PVSYST
PHOTOVOLTAIC SOFTWARE

Simulation of Grid-connected PV Systems with Battery Storage

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Contents

Battery Model Overview

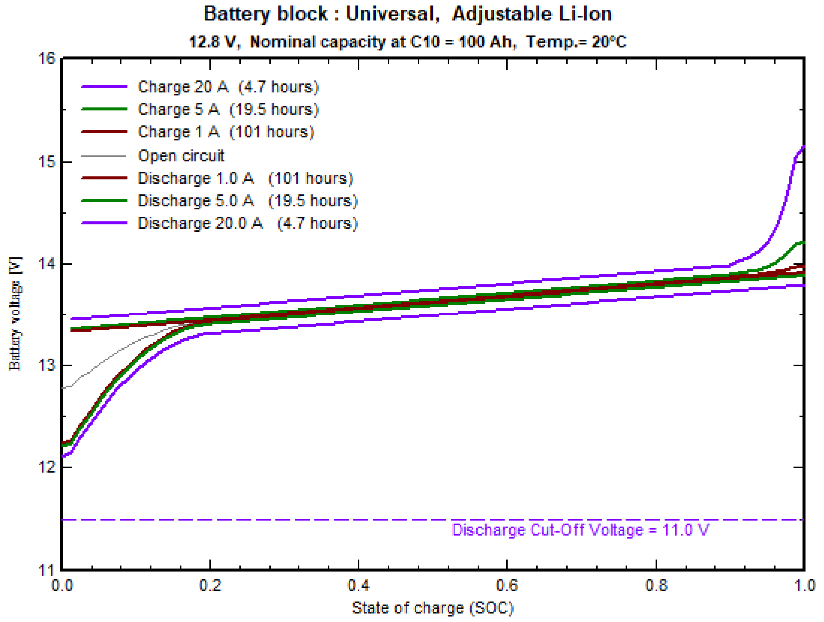
Technologies: Lead-acid and Li-Ion

Battery behavior is simulated as function of:

- Charge/Discharge rate
- Temperature
- Depth of discharge (DoD)

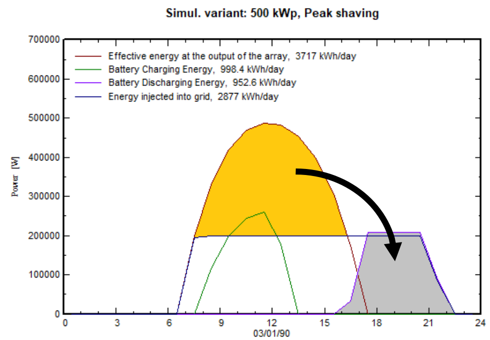
Model determines:

- State of Charge (SOC)
- Battery Voltage
- Battery Losses
- Ageing (State of Wear SOW)



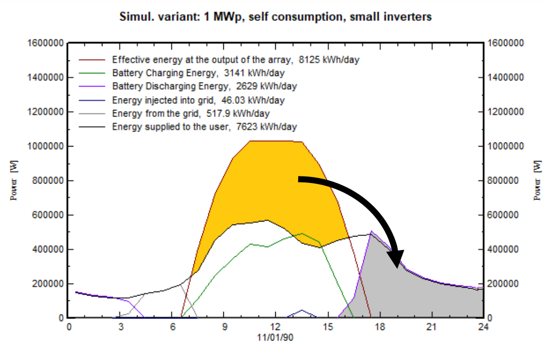
Operating mode (charging/discharging) according to SOC (or Voltage)

