A tool for building integrated energy systems design

Sizing and operation of PV and battery systems in buildings with flexible loads

Introduction

This online tool aims to promote self-sufficiency in buildings with flexible loads, by properly sizing the photovoltaic and battery storage systems to be installed in a building, and providing an efficient schedule for the flexible loads. The tool has been developed in the framework of "*Cost-effective rehabilitation of public buildings into smart and resilient nano-grids using storage - BERLIN*" project. The objective of BERLIN is to implement cross-border pilot measures to support innovative and cost-effective energy rehabilitations in public buildings based on the nano-grid concept, the building block for smart micro-grids. The project focuses on increasing grid penetration, combined with energy storage and demand-side management, along with enhancement of energy efficiency in buildings. The goal is to increase the level of self-resilience in public buildings and to make them greener, smarter, and sustainable.

The tool calculates the proper size of a hybrid PV+storage system to achieve one of the following objectives:

- Maximum self-sufficiency
- Maximum net present value (NPV)
- Cost-effective solutions for enhanced self-sufficiency

The tool also incorporates an option for an exhaustive analysis, that delivers the results for all possible PV and battery system size combinations. The required inputs are: electrical consumption, building location, PV and battery size range for the analysis, electricity costs, and the policy applying to renewables in the region of the case study. A financial analysis is undertaken for a period of 5-25 years (based on user's choice), taking into consideration several technical and financial parameters. The tool can be used by both professionals and non-professionals users. An analytic description of the analysis methods of the tool is available in [1].

Feel free to use the tool for your analyses.

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Please cite as:

[1] N. S. Kelepouris, A. I. Nousdilis, A. S. Bouhouras and G. C. Christoforidis, "Enhancing Self-Sufficiency in Buildings with Hybrid PV-Battery Systems and Demand Side Management: A sizing tool," IEEE Int. Conf. Environ. Electri. Eng. And IEEE Ind. Commer. Power Syst. Europe (EEEIC / I&CPS Europe), 2021, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope51590.2021.9584559.

Manual

This document is a short manual, providing the user with simple instructions. The procedure that should be followed to get the desired results is divided into 8 separate steps:

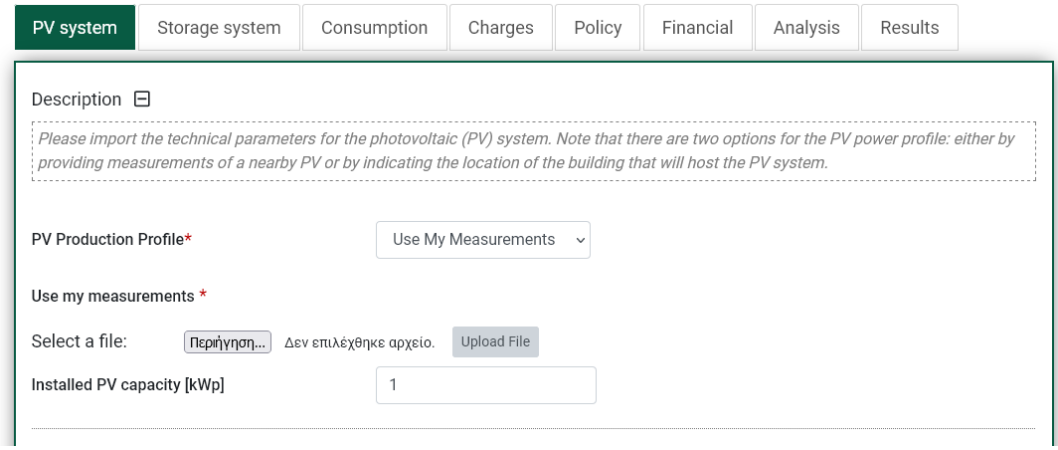
- Step 1: PV System Data
- Step 2: Storage System
- Step 3: Consumption Data
- Step 4: Electricity Charging Mechanism and Prices
- Step 5: Policy Data
- Step 6: Financial Data
- Step 7: Analysis Options
- Step 8: Getting the Results

These steps are further analyzed in the remaining document.

Step 1: PV System Data

i. The "*PV production profile*" is essential for the tool calculations. The user should select one of the following two options:

a) If PV power measurements of a specific installation are available, the user can import these data in a *.xlsx* file and upload it by clicking *"Upload"*. The data should be entered using the template that can be downloaded from the corresponding button. Next, user should enter the PV capacity (in kWp) of the measured PV installation.

