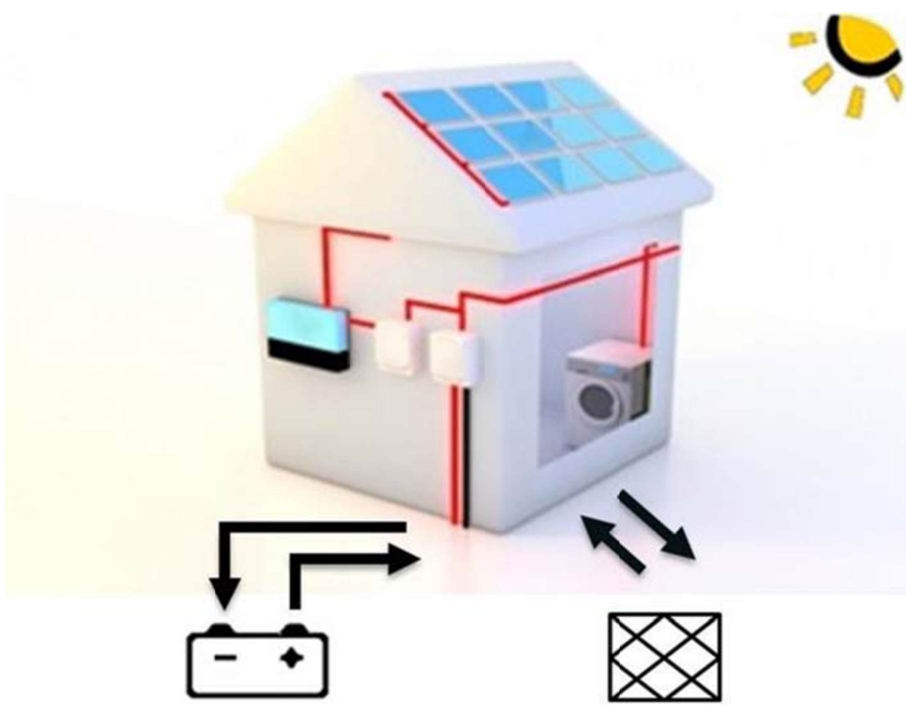
AKD-Batt Design Tool



Abstract

This project is focusing on “Renewable Energy Balancing for residential Homes”. Cost for electric energy is continuously rising. Therefore a positive trend towards self-consumption of decentralized-produced energy can be observed. Renewable sources like photovoltaic or wind are occurring in rather fluctuating manners. To increase the self-consumption storage solutions are needed. Batteries meet the specifications a storage system needs for a residential home. Batteries are small and powerful.

The scope of this project is to find out:

“How much battery capacity is needed for a residential home and how much self-consumption can be achieved with it?”

A MS-Excel-based program-tool has been developed to guide the design process. The main requirement for this tool was to be easy-to-use. A particularity is the user-definable load and generation profiles. Self-consumption can be increased to encouraging high levels, whenever the renewable energy generation is both frequent and sufficient.

Kurzfassung

Dieses Projekt fokussiert sich auf das „Regeneratives Energien-Management für Wohnhäuser". Kosten für elektrische Energie steigen stetig. Aus diesem Grund gibt es einen positiven Trend zum Eigenverbrauch dezentral erzeugter Energie. Das Auftreten von regenerativer Energie aus Photovoltaik und Wind sind von starken Fluktuationen unterlaufen. Von Nöten ist eine Speicher Lösung, um den Eigenverbrauch zu steigern. Batterien erfüllen als Speicher die Anforderungen von einem Wohnhaus, da diese klein und leistungsstark sind.

Im Rahmen des Projektes ist zu ermitteln:
„Welche Dimensionierung der Batteriekapazität ist nötig für ein Wohnhaus und wie viel Eigenverbrauch kann damit erreicht werden?"

Ein Programm wurde entwickelt zur Überprüfung der Auslegung. Die Anforderungen wurden auf eine einfache und leicht handhabbare Software gelegt. Die Berechnung erfolgt als Besonderheit über eigens anpassbare Last- und Generator-Profile. Eigenverbrauch kann zu einem zufriedenstellenden Maße erhöht werden. Die Bedingung dafür sind fortlaufende und hinreichende Energieerträge von der Generator Seite.

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List of Abbreviations

DoD	Depth of Discharge
ESC	Energy Supply Company
ICQ	Internal Consumption Quote
SSQ	Self-sustainability Quote
kWp	kilo Watt peak
PV	Photovoltaic
SoC	State of Charge
VBA	Visual Basic for Application (language)

Introduction

Welcome to the

PV Battery Tool

Here is a short overview of how a battery system works:

(1) **PV Generator**

(2) **Inverter**

(3) **Feed In Meter**

(4) **Two Way Meter**

(5) **Battery**
- Storage of Excess Energy, if demand is already taken care off
- Power Demand, if Generation is sufficient

(6) **Grid**
Full Battery:
- Feed In Grid

Empty Battery:
- Power Demand via Grid

(7) **Consumer**

Quelle: gepowercontrolscom

Basics for Software Development

Methodology

The methodology contains the step by step proceedings of the program design and operation procedures. The PV battery program was designed to be with KISS approach (Keep it short and simple). Therefore Excel and the integrated Visual Basic for Applications language (VBA) were chosen as program platform. The office product is wide spread.

First approach:

- One generator profile
- One H0 load profile
- One ideal storage “bucket“

One generator (photovoltaic) supplies the consumers of a residential house in addition to the grid. The consumption of the house hold is described via a standardised load profile called H0. H0 is the only profile for residential homes. For non-residential homes there are other profiles like G0 for business, N0 for night powered heaters, L0 for farmers and A0 for Traffic lights.

The profile H0 is an average of 150 households. Time steps accuracy is 15 minutes. The interval size of 15 minutes is used as default by utilities for accounting. The PV data was obtained via SQL database of GE Global Research Europe in Garching near Munich. The one second accuracy was summed up to 15 minute means.

The load and generation profiles can be subtracted for reckoning the energy value which has to be charged or discharged (see Equation 0-1):

$$\text{Battery Energy Discharge} = \text{Load Energy General} - \text{PV Generation}$$

Equation 0-1: *Equation for Battery Energy Discharge*

The battery calculation algorithm was designed next. Excess energy is stored to the battery within set boundaries. Energy is supplied by the battery as long the minimum state of charge is not reached. The internal consumption quote in the program is applies to the total load data and not to the total generation.

The first extension stepped into action soon afterwards. Three more generators and loads can be added to the calculation. Efficiency for the battery was added. Losses for charging and discharging can be set to different efficiency values.

To exchange the profiles more comfortably, instead of copy paste procedure, a macro (VBA-function) enables the user to easily do the exchange.

Definitions

Definitions make understanding much simpler. For example battery is often used as a synonym for a rechargeable battery. In the sub-chapters following items will be declared:

- Generators and Loads
- Internal Consumption and Self-Sustain Quote
- Battery States

Generators

Generators produce electric energy. The energy values are set in profiles. Four generators are applied as shown in Table 0-1. The generation profiles have to be in 15 minute intervals for a whole year.

Table 0-1: *Generators for PV-Battery-Tool*

Generators
Photovoltaic (PV)
Wind
Combined Heat and Power (CHP)
GenX*

* GenX is open for a back-up generator or a self-defined generator

Loads

Loads consume electric energy. Loads are a gathering of residential appliances or high power consumers like the heat pump or an electric vehicle. The energy values are set in profiles. Four loads are applied as shown in Table 0-2. The load profiles have to be in 15 minute intervals for a whole year.

Table 0-2: *Loads for PV-Battery-Tool*

Loads
General (entire Household)
Car
Heat Pump
LoadX*

* LoadX is an open profile for a self-definable load

Internal Consumption and Self-Sustainability Quote

The internal consumption quote used in the program is the self-sustainability quote described as SSQ. Since the system is not meant for 100% self-sustainable residential homes it is still marked as internal consumption.

Internal Consumption Quote (ICQ)

The EEG law defines the internal consumption quote as the energy used from PV by energy produced from PV. The energy used from PV is the energy produced from PV subtracted by the energy fed into grid. The internal consumption quote can be seen in following Equation 0-2:

$$ICQ = \frac{Energy\ produced\ from\ PV - Energy\ fed\ into\ Grid}{Energy\ produced\ from\ PV}$$

Equation 0-2: *Internal Consumption Equation by EEG*

Self-Sustainability Quote (SSQ)

The EEG internal consumption equation does not describe the real ratio of the total used energy at home to the used energy from Generators. The following Equation 0-3 describes the self-sustainability grade of system.

$$SSQ = \frac{Energy\ produced\ from\ Generators - Energy\ fed\ into\ Grid}{Used\ Energy\ at\ Home}$$

Equation 0-3: *Equation of Self-sustainability Grade based on Used Energy at Home*

ICQ describes the degree of utilisation of the generator while the SSQ describes the utilisation condition of the entire.

Examples for the ICQ and SSQ equations:

Only a small PV system with 2 kW is considered. Over a year it produced 2000 kWh. An Energy amount of 1000 kWh was supplied to the grid (fed into grid). 4000 kWh have been supplied by the grid by the energy supply company (ESC) / utility.

For Equation 0-2:

$$ICQ_{example} = \frac{2000\ kWh - 1000\ kWh}{2000\ kWh} = 50\ \%$$

For Equation 0-3 used Energy is supplied energy from ESC + (Energy produced from PV – Energy fed into Grid):

$$SSQ_{example} = \frac{2000\ kWh - 1000\ kWh}{4000\ kWh + (2000\ kWh - 1000\ kWh)} = 20\ \%$$

Equation 0-3 is the equation used in the program.

In the following charts are the characteristics of IC and SSQ shown. The chart is standardised for 10.000 kWh/a of general load, the battery capacity is zero. Figure 0-1 and Figure 0-2 shows the IC and SSQ in dependency of the PV Generator size. In the first chart PV generator size is step by step increased linearly to 20 kW power and in the second chart scaled logarithmically. Standard utilisation is one thousand hours per one kW installed power.

