analysis Type

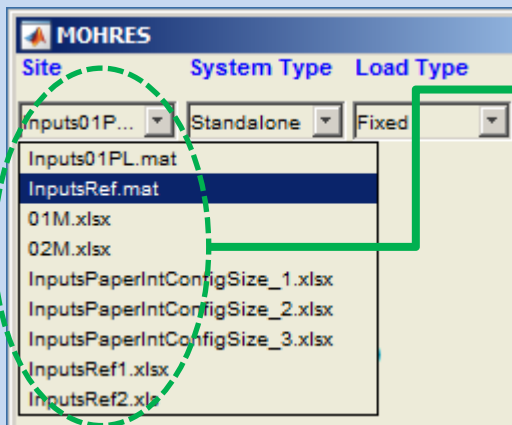
Design

- Design Method
- Optimisation Method

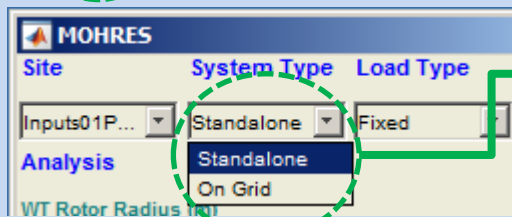
Power & Cost Models, Design & Optimisation Parameters

Load Saved Results

2 Site Data & System Type

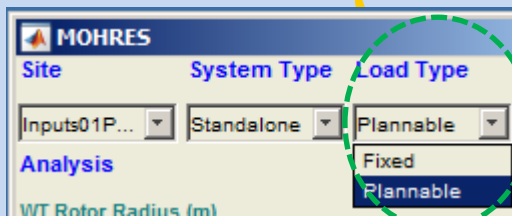
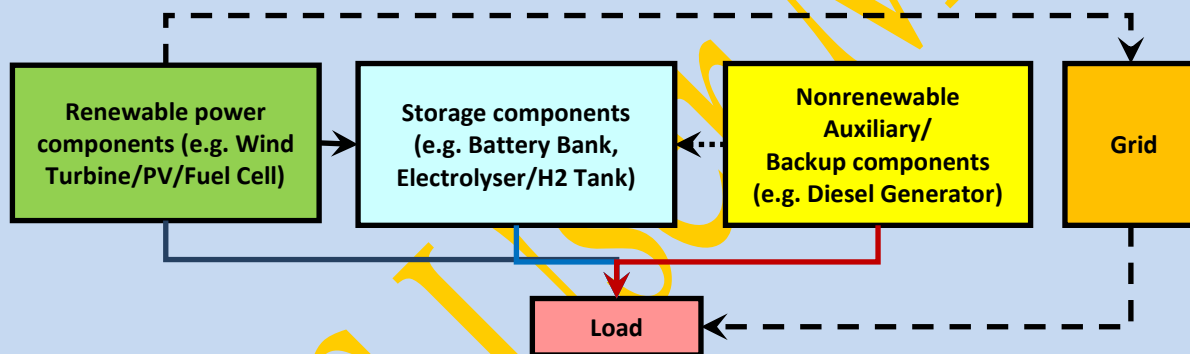


- Select the file including the demand load data and renewable resources at the site location
- Formats: .mat, .xls, .xlsx



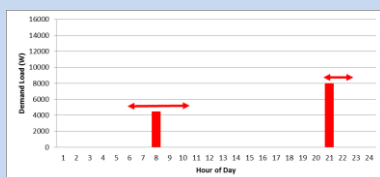
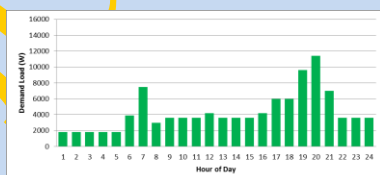
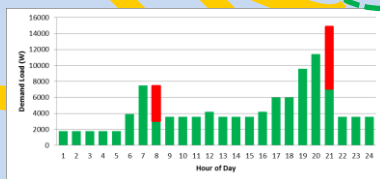
Select the type of the HRES

- Standalone
- On-grid (grid connected)



Select the type of demand load

- Fixed: The daily demand load profile is fixed (can change from one day to another but is fixed for each day).
- Plannable: In cases such as industrial loads that the demand load can be divided into fixed and flexible parts (which can be shifted within a specific time window). In such cases MOHRES finds the best load profile.



3 Analysis of a HRES

3.1 Deterministic Analysis

MOHRES

Site: Inputs01P... System Type: Standalone Load Type: Fixed

Analysis

WT Rotor Radius (m): 7

PV Panel Area (m²): 60

No of Batteries: 40

Nominal Diesel Generator Size (Watt): 5000

Nominal Fuel Cell Size (Watt): 10000

Nominal Electrolyser Capacity (Watt): 10000

Deterministic Analysis Stochastic Analysis

- Enter the size of components in the system (Zero for those components which are not included in the HRES configuration)
- If required, edit Power & Cost Model parameters

Set/Edit Design, Optimisation and Analysis Parameters

Set Usage/Charge Order

Storage/auxiliary usage order:

- Battery
- Diesel
- Fuel Cell

Storage charge order:

- Battery
- Electrolyser

Ok

- Set Dispatch Strategy: In configurations with more than one storage/auxiliary/backup component, different dispatch strategies are possible. Define dispatch strategy by setting
 - Usage order
 - Charging order
 (Clicking on a component sends it on top of the list)

Multi-objective Optimisation of Standalone Hybrid Renewable Energy Systems under Uncertainties

Pareto Frontier

System Cost (\$) Versus Total Blackout Duration (h)

System Performance

Power Balance	Perf. @ Desired LoC	PDF and PoF Distributions
System Cost (\$) =	@ LoC (%) =	
Levelised Cost of Energy (cent/kWh) =	@ LoC (%) =	
Total Blackout Duration (h) =	@ LoC (%) =	
Average Blackout Duration (h) =	@ LoC (%) =	
Maximum Blackout Duration (h) =	@ LoC (%) =	
Unmet Load (Wh) =	@ LoC (%) =	
MTBF (h) =	@ LoC (%) =	
Penetration (%) =	@ LoC (%) =	
CO2 Emission (kg) =	@ LoC (%) =	
Excess Power (Wh) =	@ LoC (%) =	