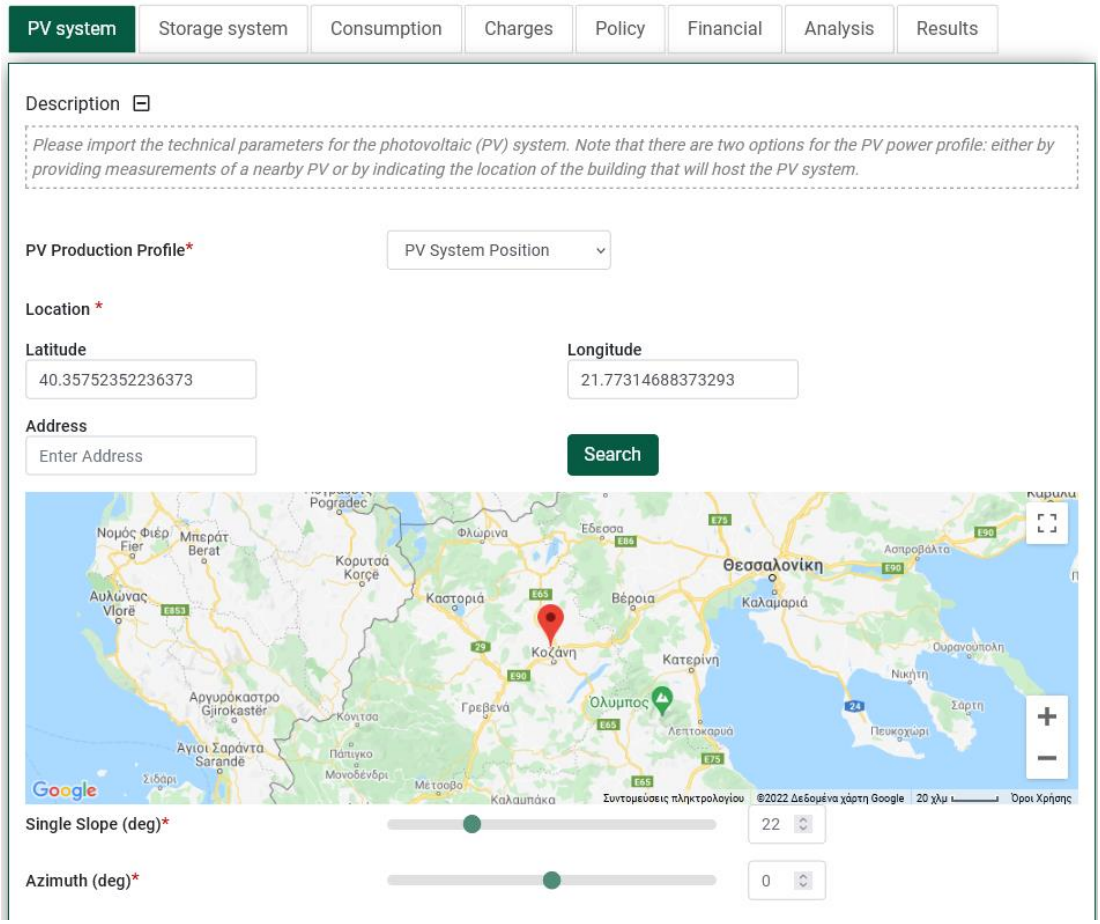


The next image is an overview of the *.csv* template file. Power should be imported in *kW*, considering a 15-min time interval.

	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Time	January	February	March	April	May	June	July	August	Septembe	October	Novembe	December
2	**00:00**	0	0	0	0	0	0	0	0	0	0	0	0
3	**00:15**	0	0	0	0	0	0	0	0	0	0	0	0
4	**00:30**	0	0	0	0	0	0	0	0	0	0	0	0
5	**00:45**	0	0	0	0	0	0	0	0	0	0	0	0
6	**01:00**	0	0	0	0	0	0	0	0	0	0	0	0
7	**01:15**	0	0	0	0	0	0	0	0	0	0	0	0
8	**01:30**	0	0	0	0	0	0	0	0	0	0	0	0
9	**01:45**	0	0	0	0	0	0	0	0	0	0	0	0
10	**02:00**	0	0	0	0	0	0	0	0	0	0	0	0
11	**02:15**	0	0	0	0	0	0	0	0	0	0	0	0
12	**02:30**	0	0	0	0	0	0	0	0	0	0	0	0
13	**02:45**	0	0	0	0	0	0	0	0	0	0	0	0
14	**03:00**	0	0	0	0	0	0	0	0	0	0	0	0
15	**03:15**	0	0	0	0	0	0	0	0	0	0	0	0
16	**03:30**	0	0	0	0	0	0	0	0	0	0	0	0
17	**03:45**	0	0	0	0	0	0	0	0	0	0	0	0
18	**04:00**	0	0	0	0	0	0	0	0	0	0	0	0
19	**04:15**	0	0	0	0	0	0	0	0	0	0	0	0
20	**04:30**	0	0	0	0	0	0	0	0	0	0	0	0
21	**04:45**	0	0	0	0	0	0.009749	0	0	0	0	0	0
22	**05:00**	0	0	0	0	0.018789	0.022621	0.010327	0	0	0	0	0
23	**05:15**	0	0	0	0	0.032497	0.034546	0.022116	0	0	0	0	0
24	**05:30**	0	0	0	0	0.045242	0.045536	0.032984	0.015007	0	0	0	0
25	**05:45**	0	0	0	0.019205	0.066868	0.060371	0.045288	0.02599	0	0	0	0

PV production (kW)

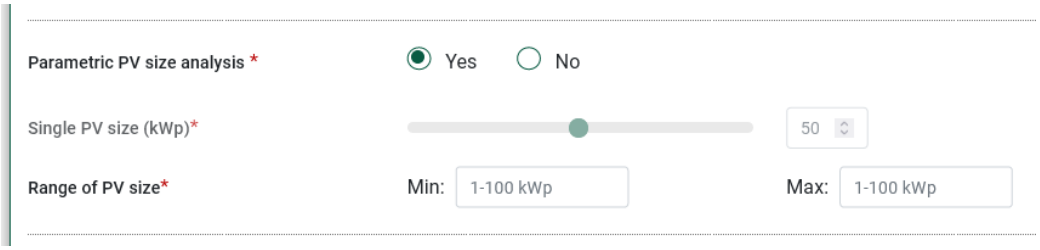
b) If no PV power measurements are available, the user can indicate the coordinates of the installation position or can place a pin on the provided map. Followingly, the PV panels orientation should be provided (slope and azimuth). The tool then communicates with the PVGIS platform[1] and obtains the necessary climatic data for the specific location in order to estimate the PV power output. The calculation procedure is described in detail in a relevant publication[2].



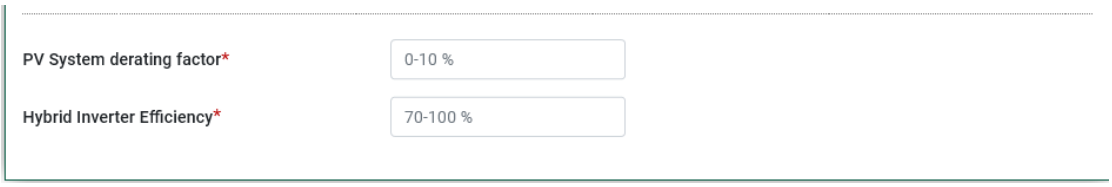
[1] https://ec.europa.eu/jrc/en/pvgis (Assessed January 2021)

[2] . G. C. Christoforidis, I. P. Panapakidis, T. A. Papadopoulos, G. K. Papagiannis, I. Koumparou, M. Hadjipanayi and G. E. Georghiou, "A Model for the Assessment of Different Net-Metering Policies", Energies, 2016, 9(4), 262; doi:10.3390/en9040262.

ii. The next option of this step refers to the type of analysis. The user can select between an analysis that examines multiple PV sizes in a given range (Parametric analysis: Yes) and an analysis that considers a single PV size (Parametric analysis: No).



iii. In the last section of this tab, the "PV System derating factor" that corresponds to the degradation of the solar panels, and the efficiency of the hybrid inverter have to be introduced.



Step 2: Storage System Data

The characteristics of the Battery Storage System (BSS) are defined in this tab. The user is able to perform an analysis for different BSS sizes.