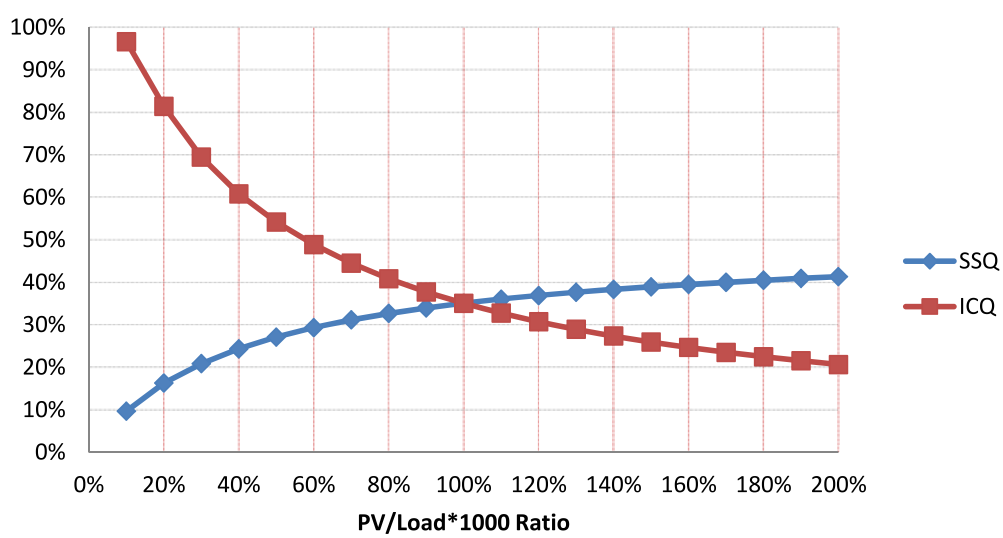


Figure 0-1: *ICQ and SSQ scaled linear to PV size multiplied by a utilization time of 1000 h divided by Load*

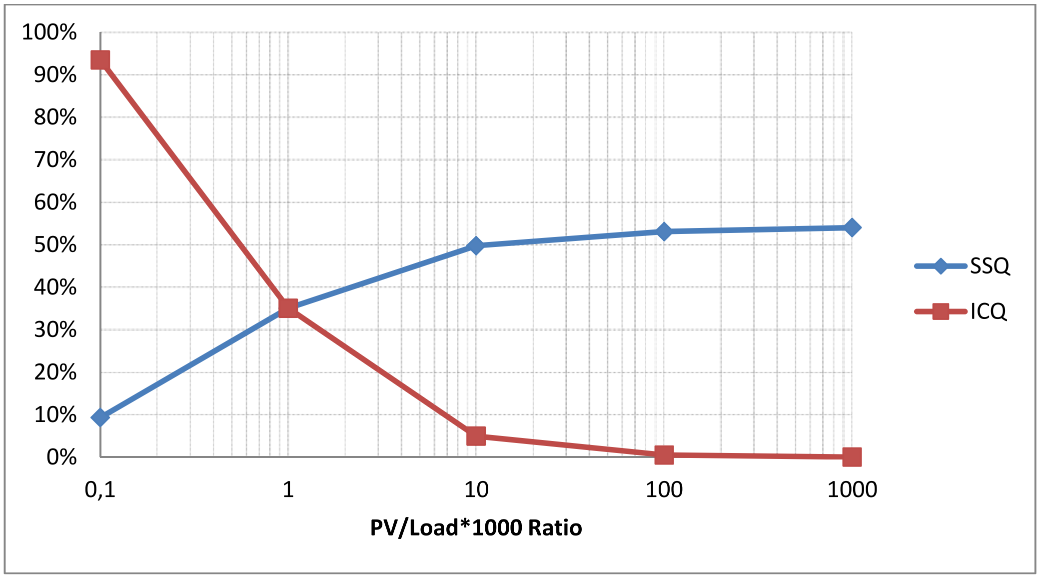


Figure 0-2: *ICQ and SSQ logarithmically scaled*

Looking at the equations for ICQ and SSQ there are three ways to improve the internal consumption quote respectively the self-sustainability grade:

1. Increase power output from generators / PV
2. Decrease energy feed into grid
3. Decrease energy use at home

These three steps refer to many possible options:

at 1. Install a more powerful PV generator,
a small additional generator to provide at every time of day.

at 2. Usage of a storage,
adjust energy consumption behaviour,
switch loads to sun shine hours (decrease idle load)

at 3. Buy class A to A+++* labelled equipment, pay attention to idle loads

*EU Classes A to D see Annex page A

In this project each point is considered, but the focus will be on storage dimensioning.

Battery Load States

Battery load states define the stored energy level. There are many boundaries to describe the battery state.

SOC max and min of the battery

If the battery is fully charged the maximum state of charge (SoC) is reached and the battery is labelled full; SoC_{max} is therefore reached. If the battery is totally discharged this state is called empty also SoC_{min} with a state of available charge of zero. For maximum and minimum SoC see Figure 0-3.

SOC max of the battery and allowed minimum

Batteries are normally not allowed to discharge beyond a certain allowed minimum SoC_{min} (see Figure 0-4).

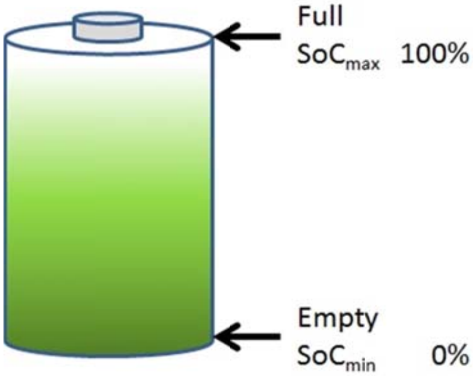


Figure 0-3: *SoC Maximum and Minimum of Battery*

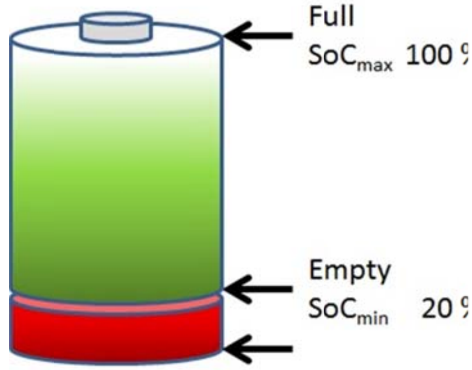


Figure 0-4: *SoC Maximum of Battery and Allowed stated Minimum*

SOC allowed maximum and minimum of the battery

The maximum SoC is normally stated 100%. In many cases also a reduced charging voltage reduces stress and increases the life time of the battery. There are two possibilities shown in Figure 0-5 to define the SoC_{max} with a percentage. The maximum SoC of the battery can be defined as 100% or the allowed maximum, SoC_{max}, can be stated 100%. For the program development the figure on the right side was chosen. DoD is the contrary of SoC. While the SoC has a zero percentage charge the DoD is at its maximum and vice versa.

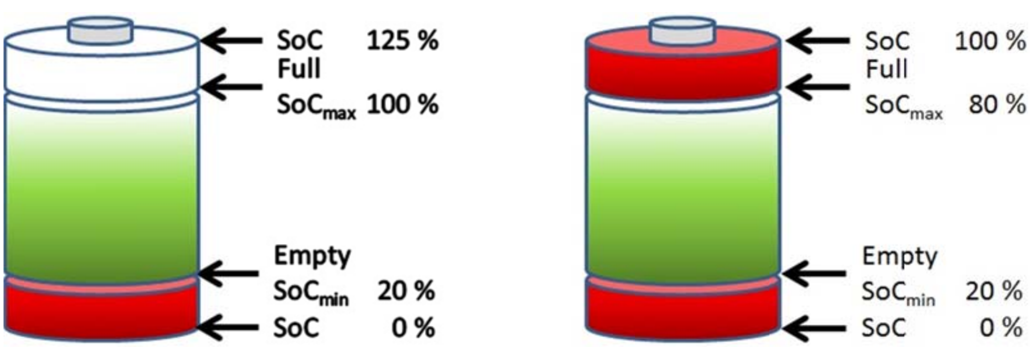


Figure 0-5: *Allowed SoC Maximum and Minimum are stated*

Cycles per Year

Cycles per year defines the energy input to the battery without further losses divided by the useable capacity of the battery (see Equation 0-4). These cycles are full cycles. The battery is not fully charged each time during the year many. The occurrences appear in case produced energy is insufficient. These cycles are less stressful to the battery.

$$Cyles\ per\ year = \frac{Energy\ Input\ before\ Losses}{Battery\ Capacity}$$

Equation 0-4: *Calculation Cycle Counts per Year*

System Storage Efficiency

Efficiency is the ratio of useable energy to the applied energy. In case of the battery efficiency for charging and discharging are applied (see Equation 0-5 and Equation 0-6).

$$Efficiency\ of\ Storage\ Charging = \frac{Stored\ Energy}{Input\ Energy}$$

Equation 0-5: *Energy Efficiency of Charging the Storage*

$$Efficiency\ of\ Storage\ Discharging = \frac{Output\ Energy}{Stored\ Energy}$$

Equation 0-6: *Energy Efficiency of Discharging the Storage*

Design-Tool for Capacity Dimensioning General

Program features-list:

- 15 Minute Time Steps
- 4 Load and Generators Profiles each
- Easy Exchange of Profiles
- Profile Example view
- Robustness Simulation
- Monte Carlo Simulation

The Simulation Tool is parted in single tabs:

(1) Main Menu

(2) Profile Overview

(3) Parameter Settings

(4) One Year Data Calculation

(5) Monte Carlo Simulation

(6) Robustness Analysis

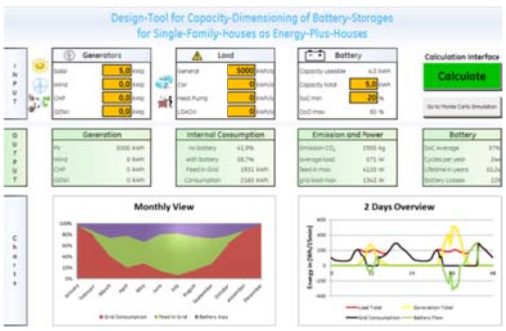
For each menu a sub-chapter can be found below.