Sort/Filter Design Candidates

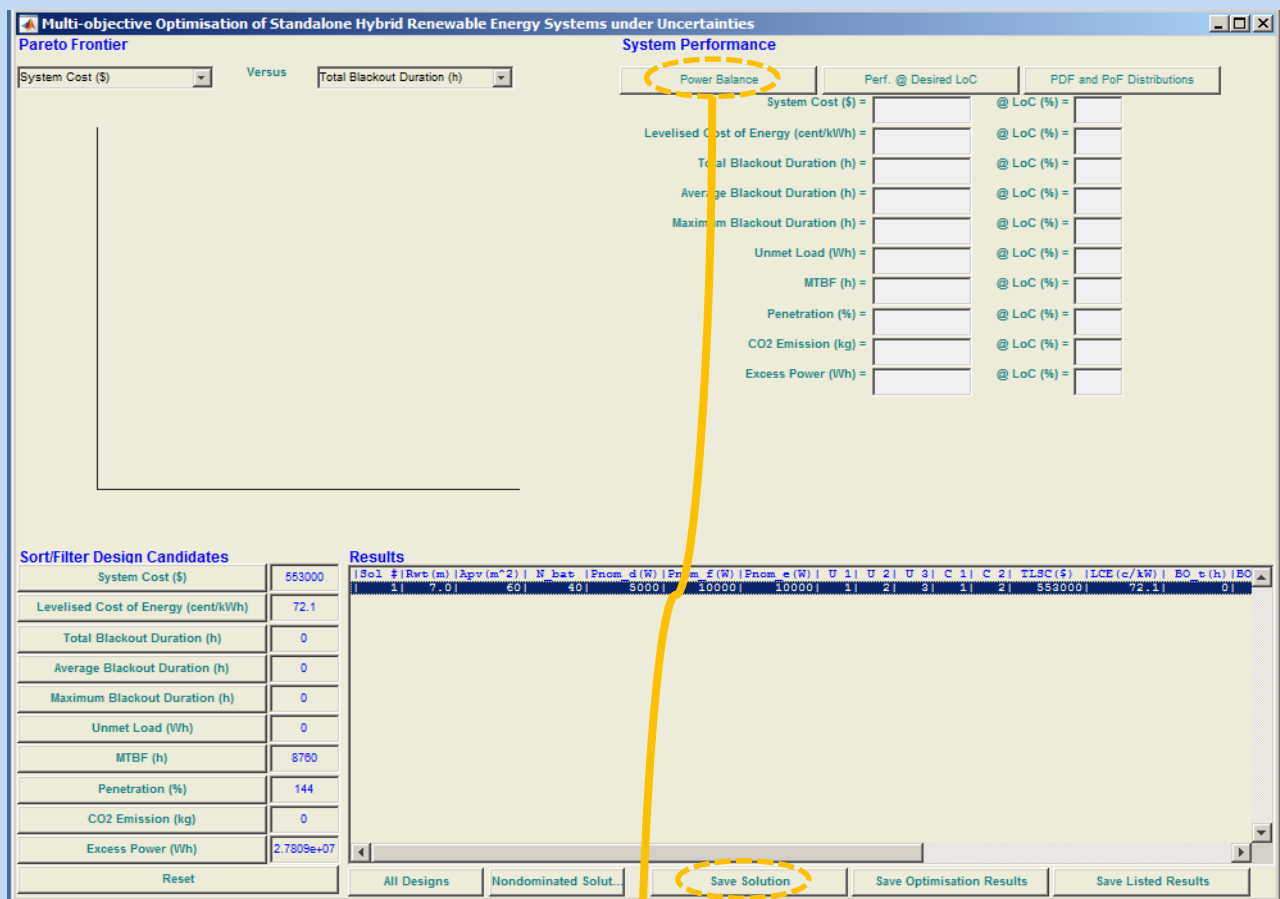
System Cost (\$)	Levelised Cost of Energy (cent/kWh)	Total Blackout Duration (h)	Average Blackout Duration (h)	Maximum Blackout Duration (h)	Unmet Load (Wh)	MTBF (h)	Penetration (%)	CO2 Emission (kg)	Excess Power (Wh)
553000	72.1	0	0	0	0	0	0	0	0

Results

Sol #	Rwt (m)	Apv (m ²)	Nbat	Pnom d (W)	Pnom f (W)	Pnom e (W)	U 1	U 2	U 3	C 1	C 2	TLSC (\$)	LCE (c/kWh)	BO t (h)	BO av (h)	BO max (h)	penet (%)	CO2 (kg)	Pexcess (Wh)
1	7.0	60	40	5000	10000	10000	1	2	3	1	2	553000	72.1	0	0	0	0	0	0

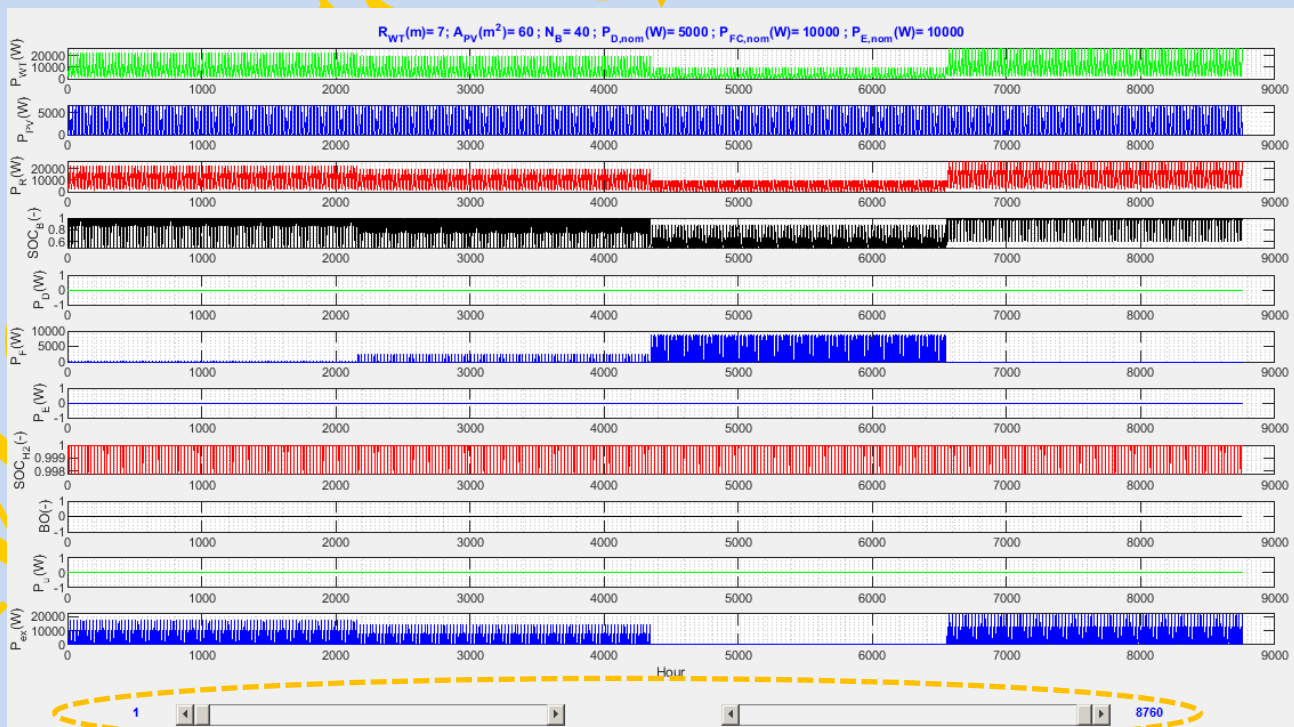
System \vec{X} = $\{R_{WT}, A_{PV}, n_B, P_{D,nom}, P_{FC,nom}, P_{EL,nom}, U_1 \text{ to } U_3, C_1 \text{ to } C_2\}$
 (U_1 to U_3, C_1 to C_2 shows the dispatch strategy: In this example, 3 components battery (identified by 1), fuel cell (2) and diesel (3) can be used in case of power deficiency; 2 components battery (1) and hydrogen tank through electrolyser (2)- are charged in case of excess power)