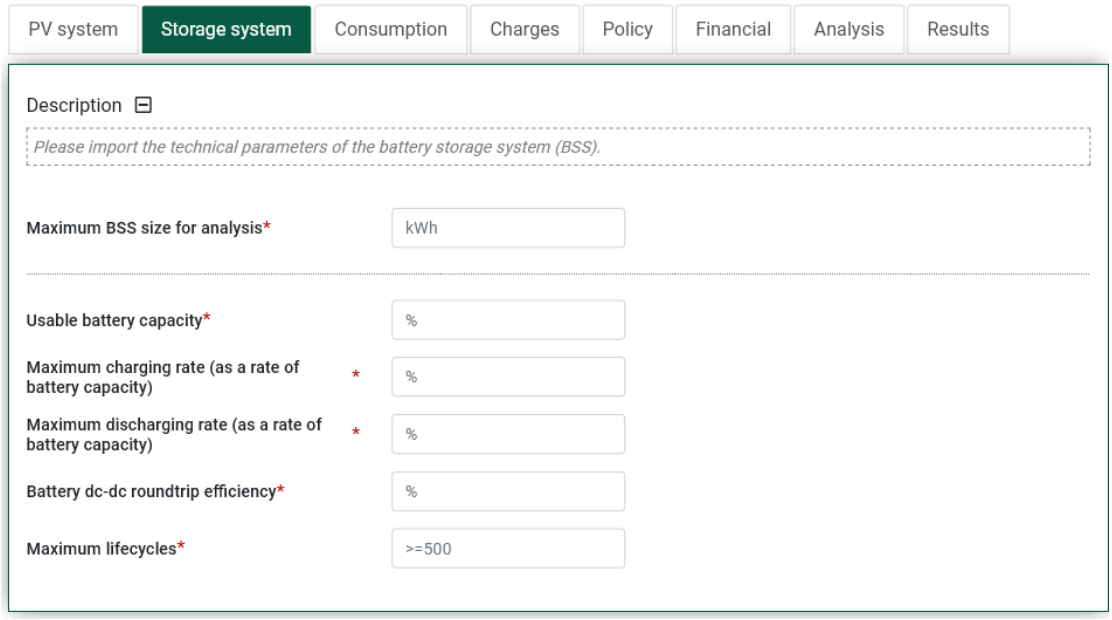
Initially, the user defines the BSS maximum size that is desired for the analysis. The analysis range spans form 0 kWh up to user defined maximum size (*in kWh*).

The user should also define the *"usable battery capacity"* that is usually provided by the battery manufacturer or can be calculated if the maximum and minimum operational state of charge (SoC) are known. For example, for a SoC operational range of 10-90%, the usable capacity is calculated as 80%.

The *"maximum charging/discharging rate"* of the BESS, as a percentage (%) of the nominal battery capacity should also be provided. For example, if 50% is selected here, a 10 kWh BESS will have a maximum rate of 5 kW.

The "Battery dc-to-dc roundtrip efficiency" should be inserted. This efficiency includes the losses of battery charging and discharging processes, at the dc-side of the BSS, excluding the losses on the hybrid inverter.

Finally, the expected *"maximum lifecycles"* should be inserted, as declared by the manufacturer of the BSS. A number of 8000 cycles could be used as a typical value for Li-Ion batteries.

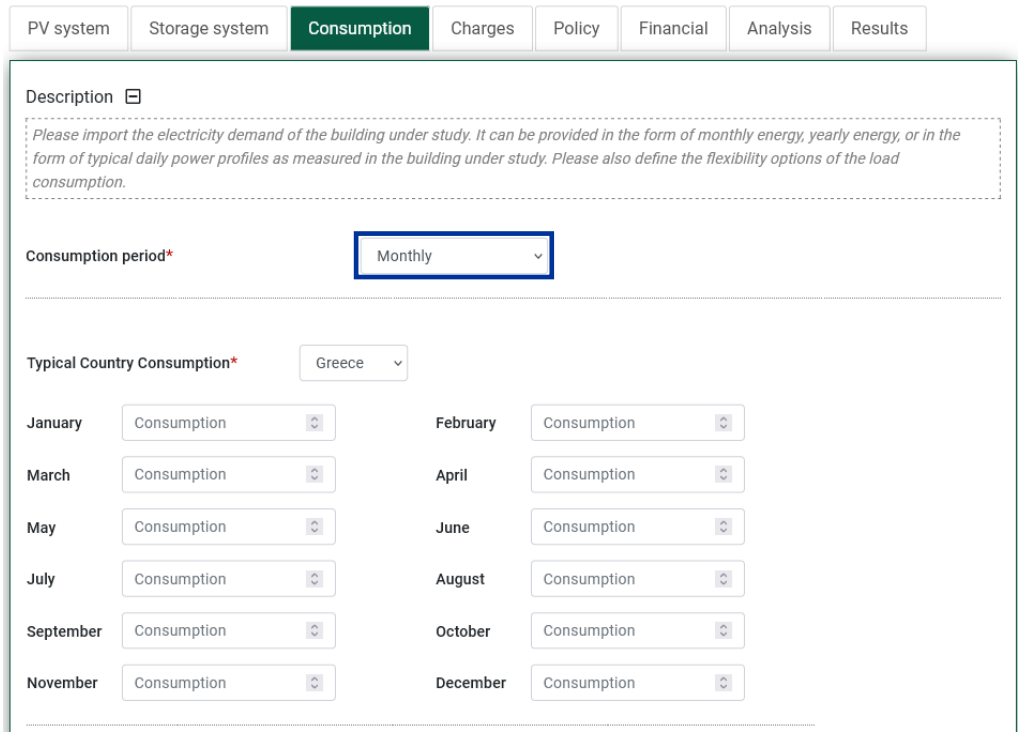


Step 3: Consumption Data

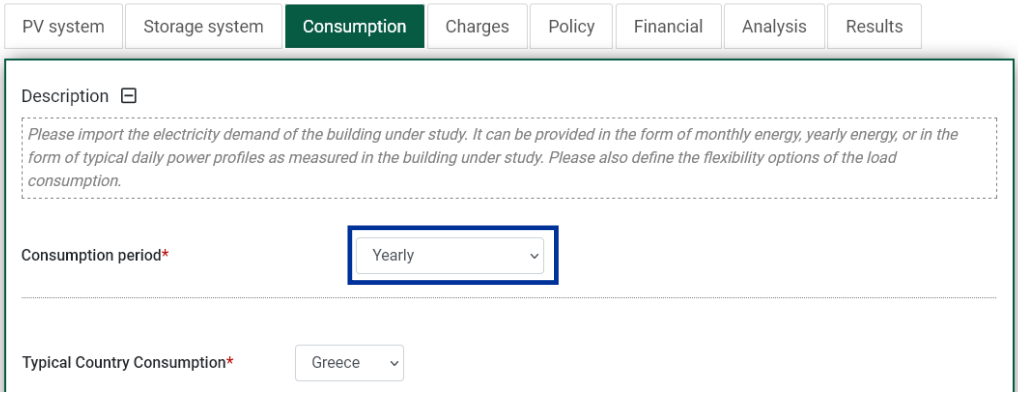
The consumption of the installation should be inserted in this tab. It can be provided in the form of monthly energy, yearly energy, or in the form of typical daily power profiles as measured in the building under study. Also flexibility options of the load consumption are defined in this tab.