At the bottom of the Excel screen the tab-bar can be found:

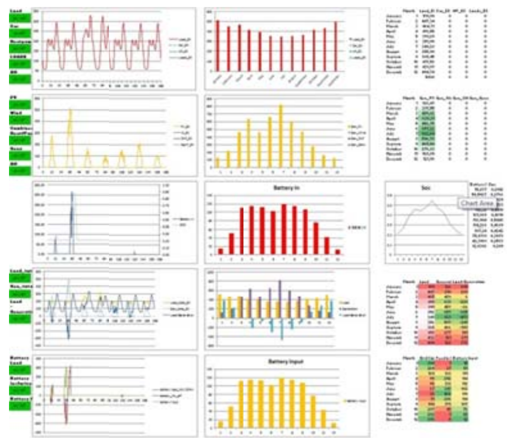
The program is structured in six tabs. The following Table 0-3 shows all tabs with a picture.

Table 0-3: *The six Program Tabs*

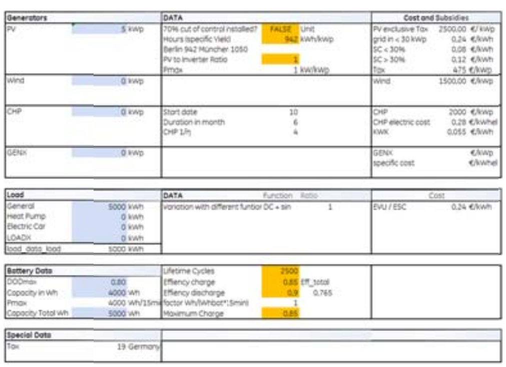
(1) Main Menu



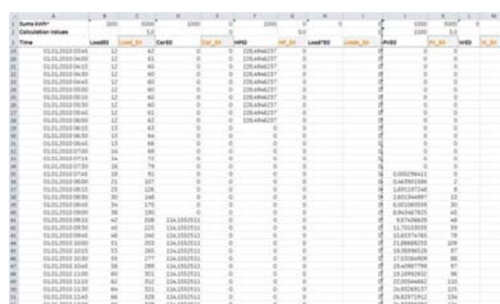
(2) Profile Overview



(3) Parameter Settings

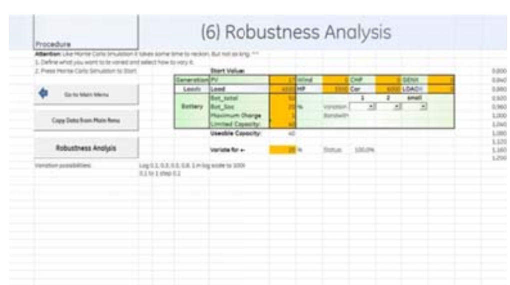


(4) One Year Data Calculation



(5) Monte Carlo Simulation

(6) Robustness Analysis



Main Menu

The main menu offers every main entry parameter for generators, loads and battery as well as important output values like energy feed into grid, energy obtained from ESC and battery characteristics (see Figure 0-6). Generation, Load and Battery size are editable. After entering data to the INPUT section - headings marked in light blue - by pressing the Calculate button on the right sight OUTPUT data, the monthly view chart as well as the two days example chart will be updated immediately. For an even more detailed analysis click “Goto Monte Carlo Simulation” next to the “Calculate” button.

The main menu supports the three sections:

- Input
- Output
- Charts

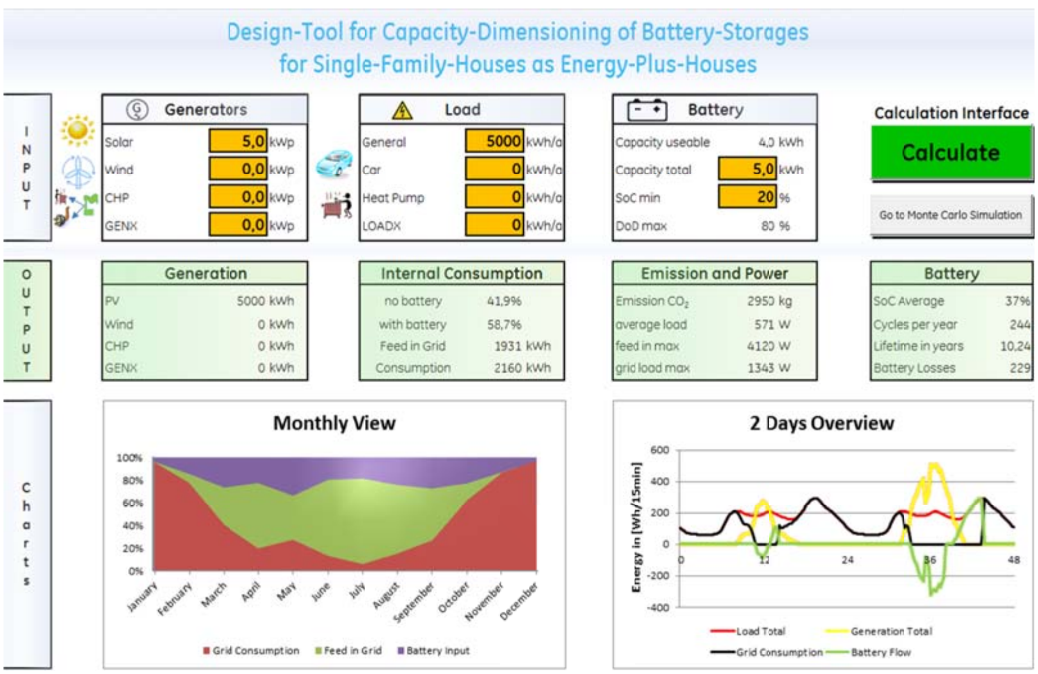
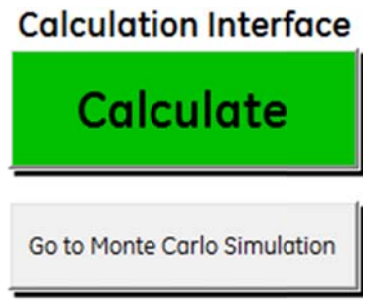


Figure 0-6: *Main Menu Tab: Input, Output, Charts and Calculation Interface*

Interface

Calculation Interface



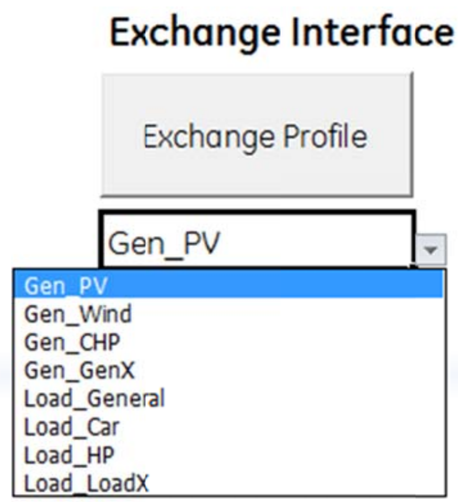
The Calculate button will change colour if an input value is changed.

Red – not yet calculated

Green – calculated

For a more detailed simulation press the Monte Carlo Simulation button. More information you will find in chapter 0.

Easy Exchange Interface



The button “Exchange Profile” will replace any profile easily. Via the drop-down menu the profile to exchange can be chosen. The specific folder will open and a selectable list of profile will be shown.

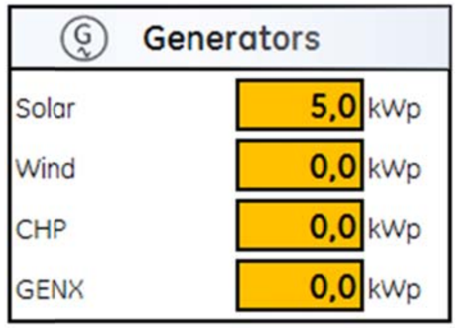
The profile file consists out of the heading and 35040 rows of data. The profile needs to have 15 minute average values and start with first of January 00:00 and end on December the 31st 23:45. In Table 0-4 an example is shown of how the *.xlsx file (Windows Update adds compatibility for EXCEL 2003 Version) have to look like:

Table 0-4: *Example cut-out Profile Table*

Time	Value
01.01. 00:00	123
01.01. 00:15	234
⋮	⋮
31.12. 23:45	345

Input

Generation

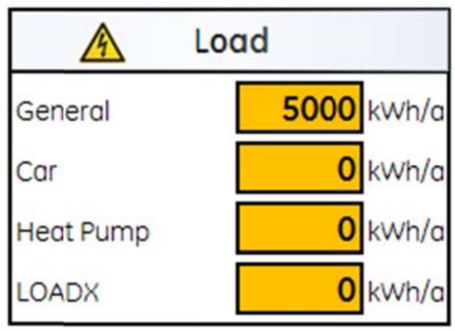


Values for Rated Power in kW for generators:

- Solar
- Wind
- Combined Heat and Power (CHP)
- GENX *

* GenX is open for a back-up generator or a self-defined generator.