Dispatch Strategies



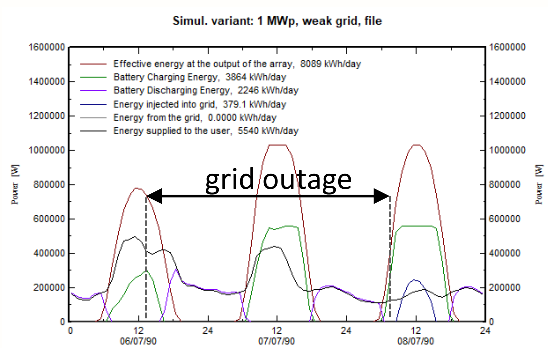
Peak shaving

PV Array + Storage + Injection power limitation



Self-consumption

PV Array + Storage + Load Profile

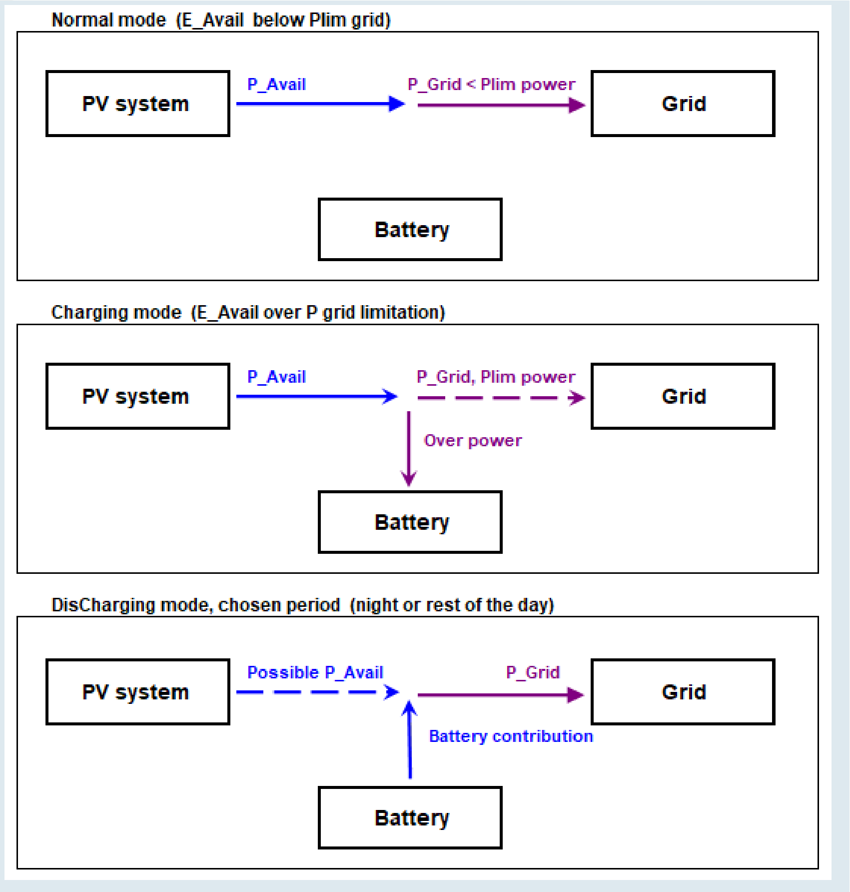


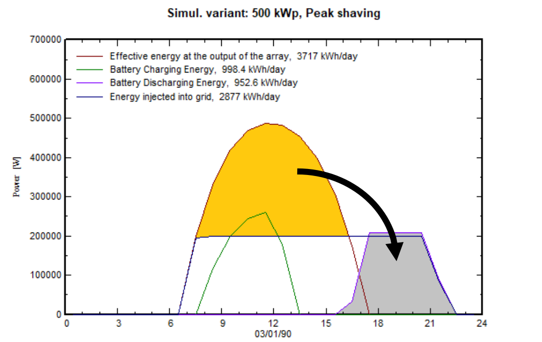
Weak Grid Islanding

PV Array + Storage + Load Profile
+ Grid Outages

Peak Shaving Mode

Aims at recovering curtailed energy generation





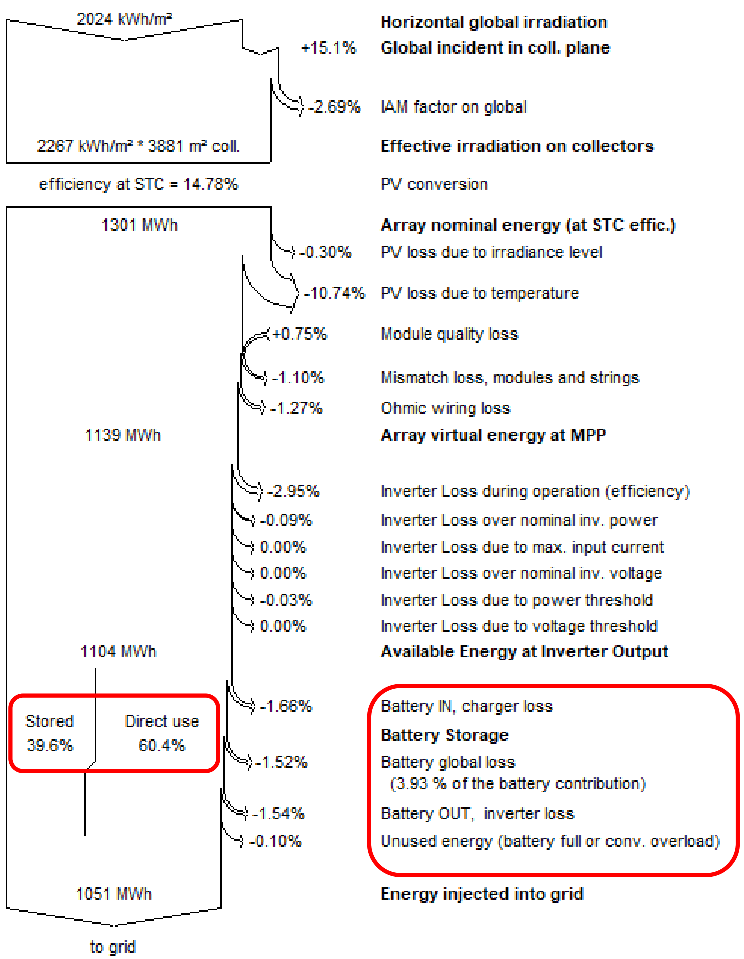
Only dispatch strategy where Battery injects into grid

Charge Battery as soon as Production is larger than threshold

Discharge either as soon as possible, or at pre-defined time intervals

Peak Shaving Simulation Results

500 kWp, Peak shaving



EBatDis: Stored energy (impacts cycling, i.e. battery lifetime)