i. Consumption data

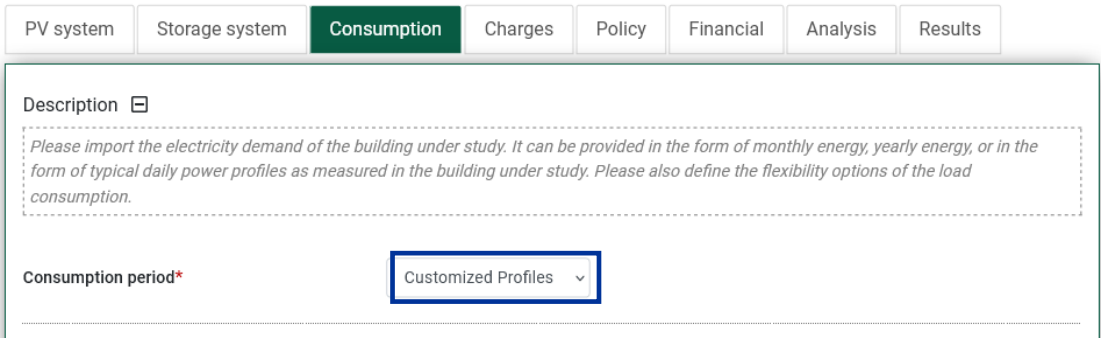
a) Monthly consumption energy data: Select the country of the installation under study and insert the energy consumption of each month over a year, in kWh.



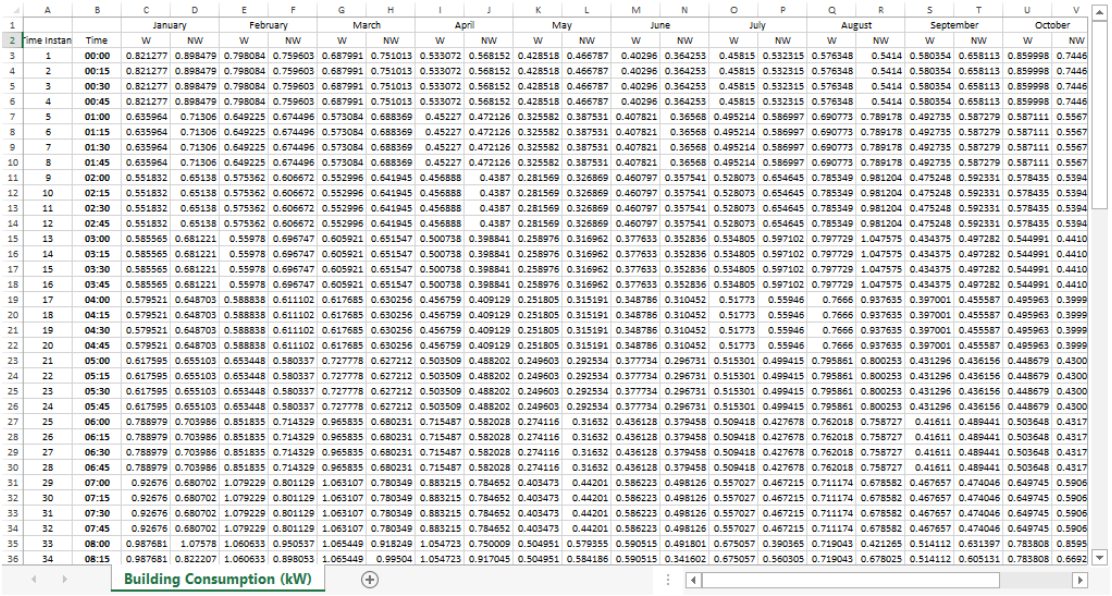
b) Yearly consumption energy: Select the country of the installation under study and insert the total energy consumption over a year, in kWh.



c) Customized Profiles: The user has the option to upload own consumption by means of an .xlsx file using the provided template. The template can be downloaded by clicking at the corresponding button.



The next image is an overview of the *.csv* template file. Power should be imported in *kW*, considering a 15-min time interval. Consumption should be inserted in the specified columns per month, taking into consideration a classification between working and non-working days.