Load

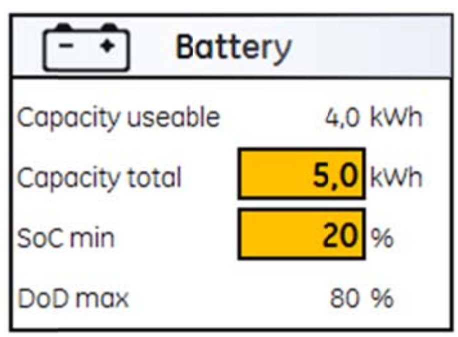


The load box preserves data in energy per year for following consumer:

- General
- Car
- Heat pump
- LOADX *

* LoadX is an open profile for a self-definable load.

Battery



The battery box allows entering following battery parameters:

- Total Capacity
- Minimum allowed State of Charge (SoC_{min})

Useable Capacity will then be calculated.

The battery parameter for the upper bound can be changed in the parameter settings (see chapter 0 “Parameter Settings”).

Output

Generation

Due to the kWp normed profiles the generation profiles are multiplied by the rated Power. PV also takes usage hours into account:

$$Factor = \frac{\mathrm{P}\ (radted\ Power) \times t\ (in\ hours)}{1000\ kWh}$$

Generation	
PV	4706 kWh
Wind	0 kWh
CHP	0 kWh
GENX	0 kWh

An Example:

Pr = 5 kW

t = 942 h (Berlin)

$$Factor = \frac{5\ kWp \times 942\ h}{1000\ kWh} = 4.7\ \Rightarrow$$

Energy Generation per year: 4706 kWh

Internal Consumption Quote (ICQ)

This Area shows the ICQ without and with an installed battery system. Also the grid consumption and feed into grid energy is shown.

Attention:
The ICQ used in the program is the SSQ defined in chapter 0.

Internal Consumption	
no battery	41,7%
with battery	58,3%
Feed in Grid	1703 kWh
Consumption	1895 kWh

Emission and Power (EP)

The EP field supports data to saved CO_2 emissions, if all sources are stated renewable. The factor therefore is 590 kg per MWh. In addition the maximum feed in grid and grid load is added.

Emission and Power	
Emission CO_2	2777 kg
average load	542 W
feed in max	3873 W
grid load max	1276 W

Battery

State of charge (SoC) shows the average charge status over the whole year, which can be an identifier for a significantly reduction of battery life time. E.g.: an average over 85 % is bad for storage reasons.

Lifetime in years is based on full cycles.

Battery	
SoC Average	42%
Cycles per year	255
Lifetime in years	9,80
Battery Losses	148

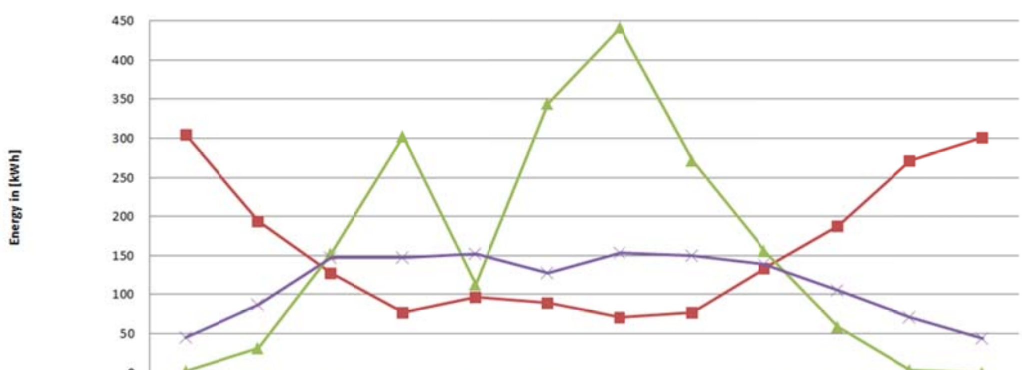
$$Lifetime = \frac{Total\ amout\ of\ achivable\ Cycles\ (see\ battery\ data\text{–}sheet)}{Cycles\ per\ year}$$

Charts

In Figure 0-7 a monthly chart shows the energy sum of each month for

- Energy from ESC
- Feed into Grid
- Battery Input

Feed into grid rises till July, green line, while grid consumption is contrary and rises in winter months; the battery throughput depends on the battery capacity. From March to September the battery input is almost identical. The capacity could be increased for higher internal consumption quotes since feed into grid is sufficient and energy has still to be supplied from ESC. Battery input hits its maxima around March and September, due to moderate irradiation and moderate energy demand. In summer the energy input is lower. There is much excess energy and demand is at its minimum. The battery is probably not even discharged during the night. For that reason the grid consumption hits also a minimum. The battery is not efficiently used between the months October with February. At this time, for better battery life expectancy the charge algorithm should be optimized for a higher average state of charge.



	January	February	March	April	May	June	July	August	September	October	November	December
Energy from ESC	304	194	128	77	97	89	71	77	133	188	271	301
Feed into Grid	2	31	153	303	113	344	441	271	157	59	4	0
Battery Input	45	86	148	148	152	128	154	150	139	106	71	44

Figure 0-7: *Monthly chart: Energy supply by ESC, feed into grid and battery input*

The following Figure 0-8 shows the ratio between the three energy sums in every month as 100 % in an accumulated view. Example July (data obtained from chart; see Figure 0-7):

$Energy\ Supply\ from\ ESC = 71\ kWh$ $Sum = 71 + 441 + 51 = 563\ kWh$

$Feed\ into\ Grid = 441\ kWh$ $\Rightarrow ESC = \frac{71}{563} = 12.6\ \%$

$Battery\ Input = 51\ kWh$ $\Rightarrow Feed\ into\ grid = \frac{441}{563} = 78.3\ \%$

$\Rightarrow Battery\ Input = \frac{51}{563} = 9.1\ \%$

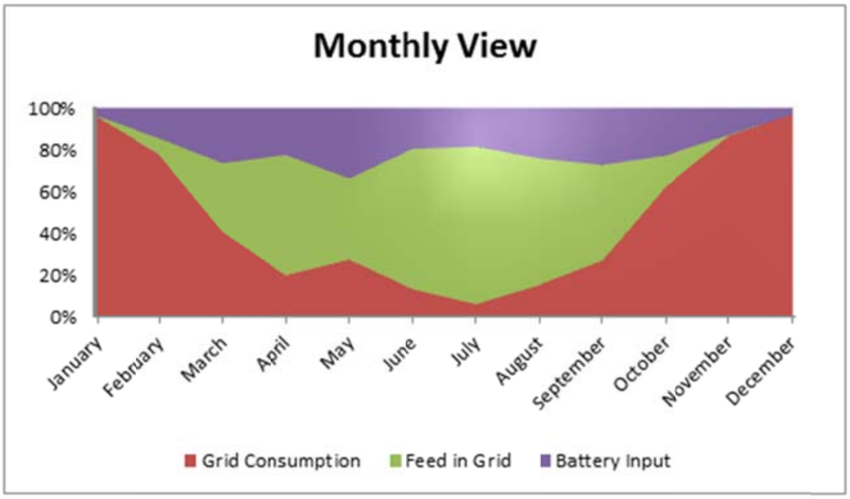


Figure 0-8: *Grid Consumption, Feed in Grid and Battery Input summed up every Month as 100 % and set into ratio*

The two day overview is an example of data in February (see Figure 0-9). The chart shows generation (yellow), battery in and output (green) under the defined efficiencies, grid consumption (black) and the current load (red). All data are directly calculation values and therefore in watt hours per 15 min Intervals. The average power is extracted by multiplying the energy values by factor four Watt per Wh/15min.

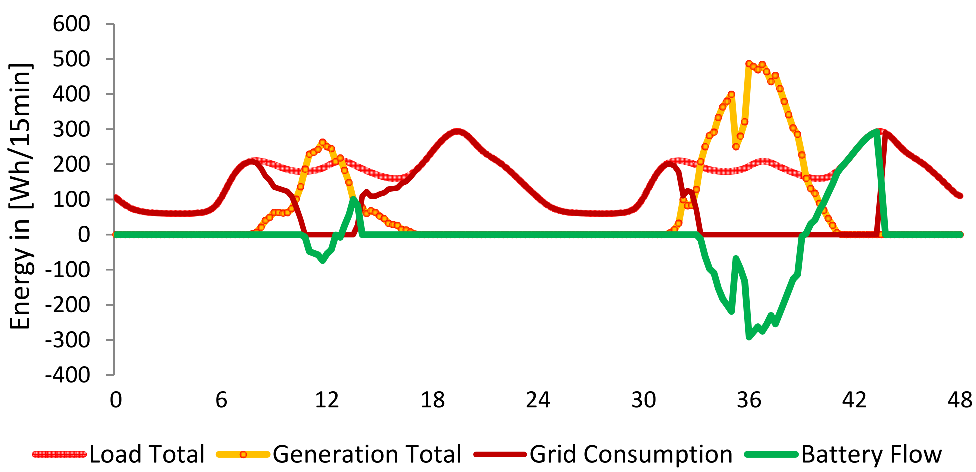


Figure 0-9: *Two days overview of the energy balancing of PV Battery system*

Profile Overview

The profile overview enables the view to the different profiles. The profiles can be shown in detail by disabling the other graphs by clicking the buttons shown in Figure 0-10. The load and generation graph has an all on/off button each to show or hide all loads / generations and enable the user to quickly display one graph again by activating it.