Performance measures \vec{Y} = $\{TLSC, LCE, BO_t, BO_{av}, BO_{max}, U_t, MTBF, penet, CO_2, P_{excess}\}$



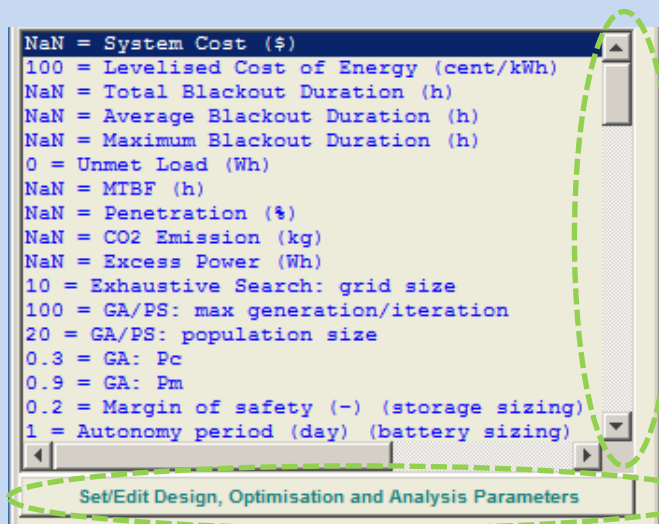
Save solution

Power Balance

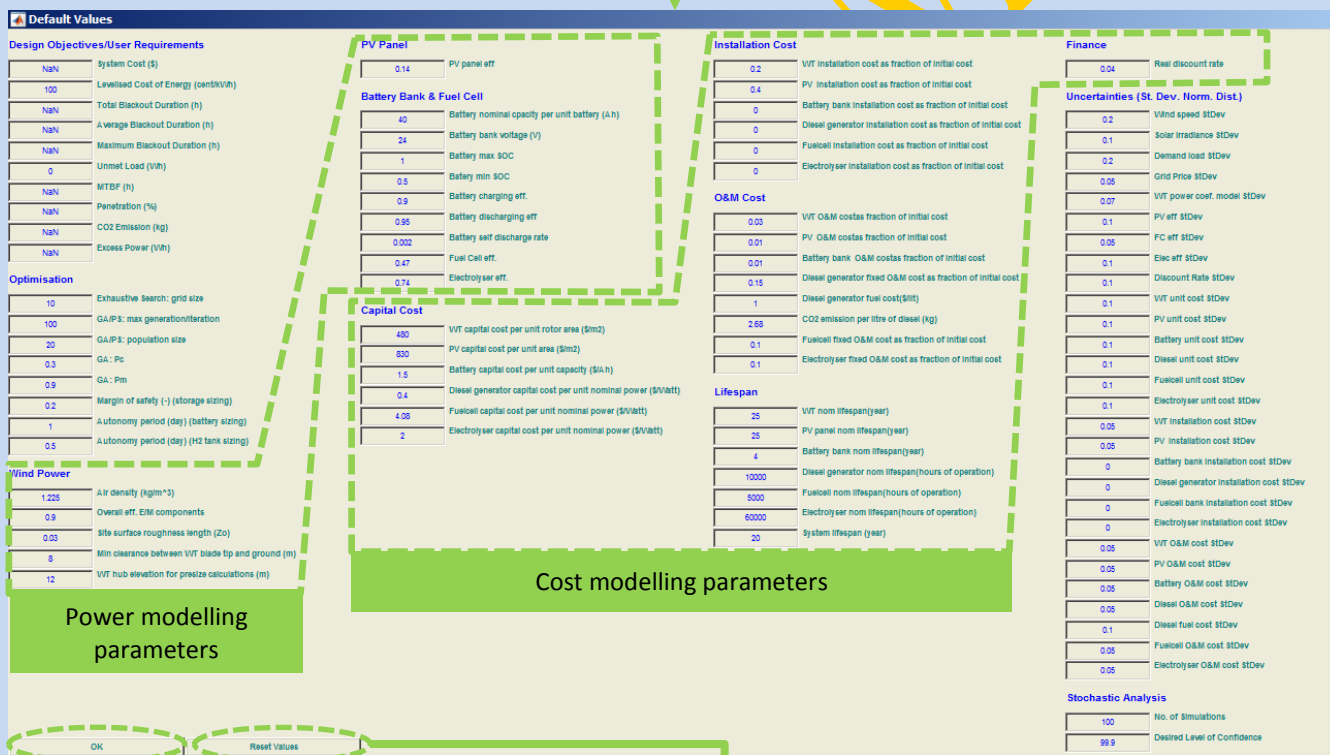


Change the observation window

3.2 Deterministic Analysis-Set/Edit Power & Cost Model parameters

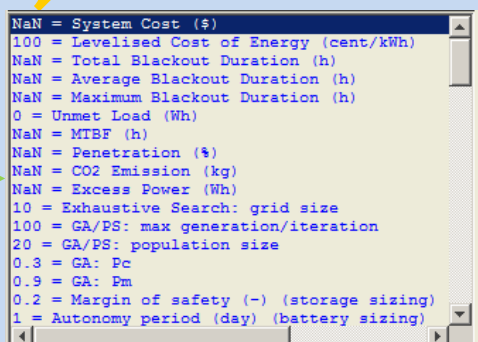


Scroll to see all power & cost models, design & optimisation parameters (default values or as set by the user)

