JÜLICH
FORSCHUNGSZENTRUM

Kraftwerk Batterie 2014, Münster

Techno-economic analysis of battery supported PV systems and the impact of demand profiles

March 26th, 2014 | Peter Stenzel, Jochen Linssen, Florian Busch

Institute of Energy and Climate Research, Systems Analysis and Technology Evaluation (IEK-STE)

Outline

- Introduction
- The BaPSi Model
- Input parameters and basic assumptions
- Sensitivity analysis: load profiles
- Summary and conclusion

Introduction

1. Economic incentive for self-consumption:
Increasing electricity and decreasing feed-in-tariff

Consumer attractiveness of
battery supported PV systems for increased self-consumption

2. Wish for autarky and independency from (large) utilities

3. Increased personal security due to UPS and emergency power supply functionality

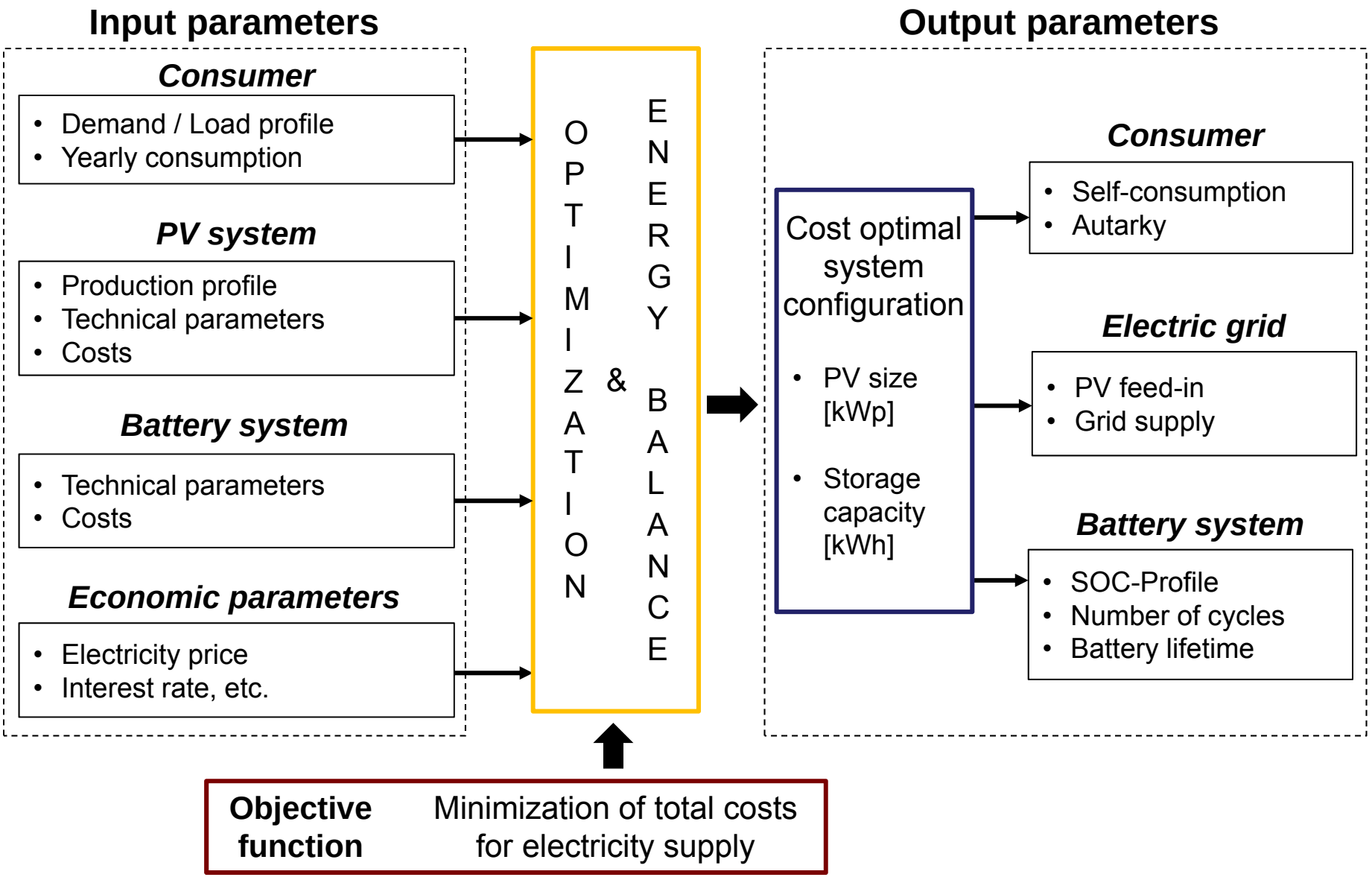
Central research question:

How big is the impact of the load profile on system design and cost-effectiveness of PV battery systems?