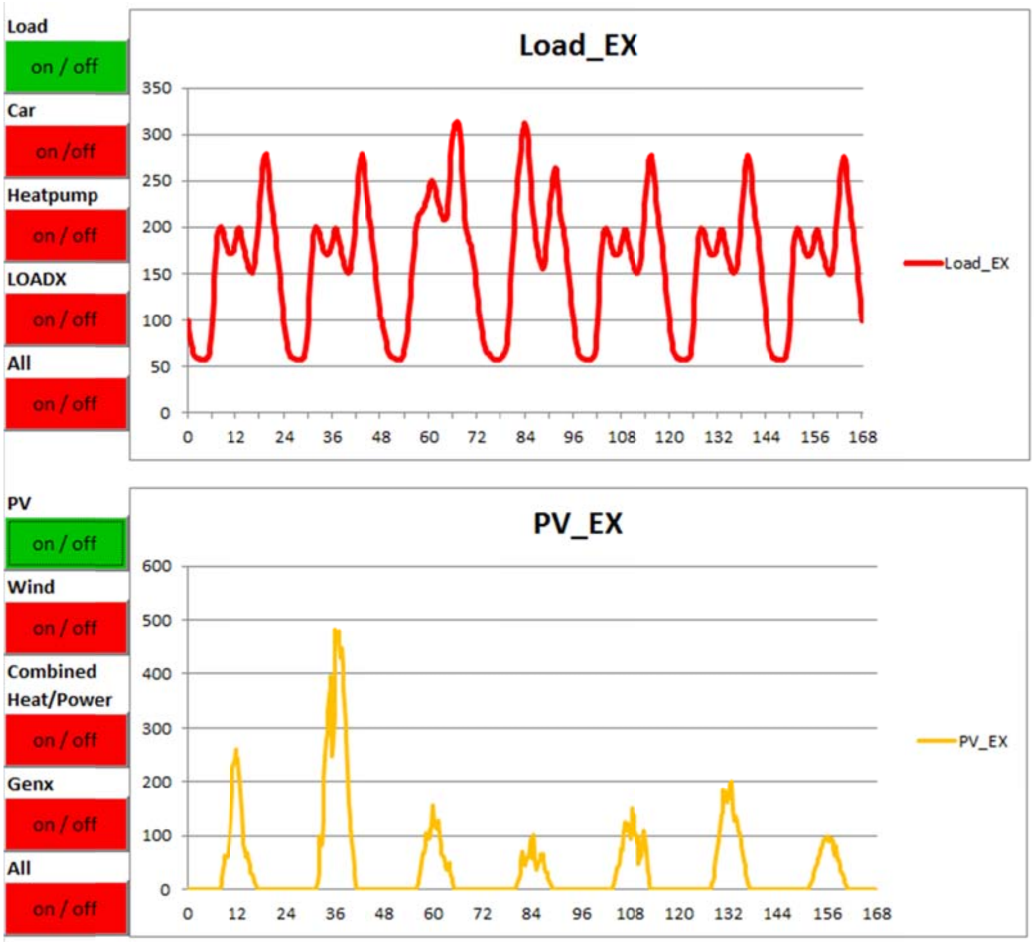


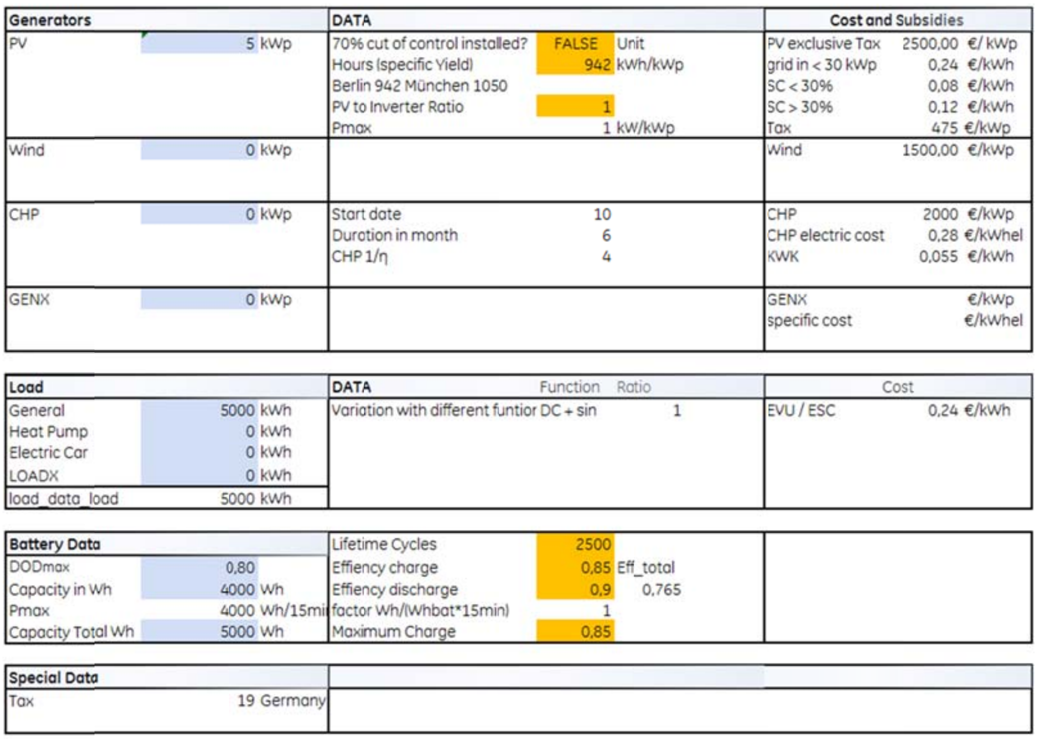
Figure 0-10 *Profile overview example of loads (first chart) and PV generation chart (second chart)*

Parameter Settings

The parameter settings tab give you the total overview of enabled and used parameters (see Figure 0-11). Data from the main menu is marked blue. The advanced settings are marked orange. A list of the editable parameters and reasonable range values can be found in Table 0-5. Generation and battery data can be edited in more detail. The blue marked fields are a copy from the main menu to give an overview of all parameters in one tab. The blue fields will be overwritten if changed in the parameter settings tab. Orange labelled fields can be edited, not filled cells are open for further implementation

Table 0-5: *Parameter and Reasonable Range Values*

Parameter	Reasonable Range
70% PV cut off	On / Off
PV – Hours	700 … 2000
PV to Inverter Ratio	0.9 to 2, 3 …
Batter – Lifetime Cycles	800 … 7000
Battery – average Input / Output Efficiency	0.8 … 0.99
Battery – Maximum Charge Level (SoC_{max})	0.8 … 1.0



Generators			DATA			Cost and Subsidies		
PV	5	kWp	70% cut of control installed?	FALSE	Unit	PV exclusive Tax	2500,00	€/ kWp
			Hours (specific Yield)	942	kWh/kWp	grid in < 30 kWp	0,24	€/kWh
			Berlin 942 München 1050			SC < 30%	0,08	€/kWh
			PV to Inverter Ratio	1		SC > 30%	0,12	€/kWh
			Pmax	1	kW/kWp	Tax	475	€/kWp
Wind	0	kWp				Wind	1500,00	€/kWp
CHP	0	kWp	Start date	10		CHP	2000	€/kWp
			Duration in month	6		CHP electric cost	0,28	€/kWhel
			CHP 1/η	4		KWK	0,055	€/kWh
GENX	0	kWp				GENX		€/kWp
						specific cost		€/kWhel

Load			DATA	Function	Ratio	Cost		
General	5000	kWh	Variation with different funtior DC + sin		1	EVU / ESC	0,24	€/kWh
Heat Pump	0	kWh						
Electric Car	0	kWh						
LOADX	0	kWh						
load_data_load	5000	kWh						

Battery Data			Lifetime Cycles	2500		
DODmax	0,80		Effiency charge	0,85	Eff_total	
Capacity in Wh	4000	Wh	Effiency discharge	0,9	0,765	
Pmax	4000	Wh/15mi	factor Wh/(Whbat*15min)	1		
Capacity Total Wh	5000	Wh	Maximum Charge	0,85		

Special Data			
Tax	19	Germany	

Figure 0-11: *Parameter Settings Tab: Blue fields, copy of main menu. Orange labelled fields are additional parameters*

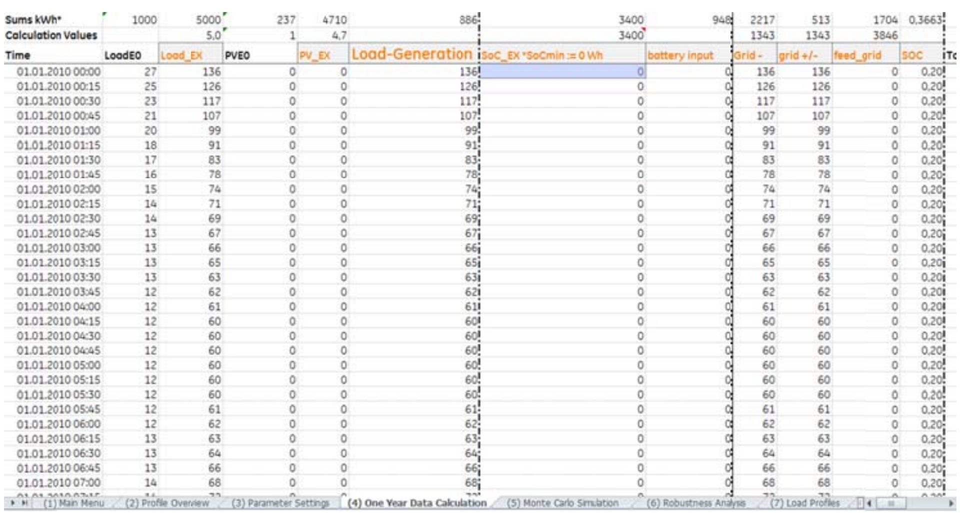
One Year Data Calculation

The one year data calculation tab contains all necessary calculations and data for a one year simulation. The display shows sums of all energy values and the multiplication factors. The first column supplies the time information in the format DD.MM.YYYY and time hh:mm. D stands for day, M for Month, Y for Year, h for hour and m for minute. The calculation columns are marked with orange front colour on grey back colour. The Indexes in the one year data calculation tab are found in Table 0-6.