EBatDis-EBatCh: Battery storage efficiency (coulombic efficiency, internal resistance, gassing),

CL_Chrg: Charger efficiency losses

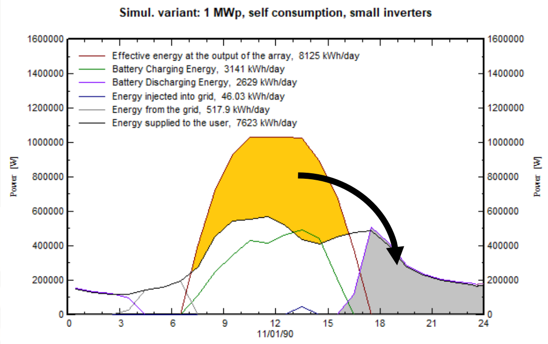
CL_InvB: Battery inverter efficiency losses

EUnused : Unused energy, either when the battery is full, or if the charging power exceeds the maximum power of the charger

E_Grid : Energy ejected into grid

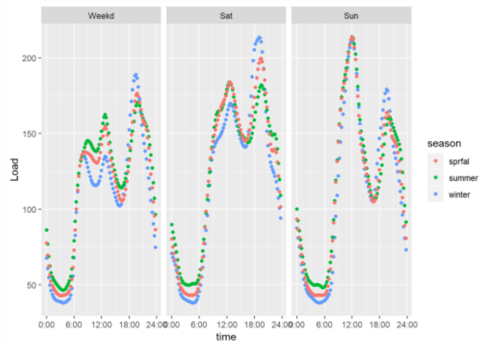
Self-Consumption Mode

Aims to minimize energy use from grid

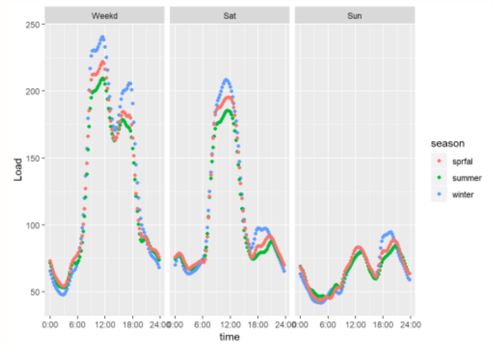


Load profiles must be supplied by user. Examples:

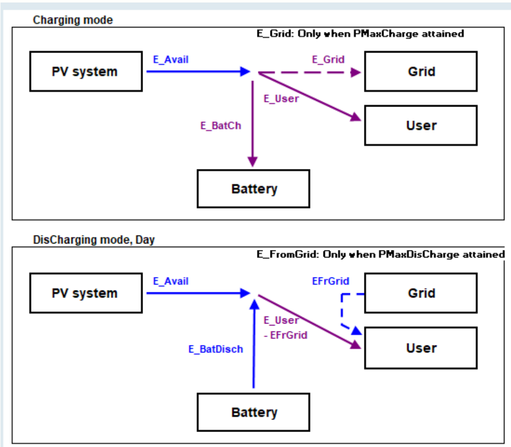
Households

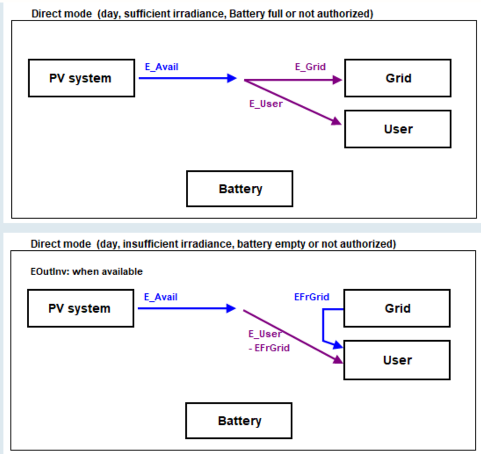


Commercial

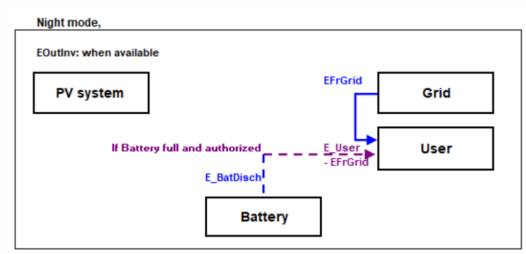


Source: Generic load profiles from BDEW (https://www.bdew.de/energie/standardlastprofile-strom/)