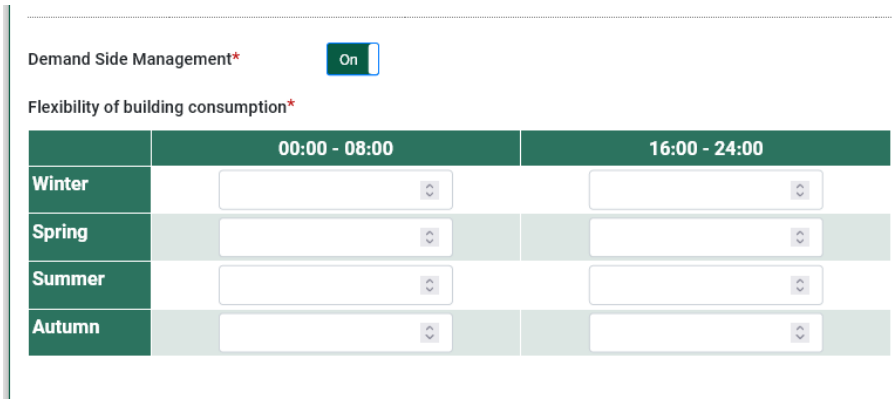


			January		February		March		April		May		June		July		August		September		October	
Time Instan	Time		W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW
1	00:00		0.821277	0.898479	0.798084	0.759603	0.687991	0.751013	0.533072	0.568152	0.428518	0.466787	0.40296	0.364253	0.45815	0.532315	0.576348	0.5414	0.580354	0.658113	0.859998	0.7446
2	00:15		0.821277	0.898479	0.798084	0.759603	0.687991	0.751013	0.533072	0.568152	0.428518	0.466787	0.40296	0.364253	0.45815	0.532315	0.576348	0.5414	0.580354	0.658113	0.859998	0.7446
3	00:30		0.821277	0.898479	0.798084	0.759603	0.687991	0.751013	0.533072	0.568152	0.428518	0.466787	0.40296	0.364253	0.45815	0.532315	0.576348	0.5414	0.580354	0.658113	0.859998	0.7446
4	00:45		0.821277	0.898479	0.798084	0.759603	0.687991	0.751013	0.533072	0.568152	0.428518	0.466787	0.40296	0.364253	0.45815	0.532315	0.576348	0.5414	0.580354	0.658113	0.859998	0.7446
5	01:00		0.635964	0.71306	0.649225	0.674496	0.573084	0.688369	0.45227	0.472126	0.325582	0.387531	0.407821	0.36568	0.495214	0.586997	0.690773	0.789178	0.492735	0.587279	0.587111	0.5567
6	01:15		0.635964	0.71306	0.649225	0.674496	0.573084	0.688369	0.45227	0.472126	0.325582	0.387531	0.407821	0.36568	0.495214	0.586997	0.690773	0.789178	0.492735	0.587279	0.587111	0.5567
7	01:30		0.635964	0.71306	0.649225	0.674496	0.573084	0.688369	0.45227	0.472126	0.325582	0.387531	0.407821	0.36568	0.495214	0.586997	0.690773	0.789178	0.492735	0.587279	0.587111	0.5567
8	01:45		0.635964	0.71306	0.649225	0.674496	0.573084	0.688369	0.45227	0.472126	0.325582	0.387531	0.407821	0.36568	0.495214	0.586997	0.690773	0.789178	0.492735	0.587279	0.587111	0.5567
9	02:00		0.551832	0.65138	0.575362	0.606672	0.552996	0.641945	0.456888	0.4387	0.281569	0.326869	0.460797	0.357541	0.528073	0.654645	0.785349	0.981204	0.475248	0.592331	0.578435	0.5394
10	02:15		0.551832	0.65138	0.575362	0.606672	0.552996	0.641945	0.456888	0.4387	0.281569	0.326869	0.460797	0.357541	0.528073	0.654645	0.785349	0.981204	0.475248	0.592331	0.578435	0.5394
11	02:30		0.551832	0.65138	0.575362	0.606672	0.552996	0.641945	0.456888	0.4387	0.281569	0.326869	0.460797	0.357541	0.528073	0.654645	0.785349	0.981204	0.475248	0.592331	0.578435	0.5394
12	02:45		0.551832	0.65138	0.575362	0.606672	0.552996	0.641945	0.456888	0.4387	0.281569	0.326869	0.460797	0.357541	0.528073	0.654645	0.785349	0.981204	0.475248	0.592331	0.578435	0.5394
13	03:00		0.585565	0.681221	0.55978	0.696747	0.605921	0.651547	0.500738	0.398841	0.258976	0.316962	0.377633	0.352836	0.534805	0.597102	0.797729	1.047575	0.434375	0.497282	0.544991	0.4410
14	03:15		0.585565	0.681221	0.55978	0.696747	0.605921	0.651547	0.500738	0.398841	0.258976	0.316962	0.377633	0.352836	0.534805	0.597102	0.797729	1.047575	0.434375	0.497282	0.544991	0.4410
15	03:30		0.585565	0.681221	0.55978	0.696747	0.605921	0.651547	0.500738	0.398841	0.258976	0.316962	0.377633	0.352836	0.534805	0.597102	0.797729	1.047575	0.434375	0.497282	0.544991	0.4410
16	03:45		0.585565	0.681221	0.55978	0.696747	0.605921	0.651547	0.500738	0.398841	0.258976	0.316962	0.377633	0.352836	0.534805	0.597102	0.797729	1.047575	0.434375	0.497282	0.544991	0.4410
17	04:00		0.579521	0.648703	0.588838	0.611102	0.617685	0.630256	0.456759	0.409129	0.251805	0.315191	0.348786	0.310452	0.51773	0.55946	0.7666	0.937635	0.397001	0.455587	0.495963	0.3999
18	04:15		0.579521	0.648703	0.588838	0.611102	0.617685	0.630256	0.456759	0.409129	0.251805	0.315191	0.348786	0.310452	0.51773	0.55946	0.7666	0.937635	0.397001	0.455587	0.495963	0.3999
19	04:30		0.579521	0.648703	0.588838	0.611102	0.617685	0.630256	0.456759	0.409129	0.251805	0.315191	0.348786	0.310452	0.51773	0.55946	0.7666	0.937635	0.397001	0.455587	0.495963	0.3999
20	04:45		0.579521	0.648703	0.588838	0.611102	0.617685	0.630256	0.456759	0.409129	0.251805	0.315191	0.348786	0.310452	0.51773	0.55946	0.7666	0.937635	0.397001	0.455587	0.495963	0.3999
21	05:00		0.617595	0.655103	0.653448	0.580337	0.727778	0.627212	0.503509	0.488202	0.249603	0.292534	0.377734	0.296731	0.515301	0.499415	0.795861	0.800253	0.431296	0.436156	0.448679	0.4300
22	05:15		0.617595	0.655103	0.653448	0.580337	0.727778	0.627212	0.503509	0.488202	0.249603	0.292534	0.377734	0.296731	0.515301	0.499415	0.795861	0.800253	0.431296	0.436156	0.448679	0.4300
23	05:30		0.617595	0.655103	0.653448	0.580337	0.727778	0.627212	0.503509	0.488202	0.249603	0.292534	0.377734	0.296731	0.515301	0.499415	0.795861	0.800253	0.431296	0.436156	0.448679	0.4300
24	05:45		0.617595	0.655103	0.653448	0.580337	0.727778	0.627212	0.503509	0.488202	0.249603	0.292534	0.377734	0.296731	0.515301	0.499415	0.795861	0.800253	0.431296	0.436156	0.448679	0.4300
25	06:00		0.788979	0.703986	0.851835	0.714329	0.965835	0.680231	0.715487	0.582028	0.274116	0.31632	0.436128	0.379458	0.509418	0.427678	0.762018	0.758727	0.41611	0.489441	0.503648	0.4317
26	06:15		0.788979	0.703986	0.851835	0.714329	0.965835	0.680231	0.715487	0.582028	0.274116	0.31632	0.436128	0.379458	0.509418	0.427678	0.762018	0.758727	0.41611	0.489441	0.503648	0.4317
27	06:30		0.788979	0.703986	0.851835	0.714329	0.965835	0.680231	0.715487	0.582028	0.274116	0.31632	0.436128	0.379458	0.509418	0.427678	0.762018	0.758727	0.41611	0.489441	0.503648	0.4317
28	06:45		0.788979	0.703986	0.851835	0.714329	0.965835	0.680231	0.715487	0.582028	0.274116	0.31632	0.436128	0.379458	0.509418	0.427678	0.762018	0.758727	0.41611	0.489441	0.503648	0.4317
29	07:00		0.92676	0.680702	1.079229	0.801129	1.063107	0.780349	0.883215	0.784652	0.403473	0.44201	0.586223	0.498126	0.557027	0.467215	0.711174	0.678582	0.467657	0.474046	0.649745	0.5906
30	07:15		0.92676	0.680702	1.079229	0.801129	1.063107	0.780349	0.883215	0.784652	0.403473	0.44201	0.586223	0.498126	0.557027	0.467215	0.711174	0.678582	0.467657	0.474046	0.649745	0.5906
31	07:30		0.92676	0.680702	1.079229	0.801129	1.063107	0.780349	0.883215	0.784652	0.403473	0.44201	0.586223	0.498126	0.557027	0.467215	0.711174	0.678582	0.467657	0.474046	0.649745	0.5906
32	07:45		0.92676	0.680702	1.079229	0.801129	1.063107	0.780349	0.883215	0.784652	0.403473	0.44201	0.586223	0.498126	0.557027	0.467215	0.711174	0.678582	0.467657	0.474046	0.649745	0.5906
33	08:00		0.987681	1.07578	1.060633	0.950537	1.065449	0.918249	1.054723	0.750009	0.504951	0.579355	0.590515	0.491801	0.675057	0.390365	0.719043	0.421265	0.514112	0.631397	0.783808	0.8595
34	08:15		0.987681	0.822207	1.060633	0.898053	1.065449	0.99504	1.054723	0.917045	0.504951	0.584186	0.590515	0.341602	0.675057	0.560305	0.719043	0.678025	0.514112	0.605131	0.783808	0.6692