Table 0-6: *Indexes used in the in One Year Data Calculation*

Index	Explanation
E	Energy
0	Standard Profile
X	Standard Profile Multiplied by factor X
Inc	Inclusive
-	Consumed from
+/-	Feed in / consumed from

Load data for the four different loads are contained in columns B to I. Column B contains the standardised profile LoadE0, while column C contains the multiplication with the Load-multiplication factor. Generation data for the four generators are contained in columns J to Q. The sum of all loads per 15 min interval is found in column R. The sum of all generation per 15 min interval is found in column S. The value for load subtracted by generation is the basis for the battery charging calculation (column T). Column U contains the state of charge energy of the usable capacity in [Wh]. Columns V to X contain battery characteristics. Columns Z to AB contains the energy supplied via the distribution grid and energy feed into grid. Column AC contains the SoC value of the total battery capacity. The simulation requires 15 minute interval averages on Energy in Wh, resulting in a 35040 rows of data for one year. Load Profiles have to be normed to 1000 kWh per year. Generation Profiles are normed to their full time usage hours or to general 1000 kWh per year. In Figure 0-12 a basic overview of the one year data calculation is shown. The basic view features a minimisation of loads and generation to the general residential load (Load_EX) and a photovoltaic system (PV_EX). The battery columns were reduced to the important columns without any battery losses.



Sums kWh*	1000	5000	237	4710	886	3400	948	2217	513	1704	0,3663
Calculation Values		5,0	1	4,7		3400		1343	1343	3846	
Time	LoadE0	Load_EX	PVE0	PV_EX	Load-Generation	SoC_EX *SoCmin := 0 Wh	battery input	Grid -	grid +/-	feed_grid	SOC
01.01.2010 00:00	27	136	0	0	136	0	0	136	136	0	0,20
01.01.2010 00:15	25	126	0	0	126	0	0	126	126	0	0,20
01.01.2010 00:30	23	117	0	0	117	0	0	117	117	0	0,20
01.01.2010 00:45	21	107	0	0	107	0	0	107	107	0	0,20
01.01.2010 01:00	20	99	0	0	99	0	0	99	99	0	0,20
01.01.2010 01:15	18	91	0	0	91	0	0	91	91	0	0,20
01.01.2010 01:30	17	83	0	0	83	0	0	83	83	0	0,20
01.01.2010 01:45	16	78	0	0	78	0	0	78	78	0	0,20
01.01.2010 02:00	15	74	0	0	74	0	0	74	74	0	0,20
01.01.2010 02:15	14	71	0	0	71	0	0	71	71	0	0,20
01.01.2010 02:30	14	69	0	0	69	0	0	69	69	0	0,20
01.01.2010 02:45	13	67	0	0	67	0	0	67	67	0	0,20
01.01.2010 03:00	13	66	0	0	66	0	0	66	66	0	0,20
01.01.2010 03:15	13	65	0	0	65	0	0	65	65	0	0,20
01.01.2010 03:30	13	63	0	0	63	0	0	63	63	0	0,20
01.01.2010 03:45	12	62	0	0	62	0	0	62	62	0	0,20
01.01.2010 04:00	12	61	0	0	61	0	0	61	61	0	0,20
01.01.2010 04:15	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 04:30	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 04:45	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 05:00	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 05:15	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 05:30	12	60	0	0	60	0	0	60	60	0	0,20
01.01.2010 05:45	12	61	0	0	61	0	0	61	61	0	0,20
01.01.2010 06:00	12	62	0	0	62	0	0	62	62	0	0,20
01.01.2010 06:15	13	63	0	0	63	0	0	63	63	0	0,20
01.01.2010 06:30	13	64	0	0	64	0	0	64	64	0	0,20
01.01.2010 06:45	13	66	0	0	66	0	0	66	66	0	0,20
01.01.2010 07:00	14	68	0	0	68	0	0	68	68	0	0,20

(1) Main Menu / (2) Profile Overview / (3) Parameter Settings / (4) One Year Data Calculation / (5) Monte Carlo Simulation / (6) Robustness Analysis / (7) Load Profiles

Figure 0-12 *One Year Data Calculation Sheet containing basic view of Loads, Generators, SoC of the Battery and Grid data*

Monte Carlo Simulation

The Monte Carlo Simulation (MCS) gives the opportunity to see what bandwidth variety the conclusion can have. The MCS calculate the data by diversifying the loads, generations and battery-sizes. Therefore the loads and generations are changed from plus minus X % with a Gauss-distribution in eleven quantified steps. The battery values are distributed as a Weibull-distribution, due to the fact that batteries mostly do not hit their rated capacity. Also they are affected over time by their usage, which will lead to capacity loss. As conclusion a bandwidth variety with their possibilities of occurrence are given. The parameter can be set.

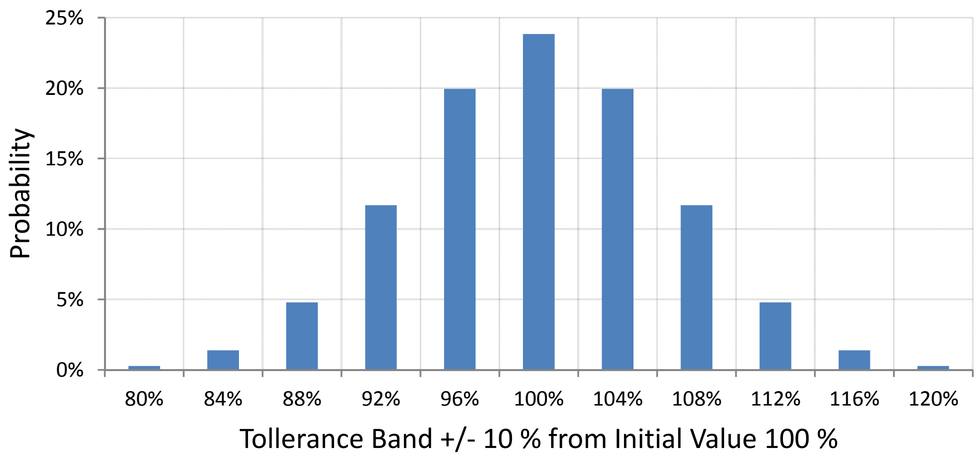


Figure 0-13: *Gauss-Distribution*

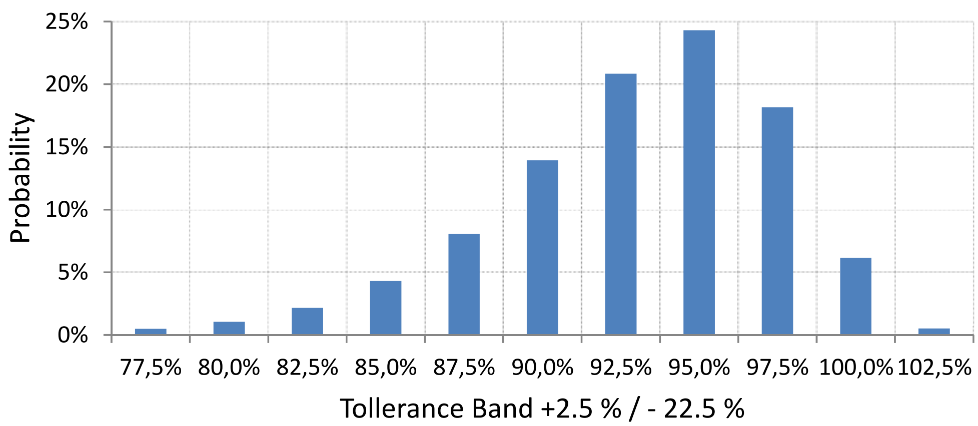


Figure 0-14: *Weibull-Distribution*

Plot for Standard Values: PV 5 kW, Load General 5000 kWh/h, Battery 5 kWh, SoC 20%, Maximum Load

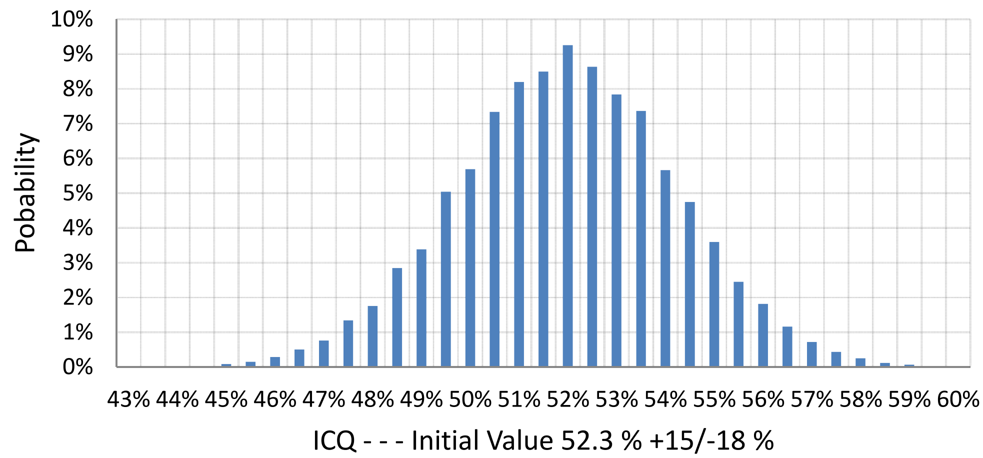


Figure 0-15: *Bandwidth – Probability over Internal Consumption Quote*

Robustness Simulation

The robustness simulation is like the MCS an analysis type where more information can be gathered. For robustness simulation ratios are taken into account. There are two ratios: PV to Load and Battery to Load ratio (see Table 0-7). Every output parameter can be displayed as dependency of the ratios which maxes similar sized systems comparable.