BaPSi: Battery-Photovoltaic-Simulation Model

- Tool for techno-economic analysis of battery supported PV systems
- Optimization model: Minimization of total costs for electricity supply
- Output: Calculation of optimal system configuration (PV + battery size)
- Battery types: Lead-acid and Lithium-Ion
- Time horizon: 20 a (according to period for PV feed-in-tariff)
- Resolution: 5 min (production and load profiles)
- Possible combination with storage system database (including 128 systems from 40 providers)

BaPSi: Model structure



Input parameters and basic assumptions

PV system (Location: Germany)	
Energy yield	1,000 kWh/kW_p
Inverter efficiency	97 %
System price (without tax)	1,640 €/kW_p
Operation costs	1.5 %/a
Maintenance costs	10 €/(kW_p•a)
Degradation	0.5 %/a

Price level Germany 1Q 2014 for PV installations < 10 kW_p
Source: BSW-Solar, 2014

Battery system (Lithium-Ion)	
DoD	100 %
System price (without tax)	1,000 €/kWh
Efficiency	95 %
Degradation	0.4 %/a

Optimistic price assumption based on further cost reductions

Actual price level in Germany is higher (> 1,250 €/kWh – for Li-Ion)
Source: IEK-STE Database, 2013

Additional gov. support program in Germany considered

Economic parameters	
Feed-in-tariff (EEG - April 2014)	13.28 ct/kWh
Electricity price (2014)	29 ct/kWh
Electricity price increase	2.5 %/a
Interest rate	4 %

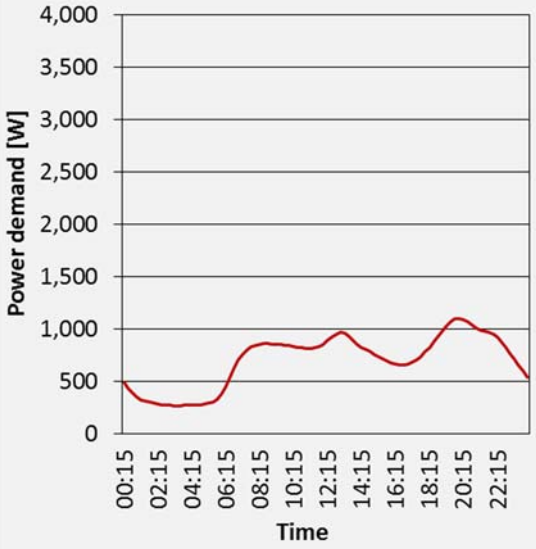
Increase in the period 2000-2013: 5.76 %/a Source: BDEW, 2013
is expected to slow down

Sensitivity analysis: load profiles

Scenario 1

- Analysis of different load profiles (peak load, base load, fluctuations)
- Annual electricity consumption (all profiles: 5,380 kWh/a)

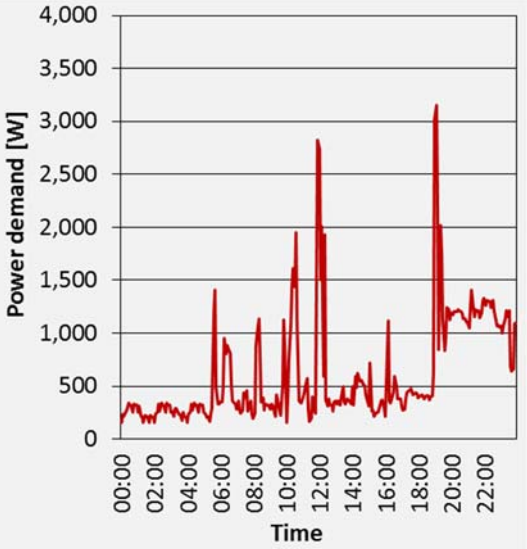
Profile 1:
Standard load profile



Source: E.ON Mitte AG, 2014

Aggregated profile used by utilities as representative load profile for housholds