Building Consumption (kW)

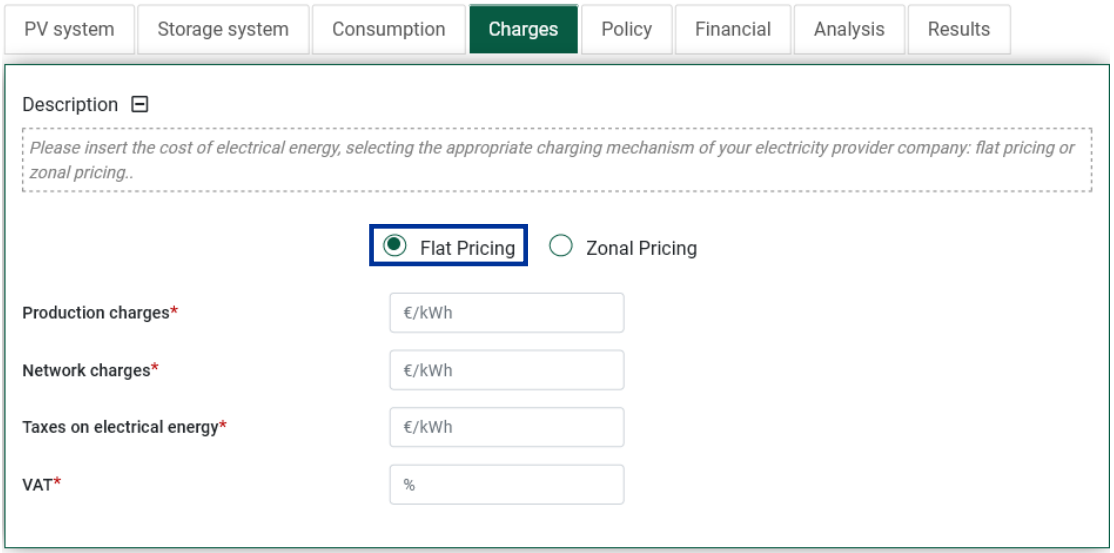
ii. Load flexibility options

The user should enter the percentage of load demand energy of each time zone (00:00 – 08:00 and 16:00 – 24:00) that is flexible and can be shifted towards other time zones.

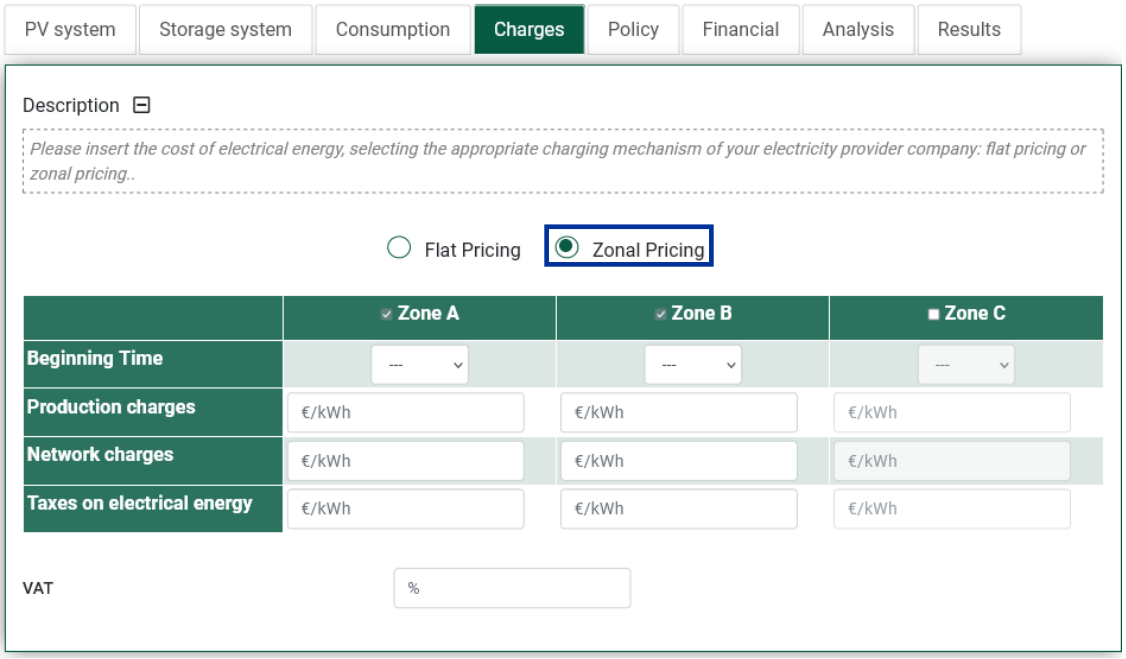


Step 4: Electricity Charging Mechanism and Prices

In this tab, the user should insert the cost for absorbed electrical energy, selecting the appropriate charging mechanism of the electricity provider company. The user can choose between either a *"flat pricing"* scheme, i.e., constant electricity charges throughout the period of a day, or a *"zonal pricing"* scheme, where the prices vary per time zone.