Table 0-7: *Ratios for Robustness Simulation*

Ratio #	Ratio between … and …	Ratio Calculation
1 PV	Generation PV and Load	0.1 … 2 $\frac{kW}{1000\ kWh}$
2 Bat	Battery and Load	0.1 … 20 $\frac{kWh}{1000\ kWh}$

Example:

Generation PV and Load Ratio = 1 (Ratio #1 PV)

$Load\ := 5000\ kWh$

$$\Rightarrow PV \quad = Load\ \times (Ratio\ \#1\ PV) = 5\cancel{000}\ kWh\ \times 1\ \frac{kW}{\cancel{1}000\ kWh} =$$
$$= 5\ \ kW$$

Battery and Load = 2 (Ratio #2 Bat)

$$\Rightarrow Battery = Load \ \times (Ratio\ \#1\ Bat) = 5000\ \cancel{kWh}\ \times 2\ \frac{kWh}{1000\ \cancel{kWh}} = \frac{2 \times 5\cancel{000}\ kWh}{1\cancel{000}} =$$
$$= 10\ kWh$$

Similar Systems:

If ratios and additional background parameters (see 0) stay the same technical output values stay the same; economical costs vary.

The results of the robustness simulation are shown in chapter 0.

Calculation for PV-Battery Tool

Calculation General

Calculation for PV-Battery-Tool elucidated the features implemented of Excel and the visual basic for application language (VBA). The calculation in Excel is done via formula written to cells (see Figure 0-16). Another way to execute function is by Macros. Macros can perform more complex functions. Macros can call automatically achieve tasks also doable by hand, but are much faster by using Macros (see Figure 0-17).

	A
1	71
2	441
3	51
4	=SUM(A1:A3)

Figure 0-16: *Formula in Cell A4 calculates the sum of A1 + A2 + A3 = 71 + 441 + 51 = 563*

```
Option Explicit

Sub BasicExampleAdd()

    Dim Sum As Integer
    Sum = Range("A1").Value _
                    + Cells(2, 1).Value _
                    + Cells(3, 1).Value
    Range("A4").Value = Sum

End Sub
```

Figure 0-17: *Mini Excel Macro: Sum up 3 values (A1, Cell 2,1 and Cell 3,1) and write them to cell A4. Cell 2,1 is A2 and Cell 3,1 is A3*

Profiles normed (Loads)

The Load profiles are normed to 1000 kWh per year.

The Energy demand x for one time step is calculated by the x kWh/a entered in the Load profile window. Factor R stands for Recalculate or Resize.

$$\bar{E}_{demand\ x} = \underbrace{\frac{x\ in\ [kWh/a]}{1000\ kWh/a}}_{\text{Factor R}} \times \bar{E}_{demand\ 0}$$

Equation 0-7: *Calculation of Energy Consumption*

The general load profile is an average of 150 Single-Households normed to 1000 kWh/a.

Resize Calculation Example:

Time — January 1st 00:00

General Energy Demand x — 5000 kWh/a

Profile Energy Value — 27 Wh (in this 15 min time step)

Power:

$$P = 27\ Wh \times \frac{60\ \frac{min}{h}}{15\ min} = 27\ Wh \times \frac{4}{h} = 108\ W$$

- ⇨ Factor
- ⇨ $\bar{E}_{demand\ x}$

$$R = \frac{x\ in\ [kWh/a]}{1000\ kWh/a} = \frac{5000\ kWh/a}{1000\ kWh/a} = 5$$

$$\bar{E}_{demand\ x} = R \times 27\ Wh = 5 \times 27\ Wh = 135\ Wh$$

Profiles normed to 1 kW (Generators)

Generation profiles are normed to 1 kW of generator power; except PV; PV is normed to 1000 kWh/a. The PV full time usage hours for the year can be edited in the parameter settings tab. As well the PV to Inverter Ratio can be edited to limit PV generation output.

Battery Algorithm

The battery algorithm is shown by the three sequence charts. The battery system recalls generation and load data (see Figure 0-18). In case generation exceeds the consumption energy the battery switch to the battery charging algorithm, else the battery is dis-charged. In case load energy is equal to the generation energy the charge algorithm is applied.

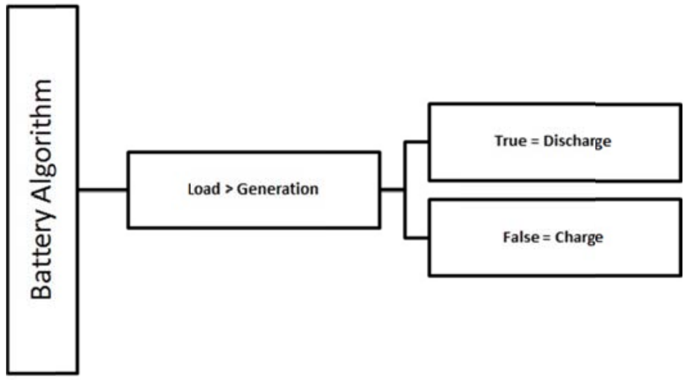


Figure 0-18: *Battery Algorithm to switch to Charge or Discharge Algorithm*

Battery Charging Algorithm

In case the battery enters the charging algorithm the next step is to recall the actual SoC. If SoC is bigger or equal to the maximum SoC the program checks if the maximum SoC would be exceeded. If so the battery is not charged to the maximum SoC limit. The surplus is fed into the grid. If the last SoC is the maximum SoC all energy is fed into the grid (see Figure 0-19).

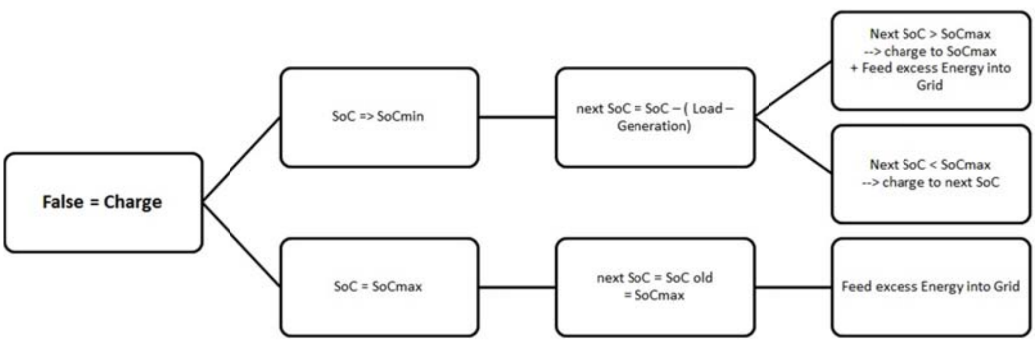


Figure 0-19: *Battery Charging Algorithm; the steps are checked from right to left*

Battery Discharging Algorithm

The battery discharging algorithm recalls the SoC first. The next step in case of the SoC is lower or equal full capacity but not minimum SoC the battery is discharged. If the minimum SoC would be underrun, the battery is only discharged to the minimum SoC. The remaining demand for powering the loads is withdrawn from the power grid. If the SoC is already the minimum SoC the entire demand is powered by the grid (see Figure 0-20).

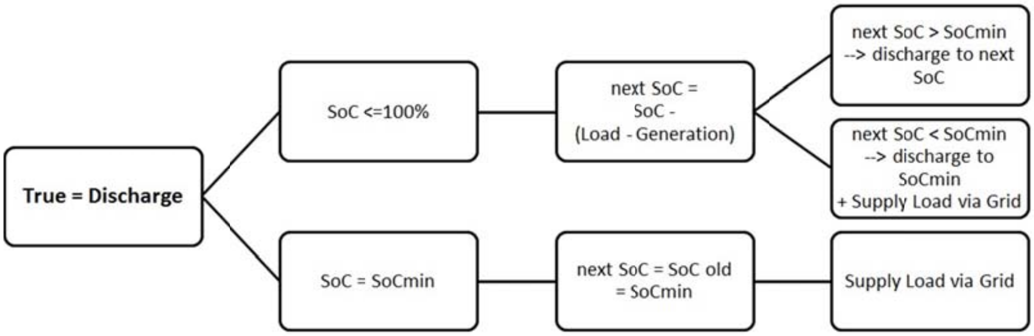


Figure 0-20: *Battery Discharging Algorithm; the steps are checked from right to left*

PV Inverter Ratio and 70 % Cut Off

The PV inverter ratio and the 70 % cut off are directly implemented to the PV profile (e.g. see Figure 0-21). The 70 % cut off is equivalent of an inverter ratio of one divided by 0.7 resulting in a factor of 1.43. Modern PV plants will have a ratio of 1.4 or higher depending on PV module price and utilisation of the exceeding energy.

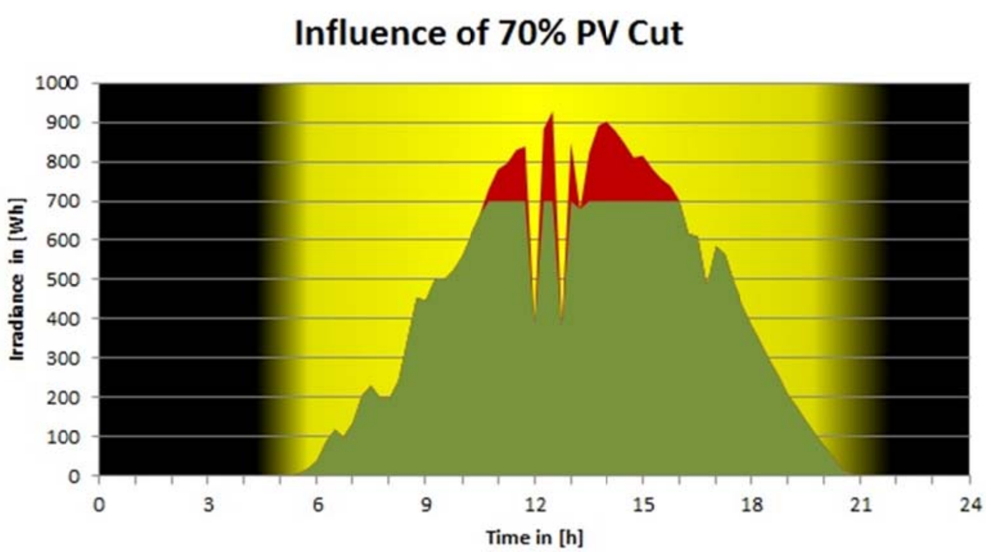


Figure 0-21: *70 % impacts on energy output of PV generator*

Software Development Method

Program Analysis and Finding Best Parameters

Several simulations were run with different load distributions. For running the simulation the standard generator is PV. Several standard households were defined. For a better compatibility only the ratios of the robustness simulation were taken into account (see chapter 0). The ratios enable the comparison to similar sized systems.