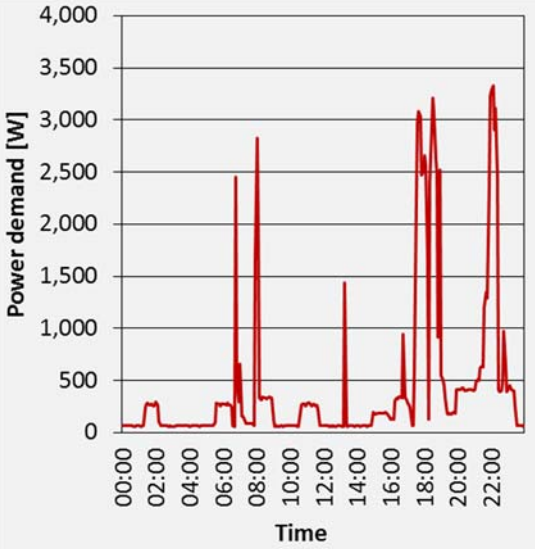
Profile 2:
VDI 4655



Source: VDI, 2008

Weighted average of 5 measured profiles of single family houses

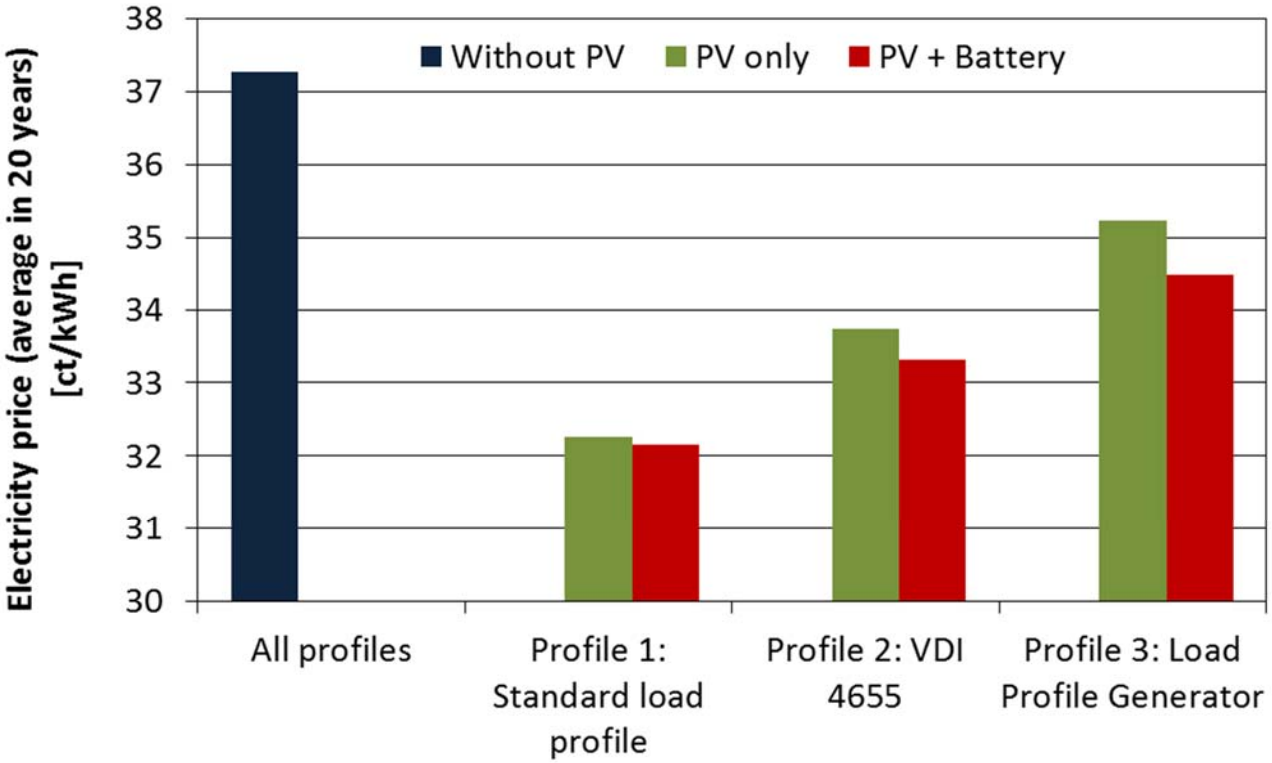
Profile 3:
Load Profile Generator



Source: TU Chemnitz, 2014

Synthetic load profile based on a simulation tool

BaPSi: Optimization results



Battery size:	0.5 kWh	2.0 kWh	3.7 kWh
PV size:	4.1 kWp	4.1 kWp	5.3 kWp

Basis price for battery system:

1,000 €/kWh
(without tax and with gov. support)

Break even price (compared to PV only):