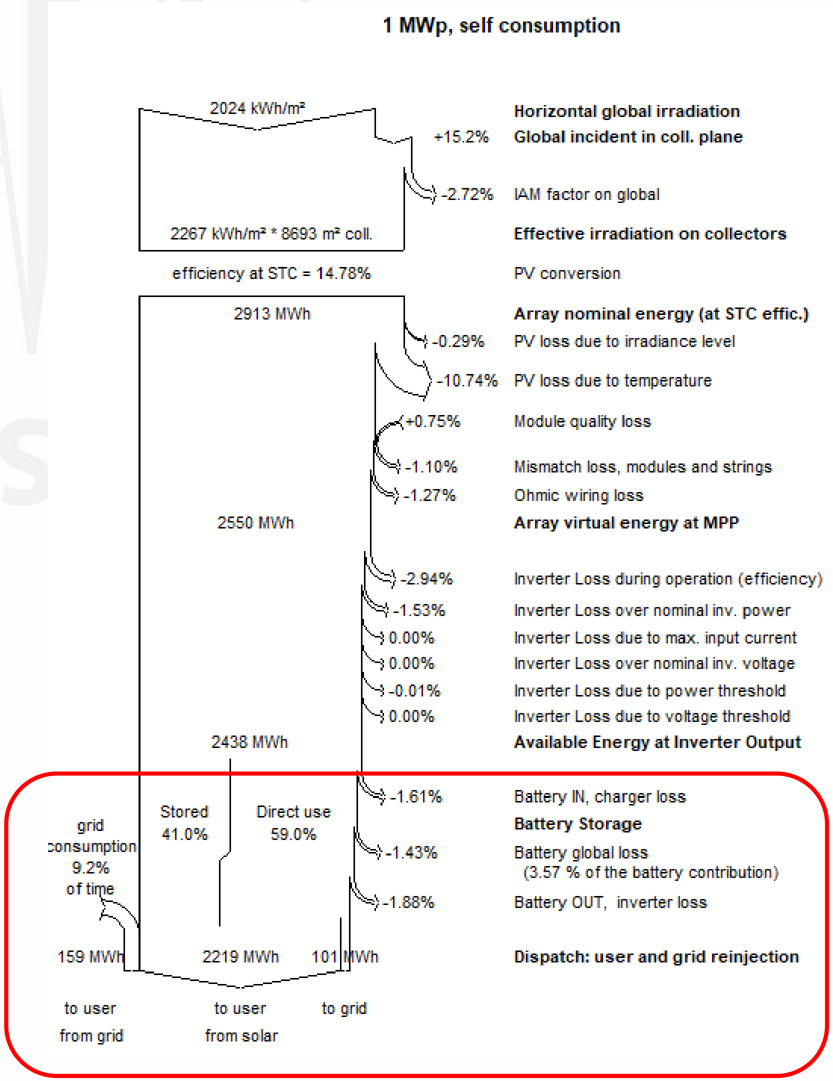




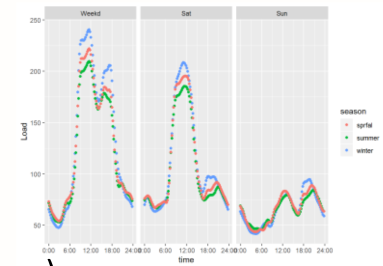
No injection from battery
No charging of battery from grid



Self-Consumption Simulation Results



Example: Commercial, scaled to 2463 MWh/year



EBatDis: Stored energy (impacts battery lifetime)

EBatDis-EBatCh: Battery storage efficiency (coulombic efficiency, internal resistance, gassing),

CL_Chrg: Charger efficiency losses

CL_InvB: Battery inverter efficiency losses

E_User: Total energy consumed by user (hourly load profile)

E_Solar: Consumption coming from PV

EFrGrid: Energy from grid

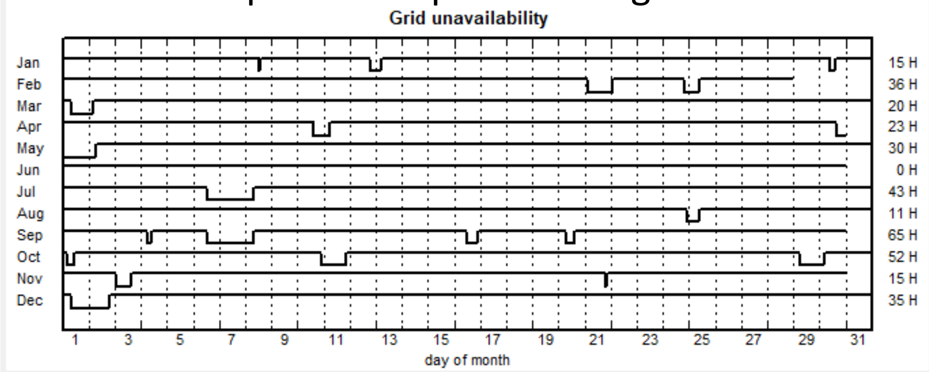
SolFrac: "Solar Fraction" (ratio of solar energy, to total consumption)

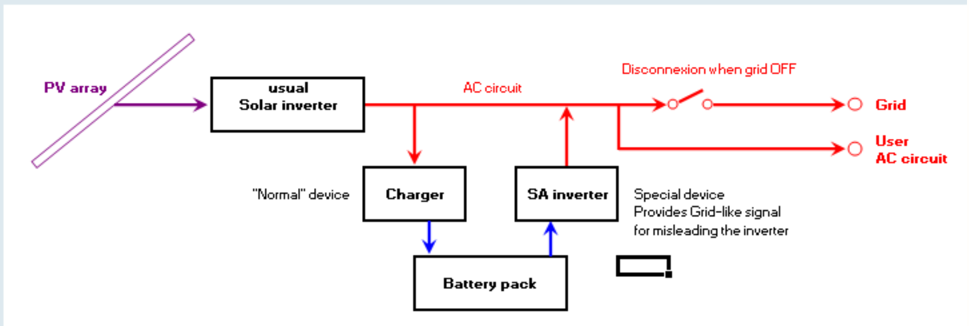
E_Grid: the excess energy, injected into the grid