Robustness Simulation

The following diagrams make clear how the internal consumption can be increased. The ratio PV/Load and Battery/Load have to be increased. PV or battery capacity has to be raised or load has to be decreased. The internal consumption and battery lifetime is dependent on the generation and load profiles.

Standard Household 1 features mostly daily concentrated loads during the day and at night no big idle consumers are connected to the system.

Standard Household 2 instead has got electric vehicles, which consumes as much power is the general household load.

Standard Household 3 got a heat pump and electric vehicles which could be enabled during daytime, but the tariff from the energy supply company allows a special contract to just use the heat pump during night hours.

Each standard household is the used data and profile given. The heat pump of “Standard Household 3” the heat pump operation algorithm can be improved by using the heat pump on days with high solar irradiance and other occasions which fit the energy supply company needs. The internal consumption quote rises when generation and load appear simultaneously. The battery is less used and lifetime is increased. If load and generation do not happen simultaneously the battery is able to store the energy and supply it when the generator cannot supply energy. Thus battery is used often and its lifetime decreases. This case applies for PV. The generator only produces power during daytime. Loads which are demanded during night hours cannot be supplied instantly. For each standard household two graphs are shown as well as the used profiles names. Table 0-8 shows the Inputs and the assigned profiles or data. The profile for load general is my own profile from the first three month of 2012 put together four times for a whole year.

Table 0-8: *Inputs and Profile Assignment for Standard Household 1, 2 and 3*

Input	Profile / Data
Generator PV	PV_Garching_1000kWh
Load General	Rics_Loadprofile_MiddleOfJanuaryToMiddleOfMarch
Load Heat Pump	HP_night_Optimized_0_to_6
Load Car	Car_night_0_to_6_1000kWh_per_year
PV	70 % cut off: No PV/Inverter Ratio: 1
Battery	SoC_{min}: 0 % SoC_{max}: 100 % Cyclestability: 2500 Input/Output Efficiency: 98 %
Ratios #1 PV	0.1 … 2 $\frac{kWp}{1000\,kWh}$
Ratio #2 Bat	0.1 … 4 $\frac{kWh}{1000\,kWh}$

Chart Interpretation General

The first table shows the lifetime expectation for the battery (see Figure 0-22). The red area shows insufficient battery lifetime, the blue to dark blue area sufficient lifetime up to 20 years and the white area the lifetime between shows the area of medium lifetime expectation. The second table in the sub-chapters named Household 1 to 3 always shows the internal consumption quote over the two ratios (see Figure 0-23). The green area shows the highest, yellow medium and red low internal consumption rates. For a quick comparison the two charts are simplified using less data and compared in chapter 0.

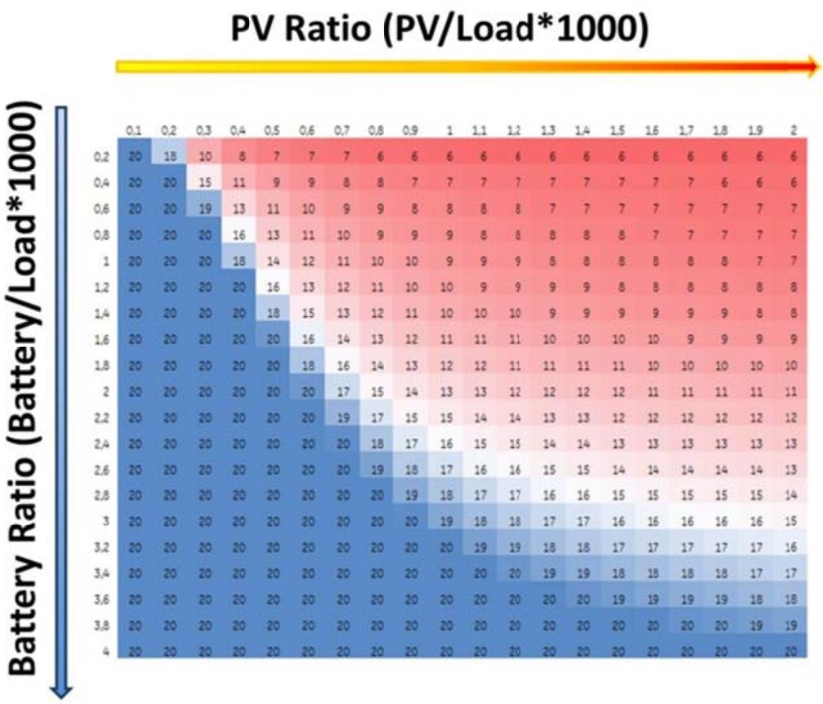


Figure 0-22: *Lifetime expectation over Battery Ratio and PV Ratio*

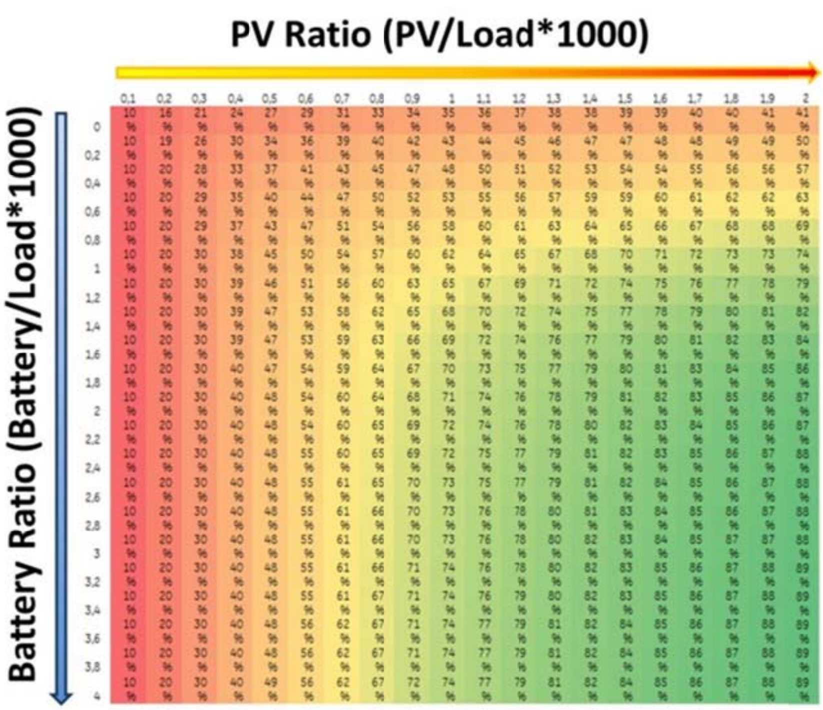


Figure 0-23: *Internal consumption Quote over Battery Ratio and PV Ratio*

Best Working Conditions

Best working conditions appear when battery lifetime and internal consumption quote gathers an optimum. Following Figure 0-24 shows a compare view of the Household charts. The first rows of internal consumption quote (ICQ) vary widely from 13 % to 41 % of one Household to another. The energy use during night is greatly increased from Household 1 over number 2 to number 3. The total energy consumption is in every case the same but the usage time differs. The internal consumption quote without battery drops dependent on the ratio of energy used during day to energy used during night the ICQ is lower for household 2 and 3 compared to household 1. For the households 1 and 2 ICQ reaches in both terms with big battery (Ratio Battery = 4) and moderate to high PV power capability (Ratio PV = 1 … 2). The lifetime for household 2 and 3 are decreased significantly. The battery should be large and the PV system should be rated to supply the energy for the whole year to satisfy consumption demand (Ratio PV = 1) to extend lifetime expectancy.

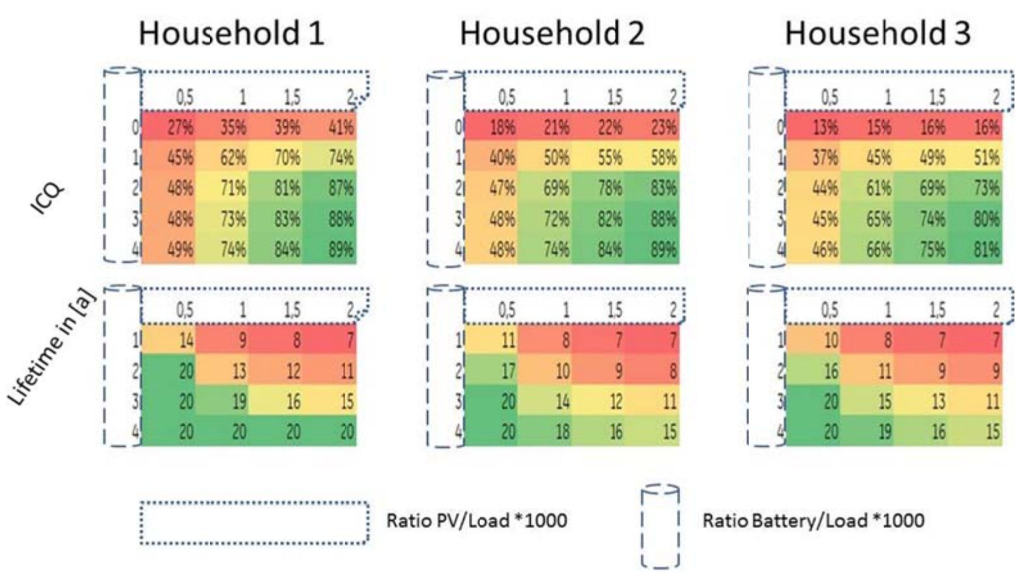


Figure 0-24: *Overview of all Households*