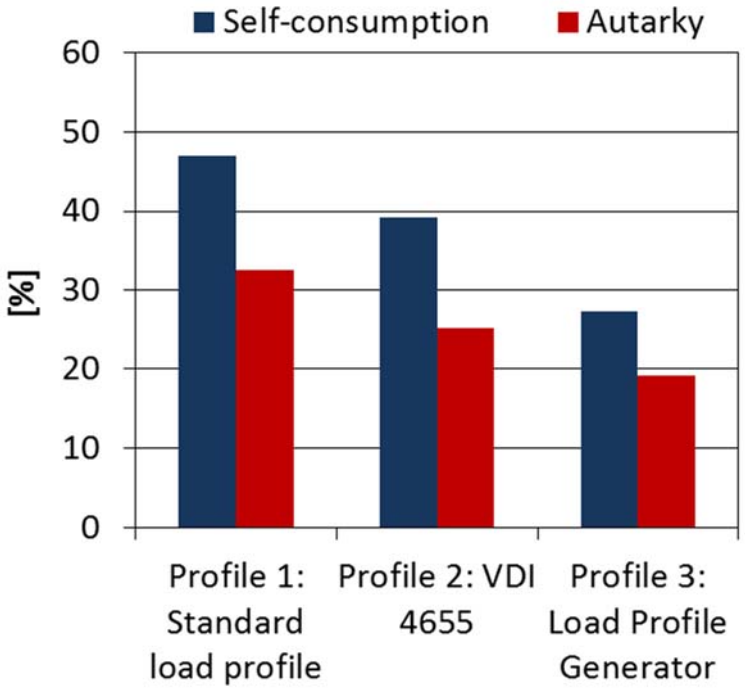
1,230 €/kWh
(without tax and with gov. support)

880 €/kWh
(without tax and without gov. support)

- Huge potential for cost reduction due to PV + battery use (highest impact by PV system)
- **Total costs, PV and battery size and battery impact on total costs vary in dependency of the load profile**

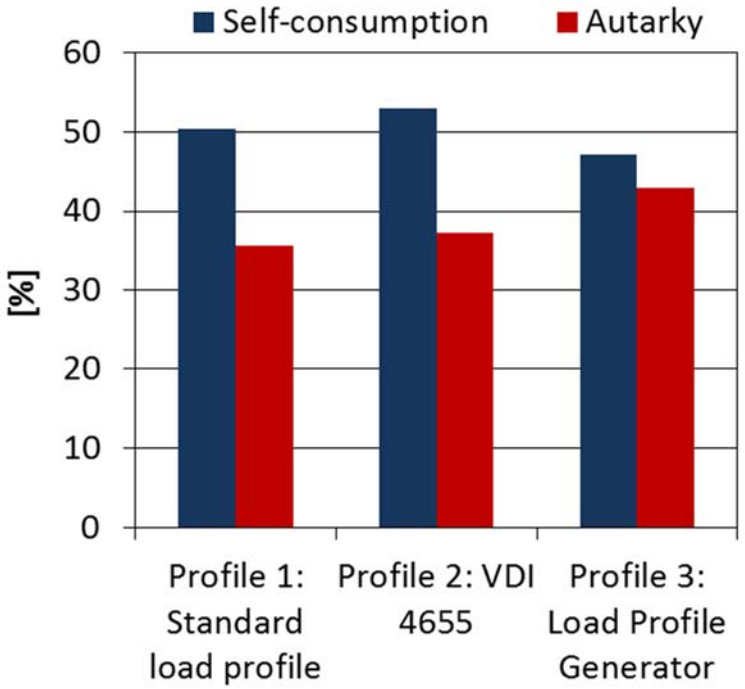
Self-consumption & Autarky

PV only



- Profiles with higher base load reach significant higher direct self-consumption and autarky
- Total costs decrease with higher direct self-consumption