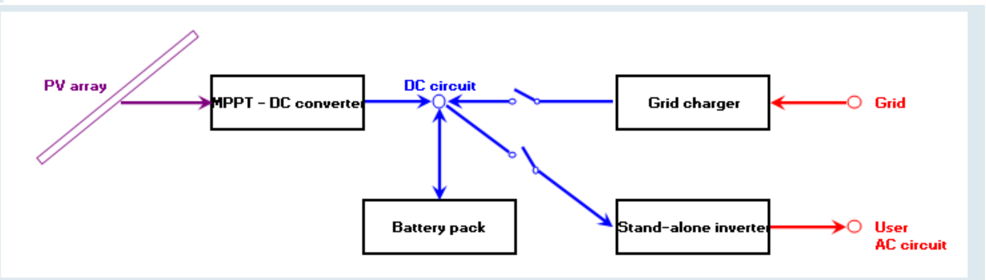
Weak Grid Islanding Mode

Like self-consumption,
Battery discharge is limited to
allow supply during grid outages

Definition of periods of power outage



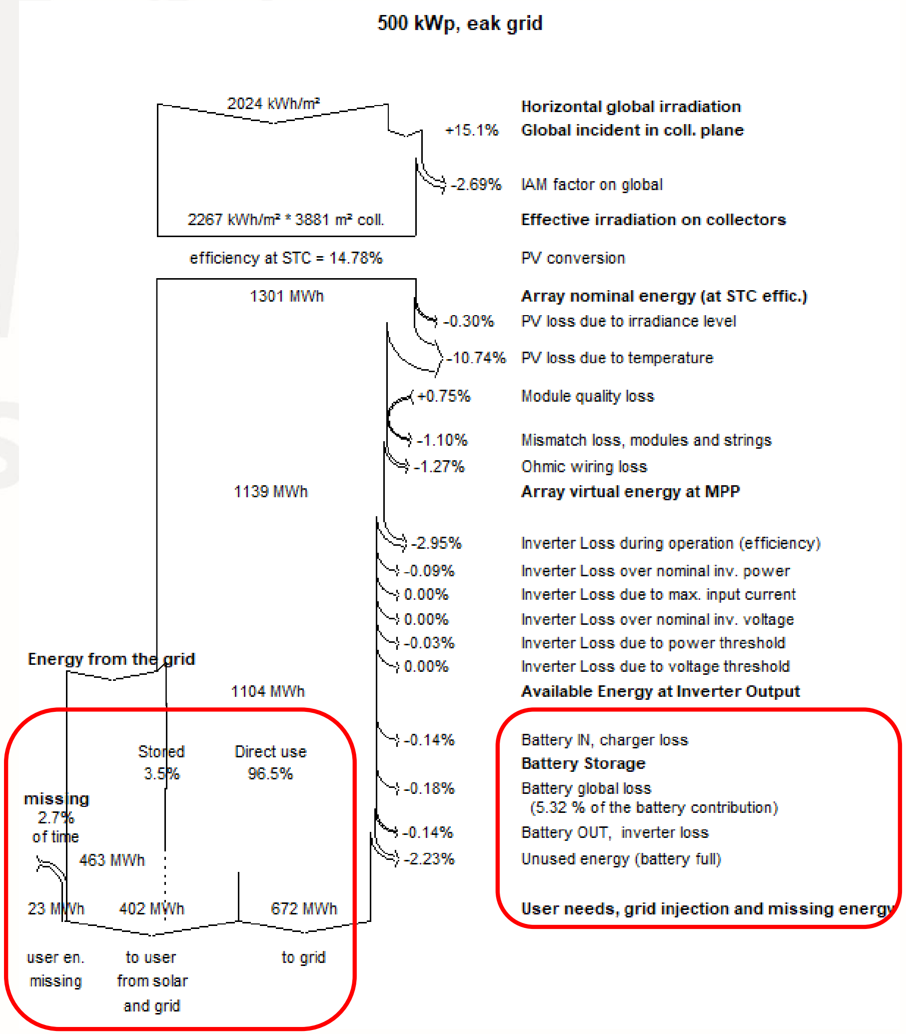




With/without grid injection
(only PV, not Battery)

Loss of Load is possible!