In the dynamic pricing scheme, the user should specify if two or three charging zones exist, by checking accordingly the *"Zone C"* option. The starting hour of each zone should be declared in an ascending order, beginning from Zone A. The ending hour is automatically filled in. Electricity costs should be inserted accordingly.



All values should be entered before VAT. Specifically,

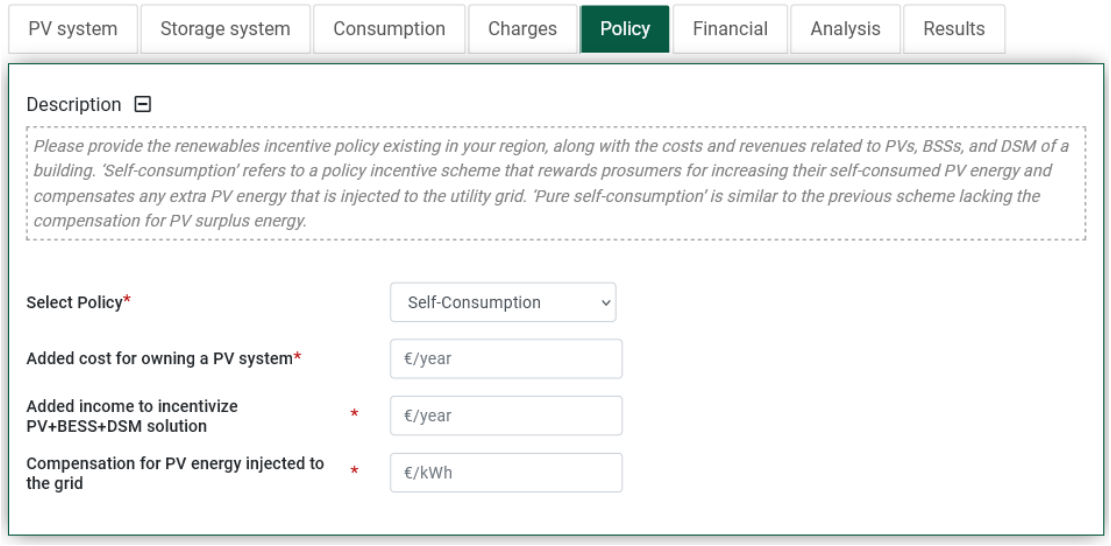
- *"Production charges"* correspond to the charges per kWh for the generation of electrical energy. It includes supply costs as well.
- *"Network charges"* correspond to the cost per kWh that are charged to the prosumer for the use of distribution network and transmission system.
- *"Taxes on electrical energy"* include all other charges that may be applicable per kWh of absorbed energy.
- *"VAT"* is the VAT that applies to the total electricity cost (sum of the above).

Step 5: Policy Data

The user should provide the renewables incentive policy existing in its region, along with the costs and revenues related to PVs, BSSs, and DSM of a building.

- "*Self-consumption"* refers to a policy incentive scheme that rewards prosumers for increasing their self-consumed PV energy and compensates any extra PV energy that is injected to the utility grid. The compensation price per kWh injected into the grid is inserted in the last field of this tab.
- *"Pure self-consumption"* is similar to the previous scheme lacking the compensation for PV surplus energy.

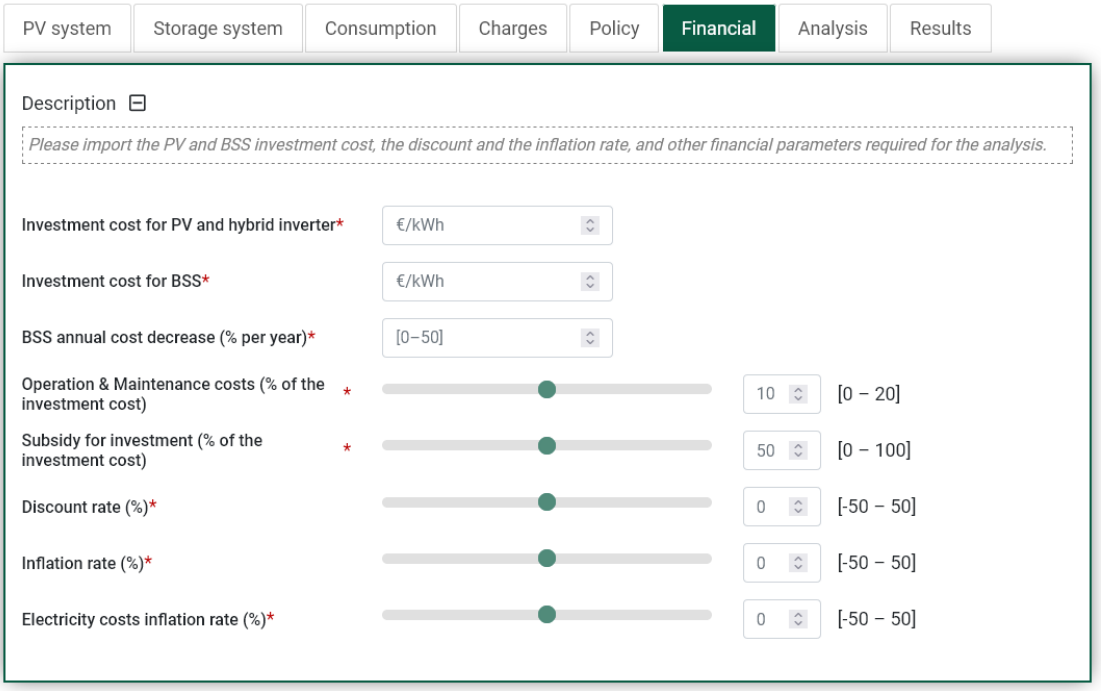
Furthermore, the user can define any added cost or added income that may apply to the prosumers for operating a PV or/and a PV-storage-DSM system.



Step 6: Financial Data

The user should define the cost of purchasing the equipment, the Operation and Maintenance (O&M) costs of the hybrid PV-storage system, the subsidy as a percentage of the overall system cost, the discount rate, the inflation rate, and the electricity inflation rate.

"Investment cost for PV and hybrid inverter" includes the cost of PV panels, the hybrid inverter, engineering, administrative, and balance of systems costs (per kWp installed), whereas *"Investment for BSS cost"* refers to the battery storage system cost (per kWh) and includes the cost of the battery bank and the battery controller.