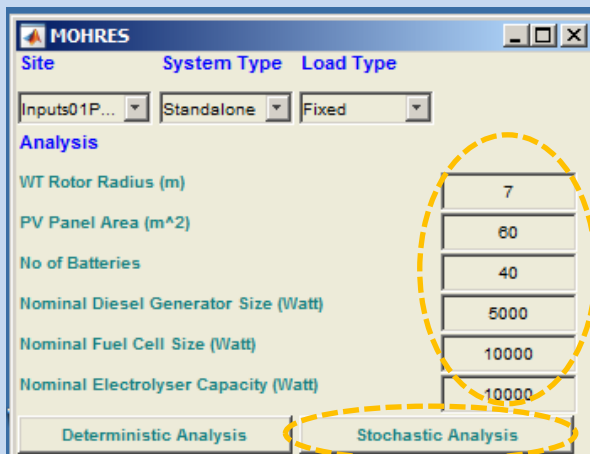


Updates the parameters and shows

Reset to
default values
and show



3.3 Nondeterministic (Stochastic) Analysis



The MOHRES main configuration window is shown with the following settings:

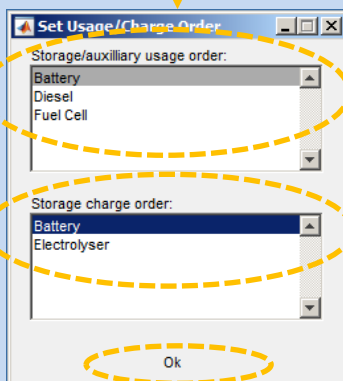
- Site: Inputs01P...
- System Type: Standalone
- Load Type: Fixed
- Analysis: Stochastic Analysis (selected)
- WT Rotor Radius (m): 7
- PV Panel Area (m²): 60
- No of Batteries: 40
- Nominal Diesel Generator Size (Watt): 5000
- Nominal Fuel Cell Size (Watt): 10000
- Nominal Electrolyser Capacity (Watt): 10000

- Enter the size of components in the system (Zero for those components which are not included in the HRES configuration)

If required, edit /set

- power & cost model parameters
- uncertainties (pdf for uncertain parameters)
- stochastic simulation parameters
- level of confidence (LoC) at which the performance is calculated (LoC_d)

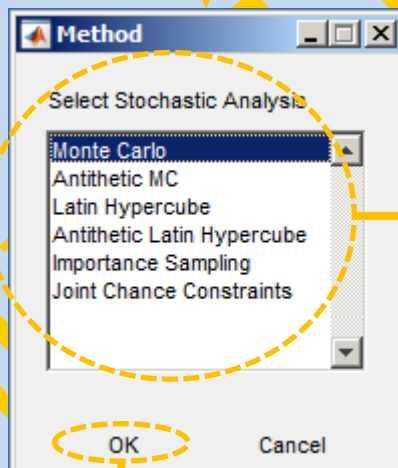
Set/Edit Design, Optimisation and Analysis Parameters



The Set Usage/Charge Order dialog box shows the following settings:

- Storage/auxiliary usage order: Battery, Diesel, Fuel Cell
- Storage charge order: Battery, Electrolyser
- Buttons: Ok, Cancel

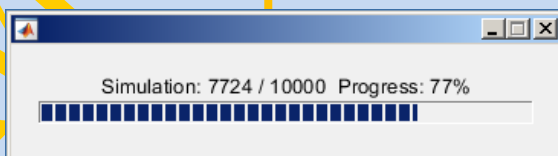
- Set Dispatch Strategy: In configurations with more than one storage/auxiliary/backup component, different dispatch strategies are possible. Define dispatch strategy by setting
 - Usage order
 - Charging order(Clicking on a component sends it on top of the list)



The Method dialog box shows the following settings:

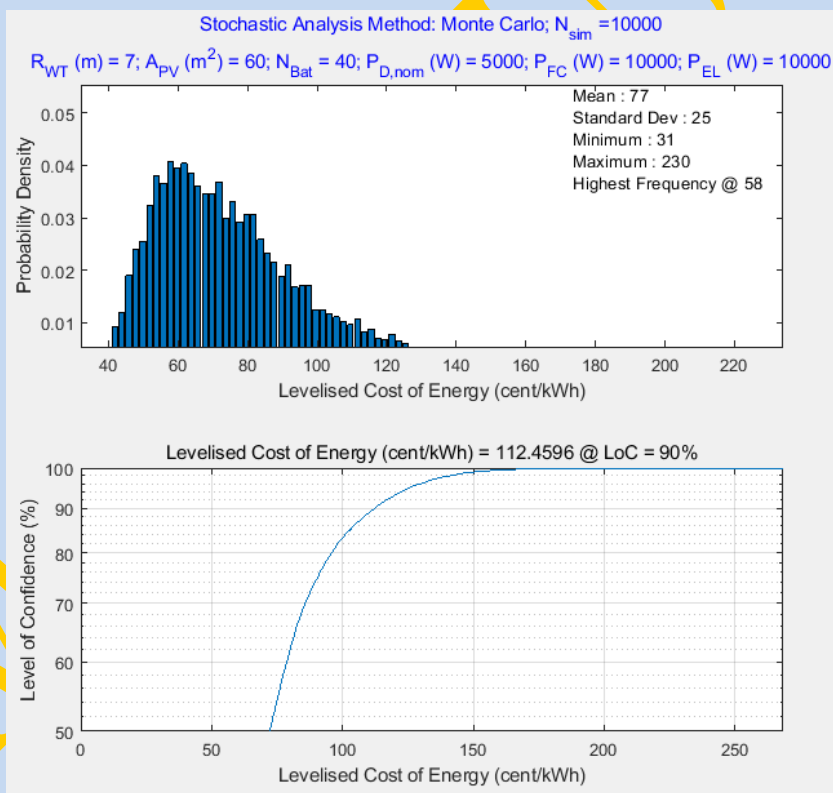
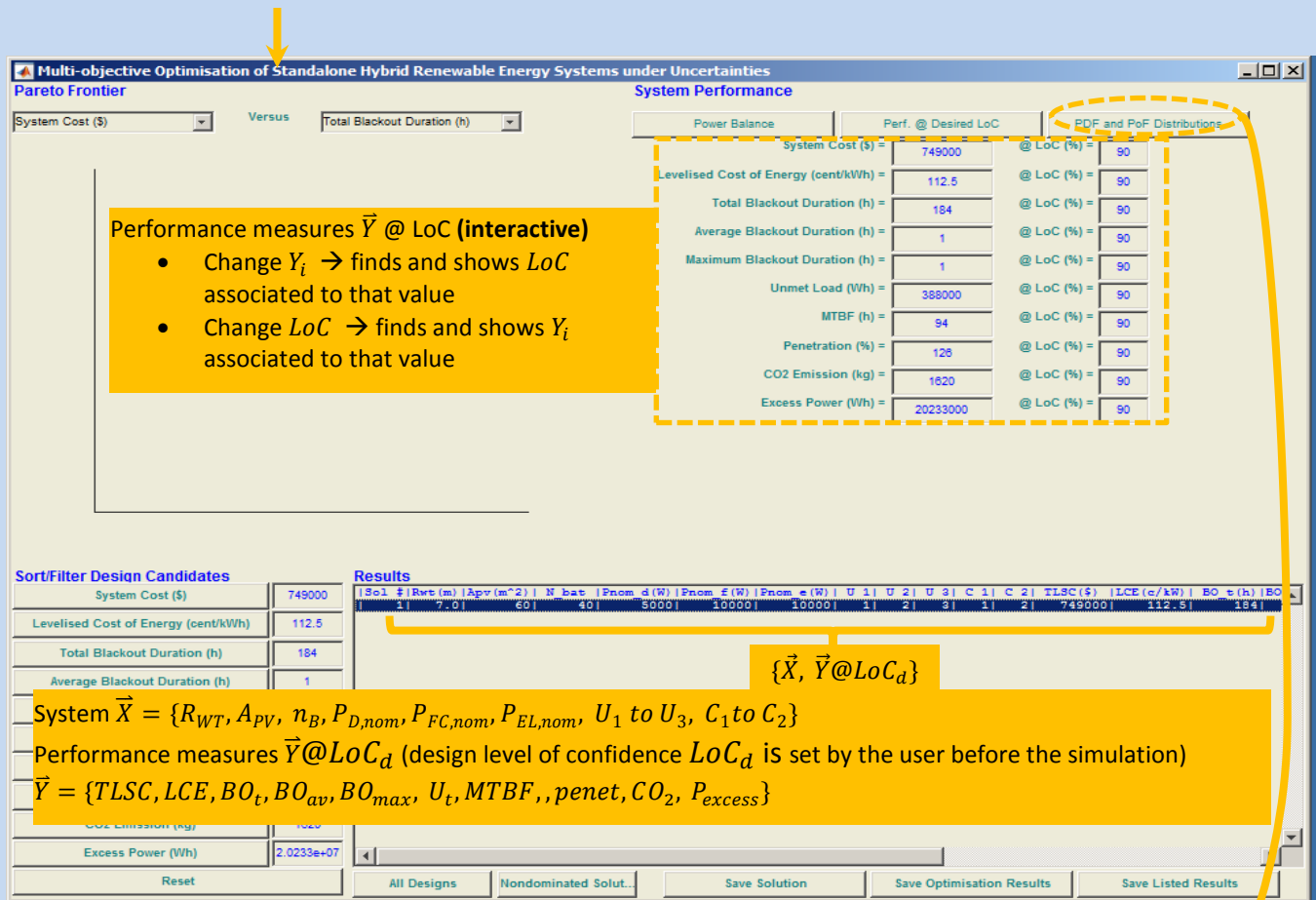
- Select Stochastic Analysis: Monte Carlo (selected)
- Buttons: OK, Cancel

- Select the stochastic method



The Simulation progress window shows the following information:

- Simulation: 7724 / 10000 Progress: 77%
- Progress bar: 77% complete



Probability density function (PDF) and level of confidence (LoC) for all performance measure (only LCE is shown here)

3.4 Nondeterministic Analysis-Set/Edit uncertainties and stochastic simulation parameters

NaN = System Cost (\$)

100 = Levelised Cost of Energy (cent/kWh)

NaN = Total Blackout Duration (h)

NaN = Average Blackout Duration (h)

NaN = Maximum Blackout Duration (h)

0 = Unmet Load (Wh)

NaN = MTBF (h)

NaN = Penetration (%)

NaN = CO2 Emission (kg)

NaN = Excess Power (Wh)

10 = Exhaustive Search: grid size

100 = GA/PS: max generation/iteration

20 = GA/PS: population size

0.3 = GA: Pc

0.9 = GA: Pm

0.2 = Margin of safety (-) (storage sizing)

1 = Autonomy period (daw) (battery sizing)

Set/Edit Design, Optimisation and Analysis Parameters

Default Values	
Design Objectives/User Requirements	PV Panel
System Cost (\$)	0.14 PV panel eff
Levelised Cost of Energy (cent/kWh)	
Total Blackout Duration (h)	Battery Bank & Fuel Cell
Average Blackout Duration (h)	40 Battery nominal capacity per unit battery (Ah)
Maximum Blackout Duration (h)	24 Battery bank voltage (V)
Unmet Load (kWh)	1 Battery max SOC
MTBF (h)	0.5 Battery min SOC
Penetration (%)	0.9 Battery charging eff.
CO ₂ Emission (kg)	0.95 Battery discharging eff.
Excess Power (kW/h)	0.002 Battery self discharge rate
	0.47 Fuel Cell eff.
	0.74 Electrolyser eff.
Optimisation	Capital Cost
Exhaustive Search: grid size	430 VIT capital cost per unit rotor area (\$/m ²)
GAP/S: max generation/iteration	830 PV capital cost per unit area (\$/m ²)
GAP/S: population size	1.5 Battery capital cost per unit capacity (\$/kWh)
GAP: PC	0.4 Diesel generator capital cost per unit nominal power (\$/kWatt)
GAP: Pn	4.05 Fuelcell capital cost per unit nominal power (\$/kWatt)
Margin of safety (-) (storage sizing)	2 Electrolyser capital cost per unit nominal power (\$/kWatt)
Autonomy period (day) (battery sizing)	
Autonomy period (day) (H2 tank sizing)	
	Installation Cost
	0.2 VIT installation cost as fraction of initial cost
	0.4 PV installation cost as fraction of initial cost
	0 Battery bank installation cost as fraction of initial cost
	0 Diesel generator installation cost as fraction of initial cost
	0 Fuelcell installation cost as fraction of initial cost
	0 Electrolyser installation cost as fraction of initial cost
	O&M Cost
	0.03 VIT O&M cost as fraction of initial cost
	0.01 PV O&M cost as fraction of initial cost
	0.01 Battery bank O&M cost as fraction of initial cost
	0.15 Diesel generator fixed O&M cost as fraction of initial cost
	1 Diesel generator fuel cost(\$/lit)
	2.65 CO ₂ emission per litre of diesel (kg)
	0.1 Fuelcell fixed O&M cost as fraction of initial cost
	0.1 Electrolyser fixed O&M cost as fraction of initial cost
	Lifespan
	25 VIT nom lifespan(year)
	25 PV panel nom lifespan(ear)
	Finance
	0.04 Real discount rate
	Uncertainties (St. Dev. Norm. Dist.)
	0.2 Wind speed \$tDev
	0.1 Solar irradiance \$tDev
	0.2 Demand load \$tDev
	0.05 Grid Price \$tDev
	0.07 VIT power cost model \$tDev
	0.1 PV eff \$tDev
	0.05 FC eff \$tDev
	0.1 Elec eff \$tDev
	0.1 Discount Rate \$tDev
	0.1 VIT unit cost \$tDev
	0.1 PV unit cost \$tDev
	0.1 Battery unit cost \$tDev
	0.1 Diesel unit cost \$tDev
	0.1 Fuelcell unit cost \$tDev
	0.1 Electrolyser unit cost \$tDev
	0.05 VIT installation cost \$tDev
	0.05 PV installation cost \$tDev
	0 Battery bank installation cost \$tDev
	0 Diesel generator installation cost \$tDev
	0 Fuelcell installation cost \$tDev
	0 Electrolyser installation cost \$tDev
	0.05 VIT O&M cost \$tDev
	0.05 PV O&M cost \$tDev
	0.05 Battery O&M cost \$tDev
	0.05 Diesel O&M cost \$tDev
	0.1 Fuelcell O&M cost \$tDev
	0.05 Diesel O&M cost \$tDev
	0.05 Electrolyser O&M cost \$tDev
	Stochastic Analysis
	100 No. of Simulations
	99.9 Desired Level of Confidence