Weak Grid Islanding Simulation Results



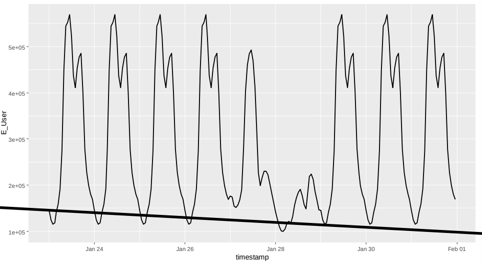
EBatDis:	Stored energy (impacts battery lifetime)
EBatDis-EBatCh:	Battery storage efficiency (coulombic efficiency, internal resistance, gassing),
CL_Chrg:	Charger efficiency losses
CL_InvB:	Battery inverter efficiency losses
E_User:	Total energy need (load profile)
E_Solar:	Consumption coming from PV
EFrGrid:	Energy from grid (if available)
E_Miss:	Missing energy (outage & empty batt.)
SolFrac:	"Solar Fraction" (ratio of solar energy, to total consumption)
E_Grid:	Energy injected into grid (if possible)
EUnused:	Battery full and no injection possible

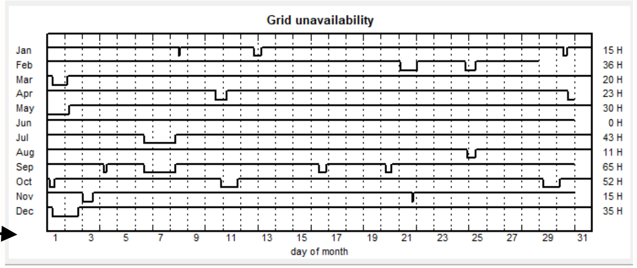
Parametric Studies (Batch Mode)

Batch mode allows to run many simulations at once,
while varying many (30-40) different simulation parameters

Parameters that are useful in parametric studies with grid storage:

- PV Capacity
- Battery capacity
- Grid injection power limitation
- Self-consumption profile
- Grid unavailability





Output variables useful in studies with grid storage:

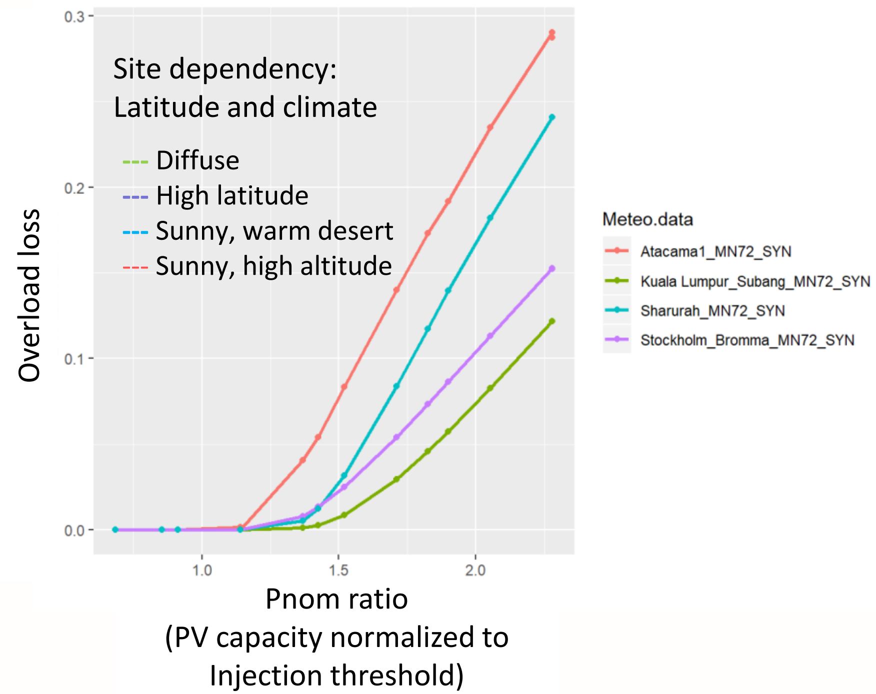
PV Power	Average SOC	Total battery loss	Solar energy
Energy after battery	SOC end of simulation step	SOC energy balance	Load direct from solar
Energy inj. to grid	Charging time	Charging loss	Supplied load
Energy from grid	Discharging time	Discharging loss	Solar fraction
Energy from Sun	Charged energy	SOW due to cycling	Missing energy
	Discharged energy	Static SOW	Loss of load

PVsyst allows to output ≈ 100 different variables containing simulation results
Output of yearly, monthly, daily and hourly values is possible

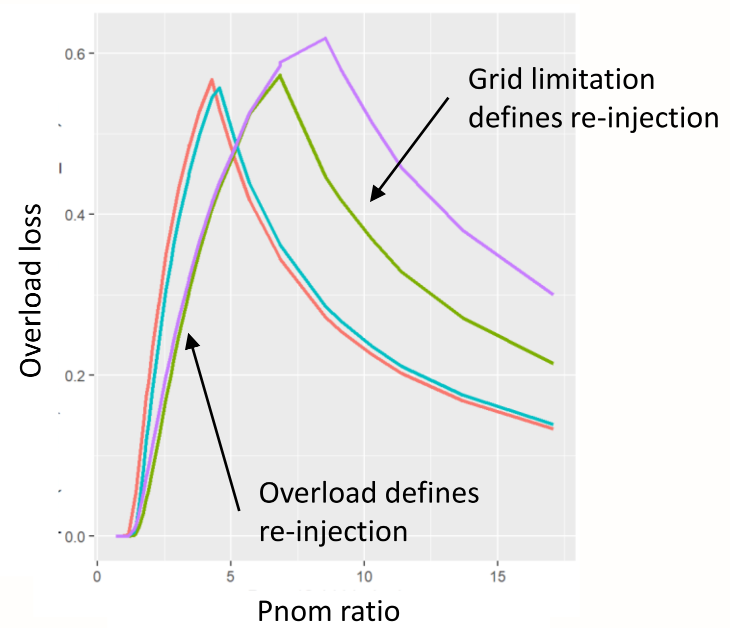
Array and System
Battery behavior
Energy use