PV + Battery

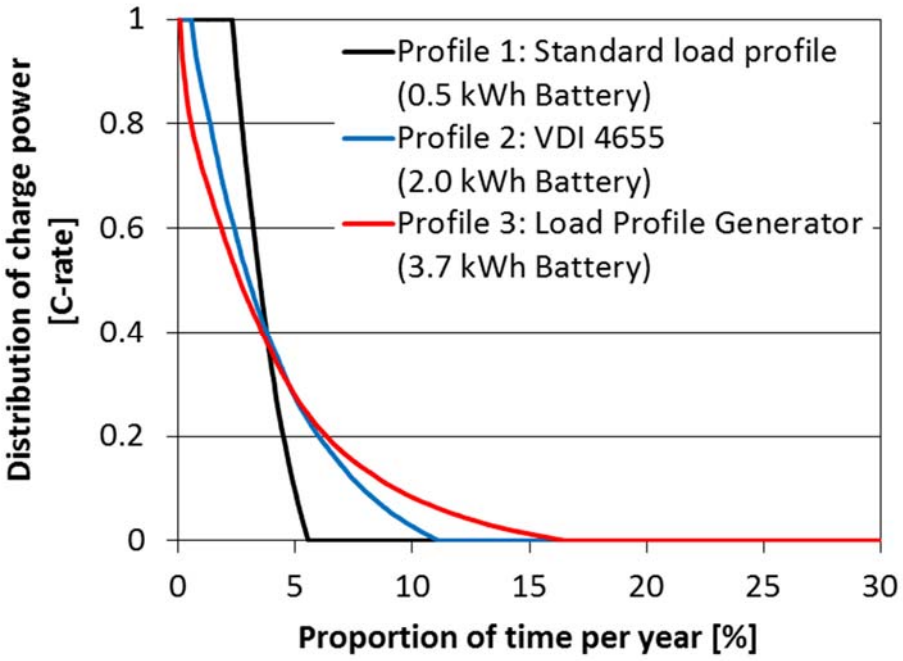


- Battery increases self-consumption and autarky level
- Increasing battery size with increasing load profile volatility