4 Design

Design

Design Method

Optimisation Method

Start D

Deterministic: Storage Sizing

Deterministic: Storage Sizing along with other Components

Deterministic: Storage Sizing based on Autonomy Period and/or Margin of Safety

Nondeterministic

Select Design Method

- Deterministic (based on deterministic system analysis)
 - Storage sizing along with the rest of components
 - Storage sizing based on worst case scenarios (using autonomy period and margin of safety)
- Nondeterministic-runs a stochastic analysis for each design candidate evaluation (runs storage sizing along with the rest of components)

Design

Design Method

Optimisation Method

Start D

GA Single Obj Constrained

PS Single Obj Constrained

NSGA II Multi Obj

Exhaustive Search

Heuristic

Response Surface Modelling

Site Name : Inputs01PL

WT Rotor Radius (m) = 7

PV Panel Area (m²) = 60

No of Batteries = 40

Nominal Diesel Generator

Select Optimisation Method:

- Single objective
 - Genetic Algorithm
 - Particle Swarm
 - Heuristic
 - Response Surface Modelling (best option for nondeterministic design)
 - Exhaustive Search
- Multiobjective
 - NSGA II
 - Response Surface Modelling
 - Exhaustive Search

Set/Edit Design, Optimisation and Analysis Parameters

Set objective and constraints (according the following rules):

- For single objective optimisation
 - Put an arbitrary negative value for the performance measure which is the optimisation objective
 - Put the constraint value for those performance measures which are constrained
 - Put NaN for those performance measures which are neither objective nor constraint
- For multiobjective optimisation
 - Put an arbitrary positive value for the performance measures which are the optimisation objectives
 - Put NaN for the rest of performance measures
- Examples:

Design Objectives/User Requirements

NaN	System Cost (\$)
-1	Levelised Cost of Energy (cent/kVh)
NaN	Total Blackout Duration (h)
NaN	Average Blackout Duration (h)
NaN	Maximum Blackout Duration (h)
0	Unmet Load (Vh)
NaN	MTBF (h)
NaN	Penetration (%)
1500	CO ₂ Emission (kg)
500000	Excess Power (Vh)

$$\begin{aligned} & \min\{LCE\} \\ & s. t. \\ & U_t \leq 0 \\ & CO_2 \leq 1500 \text{ kg/year} \\ & P_{excess} \geq 500,000 \text{ Wh/year} \end{aligned}$$

Design Objectives/User Requirements

NaN	System Cost (\$)
1	Levelised Cost of Energy (cent/kVh)
NaN	Total Blackout Duration (h)
NaN	Average Blackout Duration (h)
NaN	Maximum Blackout Duration (h)
1	Unmet Load (Vh)
NaN	MTBF (h)
NaN	Penetration (%)
NaN	CO ₂ Emission (kg)
NaN	Excess Power (Vh)

$$\min\{LCE \& U_t\}$$

Design Objectives/User Requirements

NaN	System Cost (\$)
1	Levelised Cost of Energy (cent/kVh)
NaN	Total Blackout Duration (h)
NaN	Average Blackout Duration (h)
NaN	Maximum Blackout Duration (h)
NaN	Unmet Load (Vh)
NaN	MTBF (h)
NaN	Penetration (%)
1	CO ₂ Emission (kg)
1	Excess Power (Vh)

$$\min\{LCE \& CO_2\} \& \max\{P_{excess}\}$$

Set/Edit Design, Optimisation and Analysis Parameters

Set optimisation parameters

Optimisation	
50	GA/NSGA I/PS: max generation/iteration
100	GA/NSGA I/PS: population size
0.3	GA/NSGA II: P _c
0.9	GA/NSGA II: P _m
0.2	Margin of safety (-) (storage sizing)
1	Autonomy period (day) (battery sizing)
0.5	Autonomy period (day) (H2 tank sizing)

Design

Design Method: Deterministic: Storage Sizin...

Optimisation Method: GA Single Obj Constrained

Start Design

Set system configuration and the limits for design variables (according the following rules):

- Three values: {lower limit, step (for exhaustive search), upper limit}
- Two values: {lower limit, upper limit}
- Zero: exclusion from configuration
- Single value: Inclusion in the configuration but exclusion from optimisation

Note 1: Input numbers must be separated by space or comma

Note 2: Upper limits are pre-calculated based on worst case scenarios (can be changed)

Set Limits/Inclusion of Design Variables

Set Limits/Inclusion of Design Variables

WT Rotor Radius (m)	0 0.1 22
PV Panel Area (m ²)	0 1 448
No of Batteries	0 2 400
Nominal Diesel Generator Size (Watt)	0 100 48000
Nominal Fuel Cell Size (Watt)	0 100 40900
Nominal Electrolyser Capacity (Watt)	0 100 55200

Next

Dispatch Strategy

? Storage/auxiliary usage and charge order...