Peak Shaving: Curtailed Energy

Overload loss as function of Pnom ratio

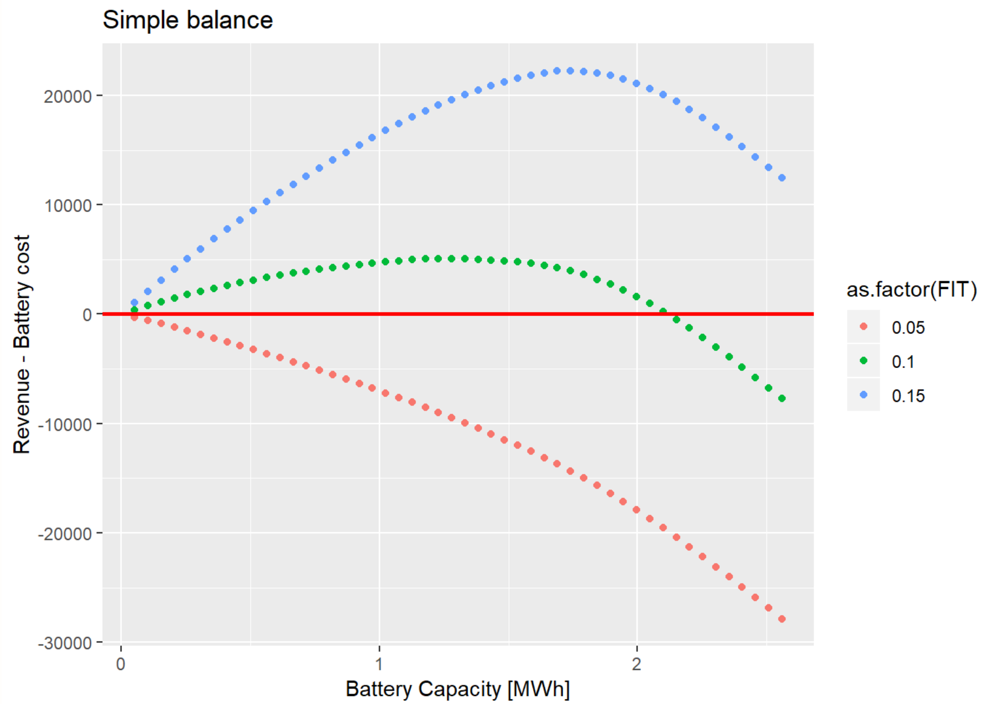


Curtailed energy that can be re-injected



Peak Shaving: Recovered Energy

Return = Battery Discharge x FIT
Battery cost = Battery Capacity x Battery price / lifetime



1MWp system in sunny desert climate

Vary Battery capacity in batch mode

Battery discharge energy is the additionally sold energy

Assume constant FIT

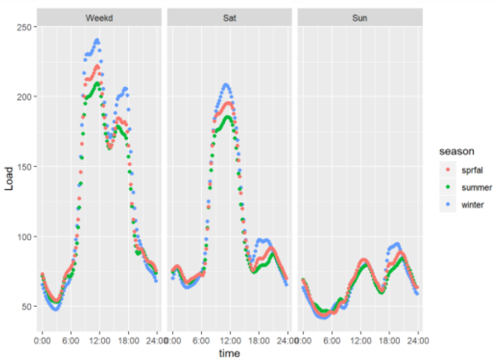
Battery price : 150 $/kWh

Battery lifetime: 8 years

More complete calculations would include cost of capital, devaluation, varying FIT, etc.

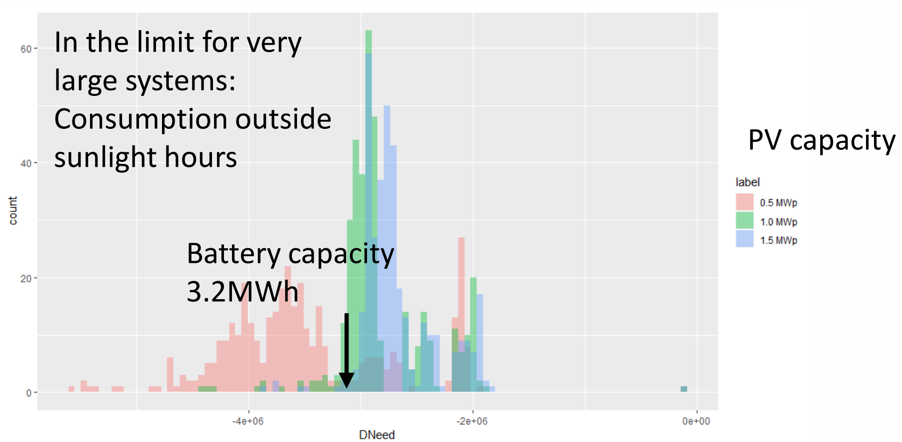
Self-Consumption: Generation/Consumption Mismatch