➡ **Realistic load profiles are a prerequisite for realistic results**

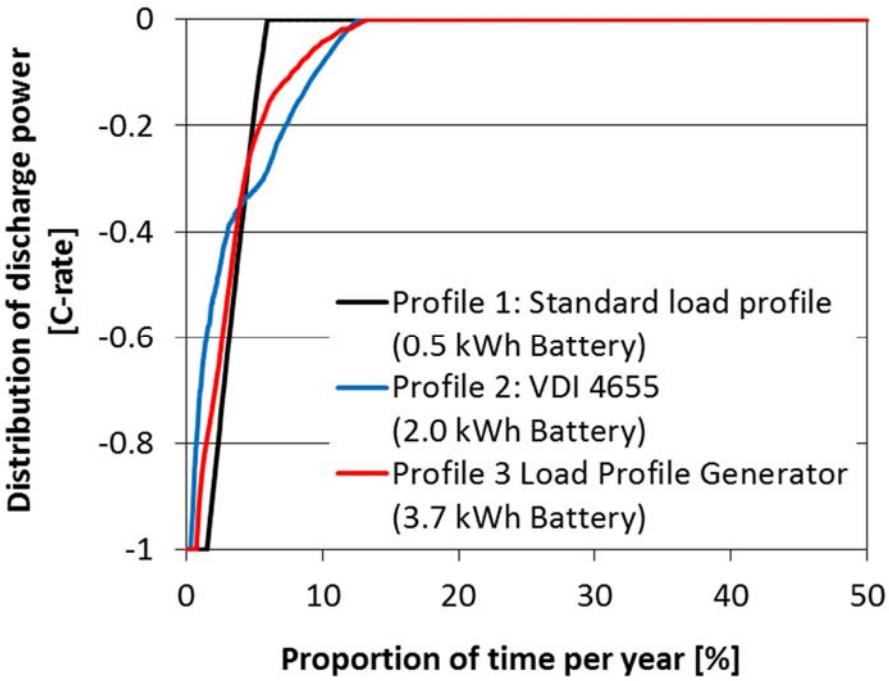
Charge and discharge characteristics

Charge



- Higher battery utilization with increasing battery size

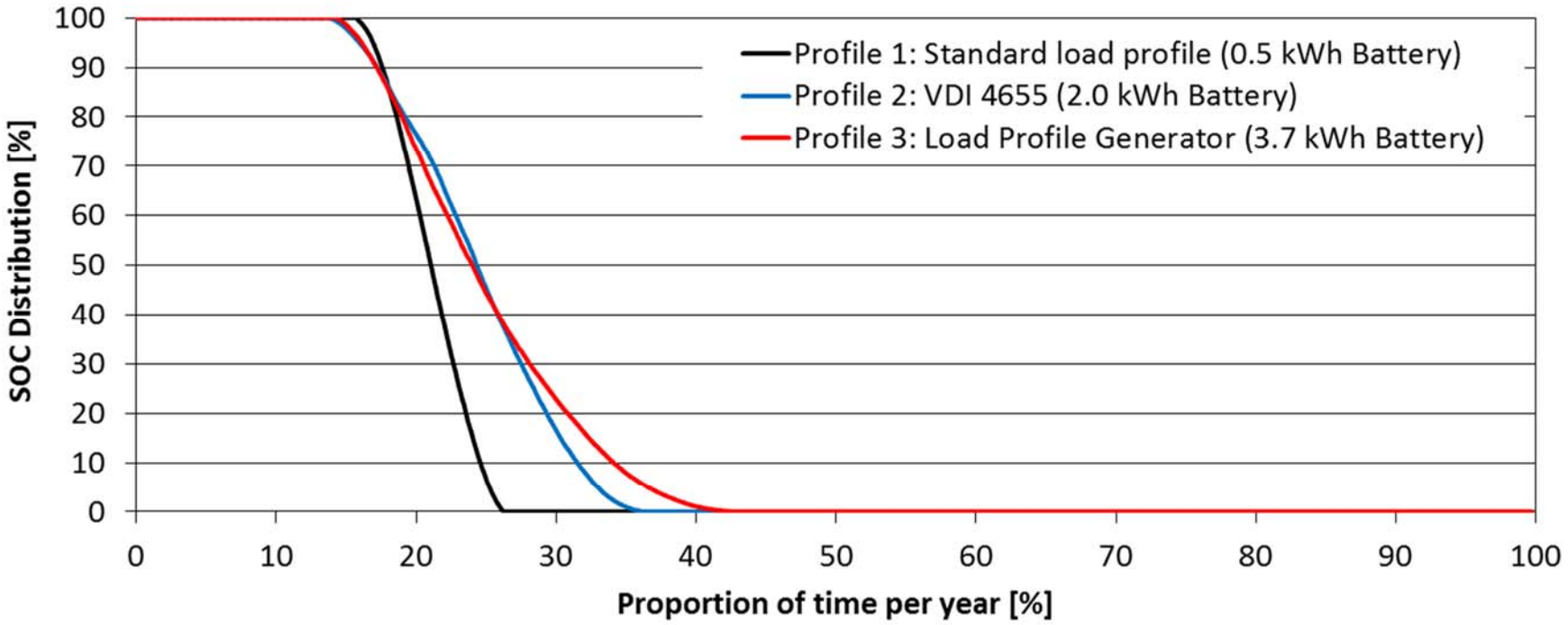
Discharge



- Smaller batteries with longer charge / discharge operation at max. power (steeper curves)

➡
- Impact of different load profiles on charge and discharge characteristics not essential for battery operation
- C-rate in operation can be limited to ≤ 1C