Include in optimisation

Select manually

Set Usage/Charge Order

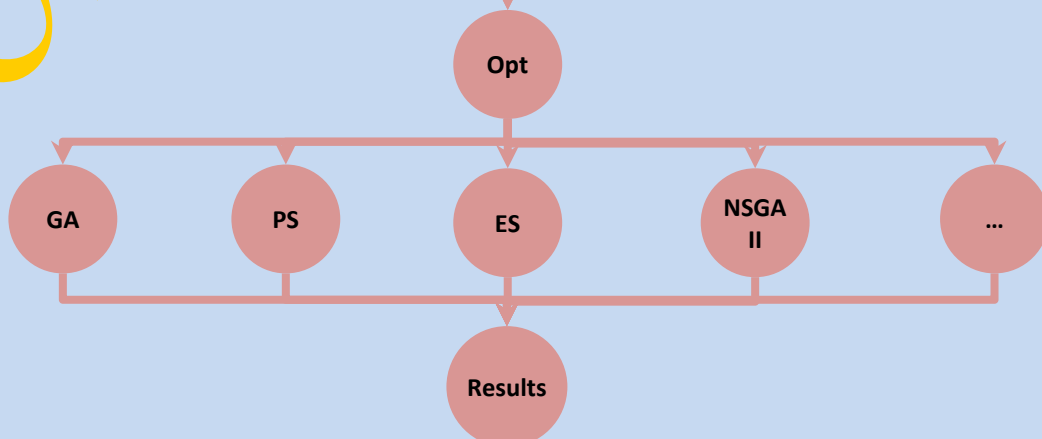
Storage/auxiliary usage order:

Battery
Diesel
Fuel Cell

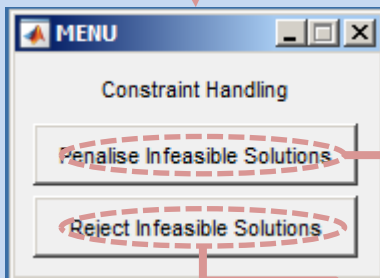
Storage charge order:

Battery
Electrolyser

Ok

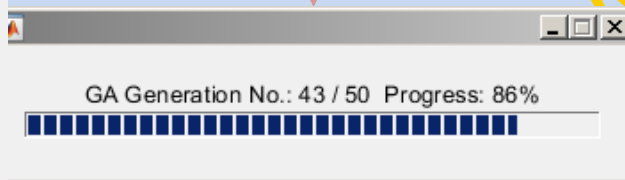
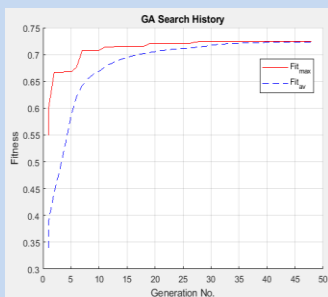
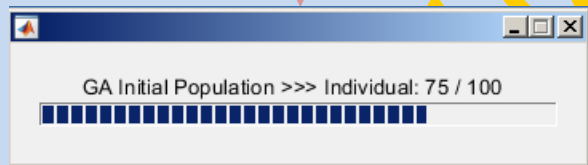
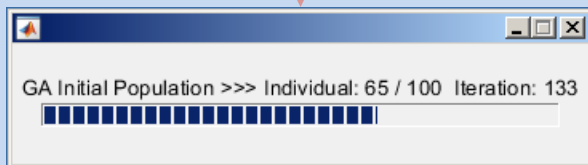


GA



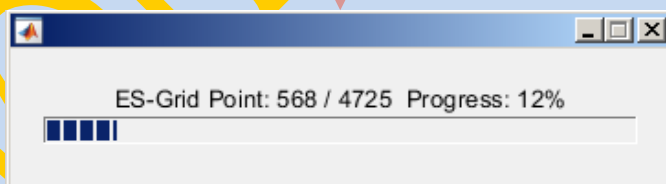
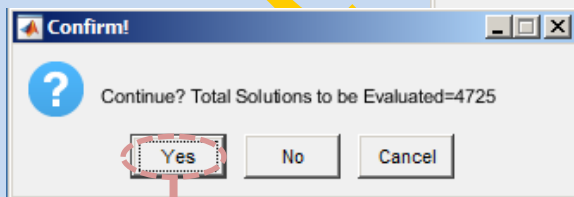
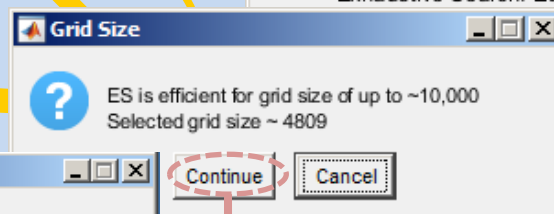
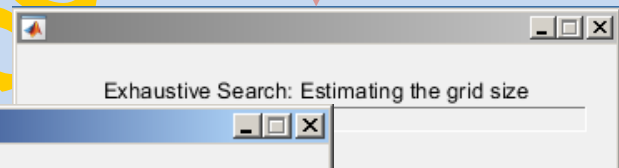
This appears when the problem is constrained

Use penalty method for highly constrained problems, when rejection method leads to a large number of failed iterations in generating feasible solutions and the initial population generation becomes time consuming.



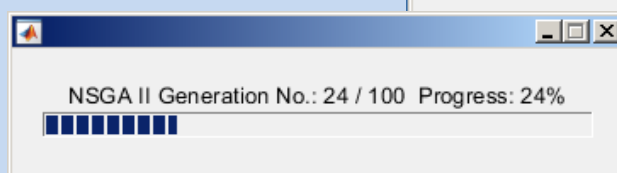
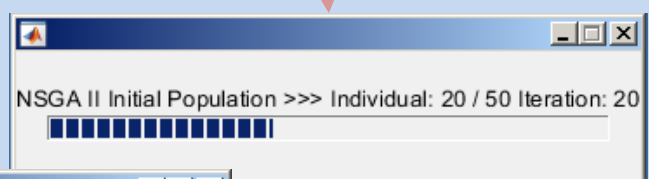
Results

ES



Results

NSGA II



Results

Results

Pareto Front: Solutions marked by red +

Levelised Cost of Energy (c...)