Assume that the battery is used for daily storage (battery transfers energy from day to night)

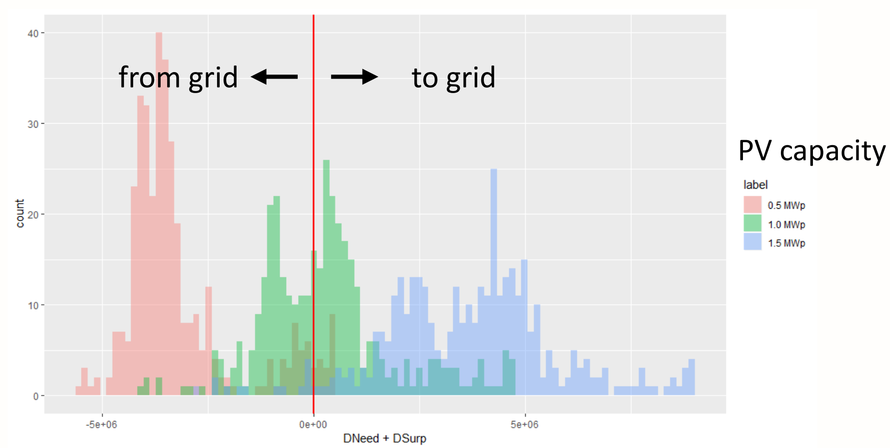


Generic load profile for commercial consumers, scaled to 2463 MWh/year
Source: BDEW

Daily energy consumption that is not covered by direct PV generation.
Determines Battery Capacity



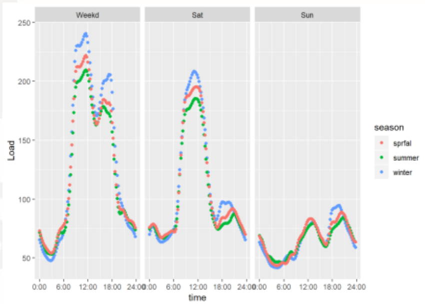
Difference between **daily** PV overproduction and energy need
Determines PV capacity



Self-Consumption: Parametric study

For a given load profile
vary PV and Battery Capacity

Commercial, scaled to 2463 MWh/year

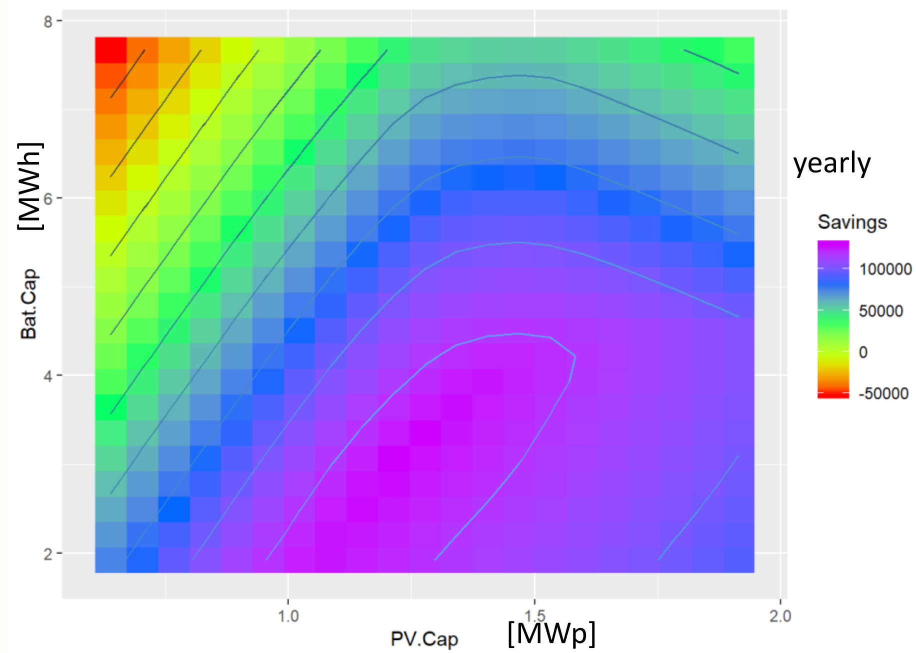


Parameters of Example:

Consumption	2463 MWh/year
Electricity price	0.13 $/kWh
PV costs	1.4 $/Wp
PV lifetime	25 years
Battery cost	150$/kWh
Battery lifetime	5-7 years
	(acc. to simulated SOW)

Simple example:
No cost of capital considered
No ageing propagation from year to year

Savings:
Avoided energy purchase – System costs
(no return for injected energy)



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Summary and Outlook

Battery models for Lead-acid and Li-Ion
Three dispatch strategies for grid-tied systems with storage:

- Peak shaving
- Self-consumption
- Weak grid islanding

Parametric scans are possible for detailed studies

- PV capacity
- Battery capacity
- Load profiles
- Power outage periods

Outlook:

- Propagate Battery ageing for multi-year simulations
- Add financial variables to batch output
- Implementation of real components
- Improve tools as understanding grows
- Implement optimization tool for storage