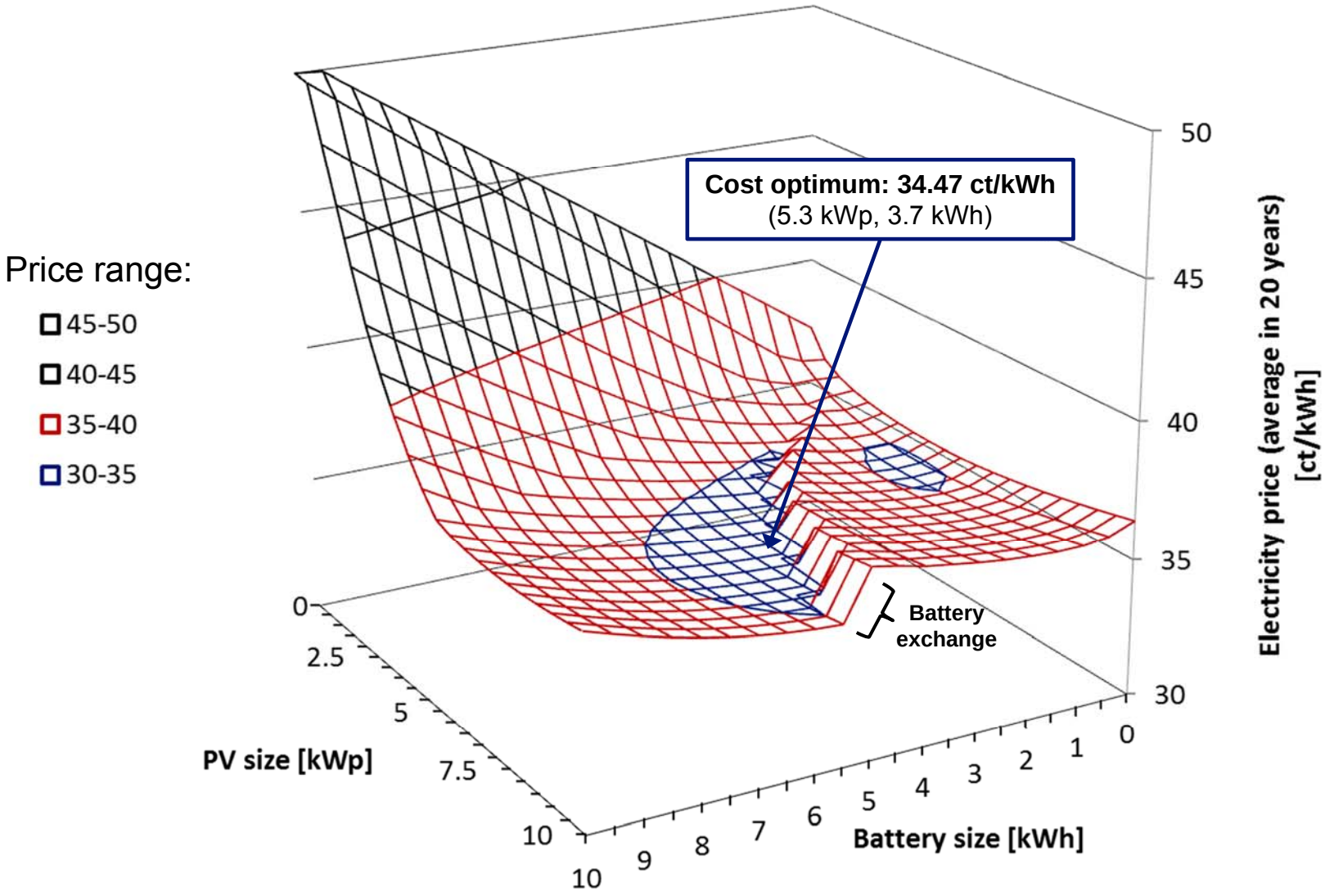
SOC profile



- Battery typically 60 %/a fully discharged and 20 %/a fully charged
- Time at SOC = 0 % (fully discharged) decreases with increasing battery size
- Comparable number of full cycles (approx. 6,600 cycles in 20a)

➡ Limited impact of load profile on SOC distribution

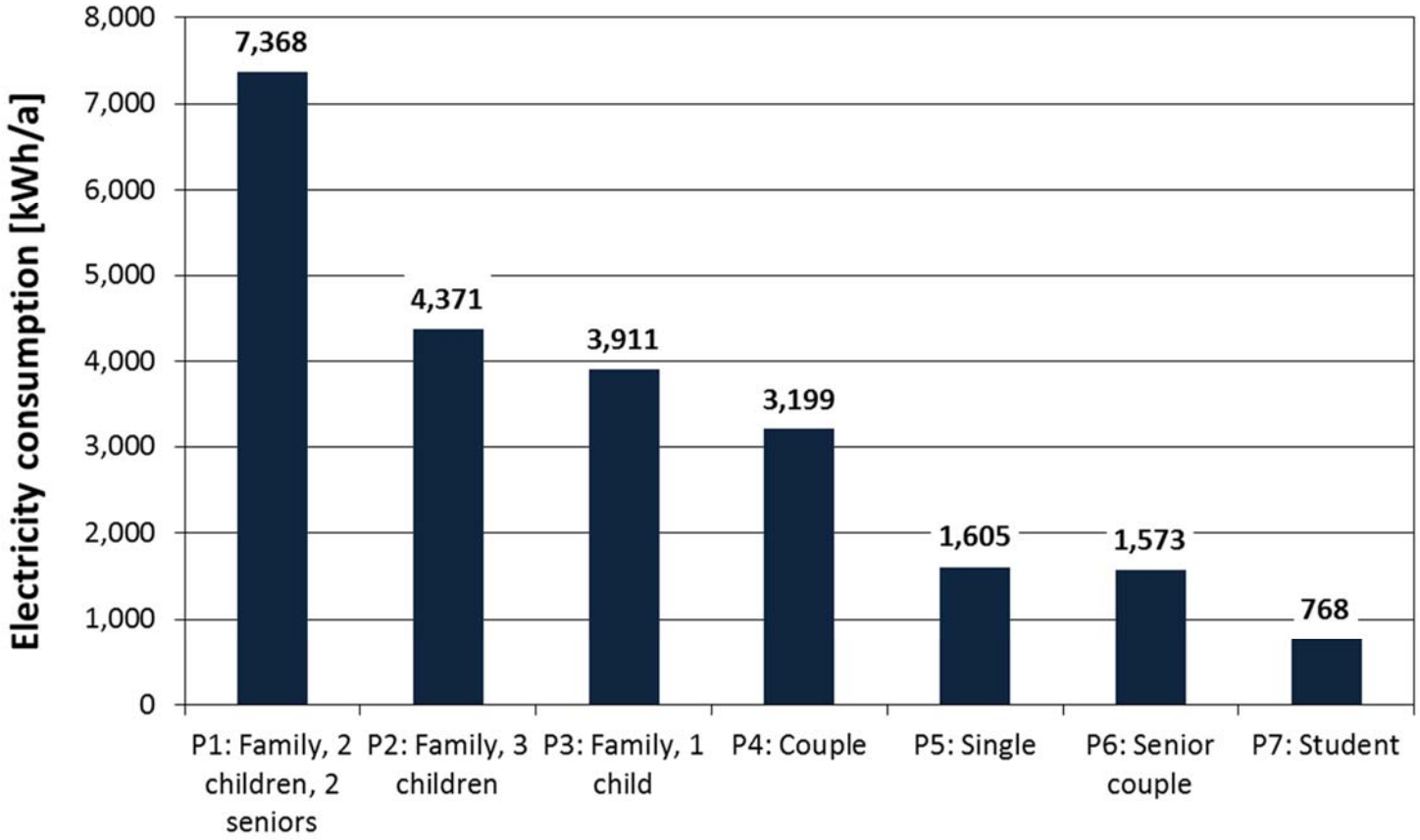
Impact analysis of PV and battery size
Profile 3: Load Profile Generator