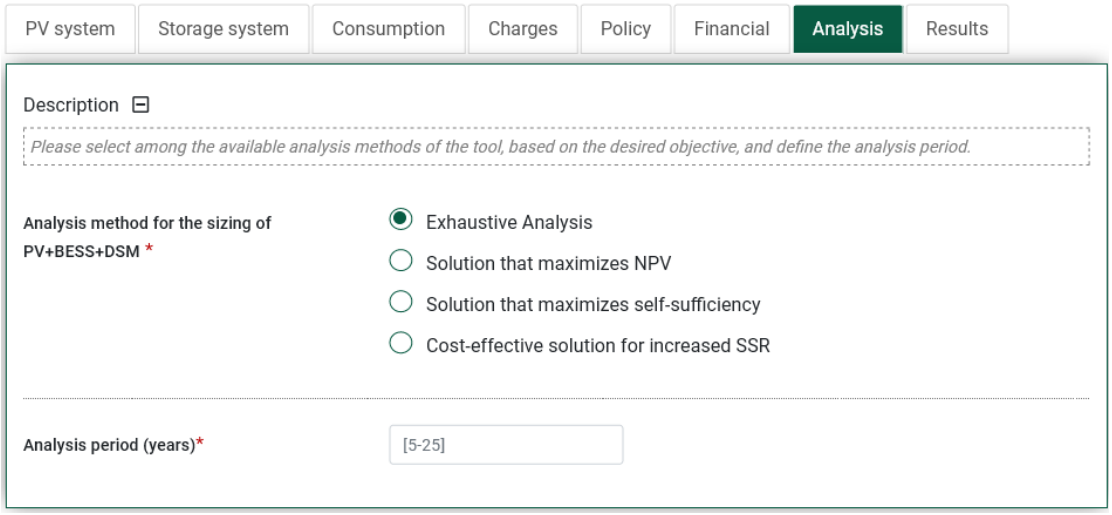


Step 7: Analysis Options

Once all the technical and economical data have been inserted, the user has to select among the available analysis methods, based on the desired objective, and then define the analysis period (in years). The offered analysis methods are the following:

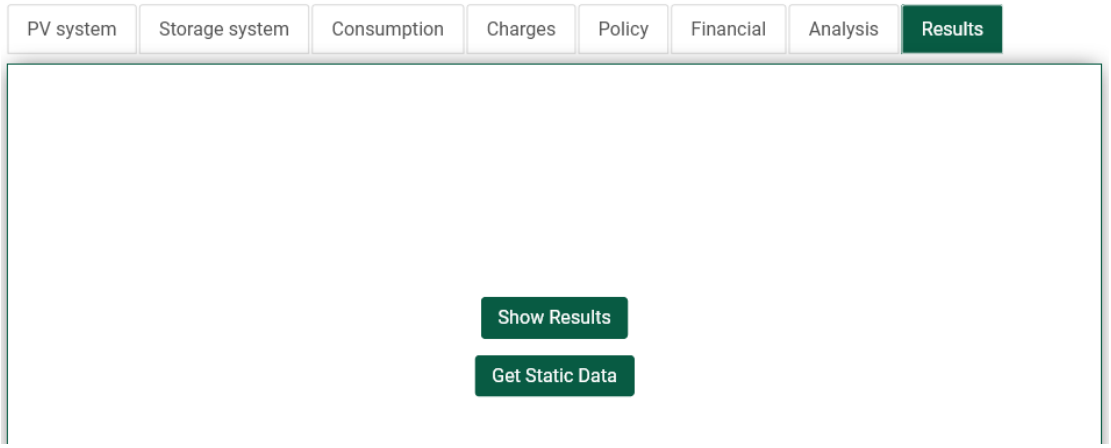
- *"Exhaustive Analysis"*: this analysis returns results for all possible PV and battery size combinations. It is not as fast as the rest methods; however, it may be useful for research and sensitivity analysis purposes.
- *"Solution that maximizes NPV"*: this option activates a thorough investigation of PV and BSS size combinations and delivers the optimal one that achieves the highest NPV. The analysis method is based on a metaheuristic algorithm and quickly provides a sole solution.
- *"Solution that maximizes self-sufficiency"*: this option activates a thorough investigation of PV and BSS size combinations and delivers the optimal one that achieves the highest NPV. The analysis method is based on a metaheuristic algorithm and quickly provides a sole solution.
- *"Cost-effective solution for increased SSR"*: this option activates a thorough investigation of PV and BSS size combinations and delivers a set of solutions that achieve a highly self-sufficient building and a high NPV at the same time. The analysis method is based on a metaheuristic algorithm and quickly provides a set of solutions.

For the last three options, the tool also offers an operation schedule for the flexible loads. The schedule corresponds to the optimal solution for each objective (maximum NPV, maximum self-sufficiency, most cost-effective solution).

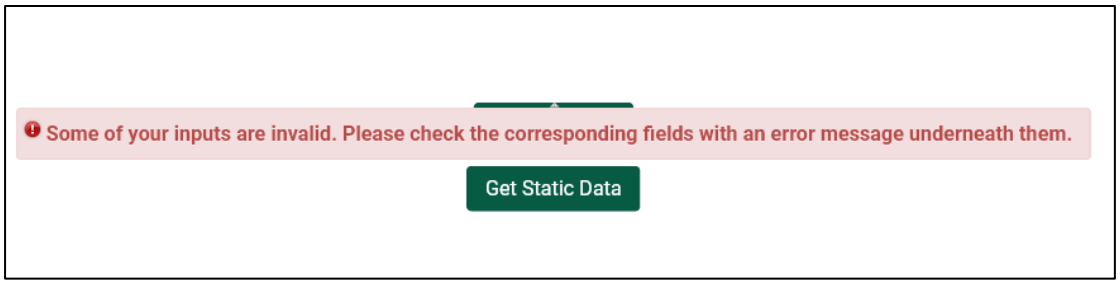


Step 8: Getting the Results

The analysis starts as soon as the user clicks at the *"Show Results"* button.



If any of the inserted data are invalid or missing, an error message shows up informing the user that it should check the corresponding input fields with a red error message underneath.



When the analysis is finished, the results will be visualized on the same tab. Analysis has a duration of several seconds to several minutes depending on the selected analysis method in Step 7.

To export the input data and the results in form of a *.pdf* or editable *.xlsx* file, the user should click on the proper buttons that appear on the right-top of the page.