System Cost (\$)

Levelised Cost of Energy (cent/kWh)

Unmet Load (Wh)

Total Blackout Duration (h)

Average Blackout Duration (h)

Maximum Blackout Duration (h)

Unmet Load (Wh)

MTBF (h)

Penetration (%)

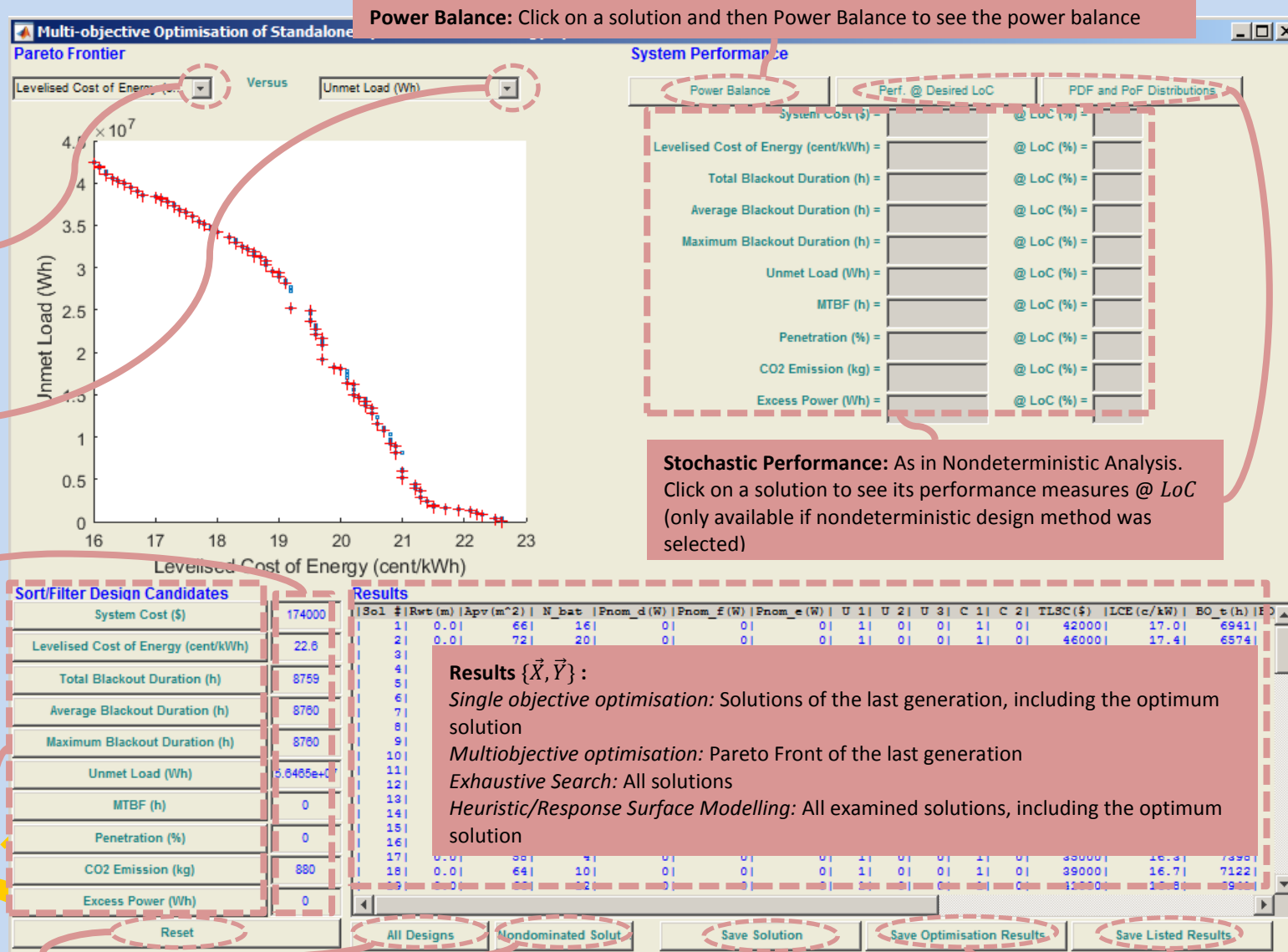
CO2 Emission (kg)

Excess Power (Wh)

Filtering: Enter a value for a performance measure to filter out those solutions not satisfying that constraint

Sorting: Click on a button to sort solutions based on that performance measure

Reset: Reset back to all unfiltered and unsorted solutions



Shows all solutions

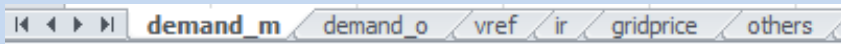
Nondominated Solutions: Filters and shows nondominated solutions

Save Solutions: Click on a solution and then Save Solution

Save: Saves all solutions

Save: Saves only listed solutions

5 Excel Data File for Site Data



Site data excel file includes 6 tabs:

- **demand_m**: averaged daily demand load associate to machinery for load planning (if chosen by the user). Cells must be zero if there is no machinery (plannable) load
- **demand_o**: contains the rest of the demand load.
- **vref**: averaged wind speed at a reference elevation (zref)
- **ir**: averaged solar irradiance
- **gridprice**: cost of buying electricity from grid for different hours of a day
- **others**

24 'hourly' averaged values ($\Delta t = 1 \text{ hr}$)
Other formats: any other value for Δt is acceptable
(Δt must be given in tab 'others')

Format for 'demand_m', 'demand_o', 'vref', 'ir' and 'gridprice':

- 12 typical days, each representing one month.
- Other acceptable formats:
 - 52: each for one week
 - 365: each for one day

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	10	10	10	20	20	20	10	10	10	10	10	10
8	40	40	40	130	130	130	80	80	80	30	30	30
9	220	220	220	330	330	330	150	150	150	190	190	190
10	430	430	430	530	530	530	370	370	370	390	390	390
11	610	610	610	690	690	690	500	500	500	560	560	560
12	750	750	750	810	810	810	570	570	570	690	690	690
13	810	810	810	870	870	870	600	600	600	750	750	750
14	810	810	810	850	850	850	590	590	590	750	750	750
15	730	730	730	770	770	770	550	550	550	680	680	680
16	590	590	590	620	620	620	450	450	450	540	540	540
17	410	410	410	450	450	450	330	330	330	370	370	370
18	200	200	200	270	270	270	190	190	190	170	170	170
19	40	40	40	110	110	110	70	70	70	20	20	20
20	10	10	10	10	10	10	10	10	10	10	10	10
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

	1	2	3	4	5	6
1	0.2	0.1	0.2	0.05	3	1
2						

Tab 'others' include

- zref (elevation at which 'vref' is given)
- Δt

Tab 'others' include

- standard deviations for the demand load (demand_o part), wind speed, solar irradiance and grid price
- standard deviations can be overwritten in

Set/Edit Design, Optimisation and Analysis Parameters

Uncertainties (St. Dev. Norm. Dist.)	
0.2	Wind speed StDev
0.1	Solar irradiance StDev
0.2	Demand load StDev
0.05	Grid Price StDev