Sensitivity analysis: load profiles

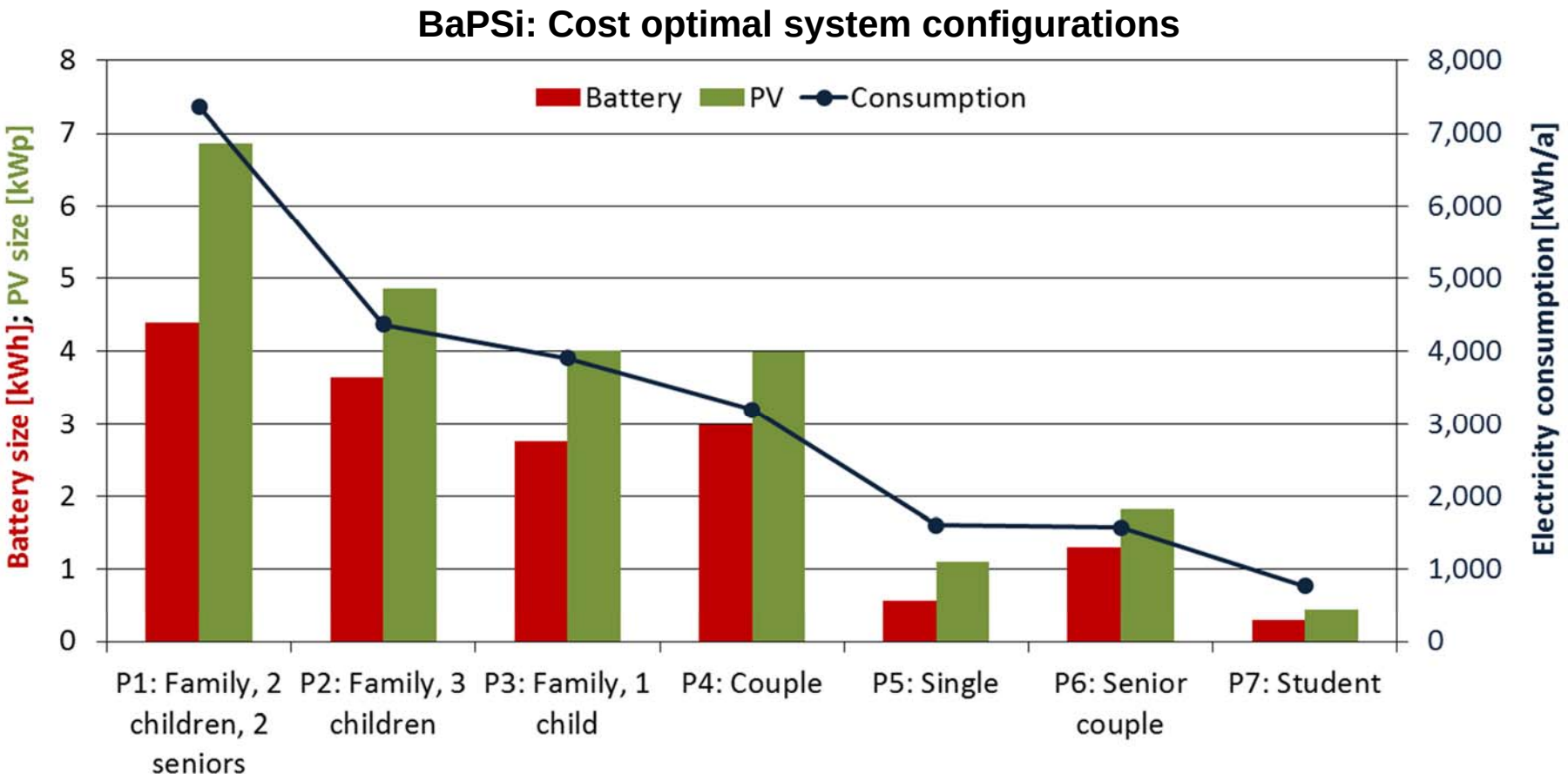
Scenario 2

- Analysis of load profiles with different total electricity consumption (based on user behaviour and electric equipment)
- Synthetic profiles (Load Profile Generator, TU Chemnitz)



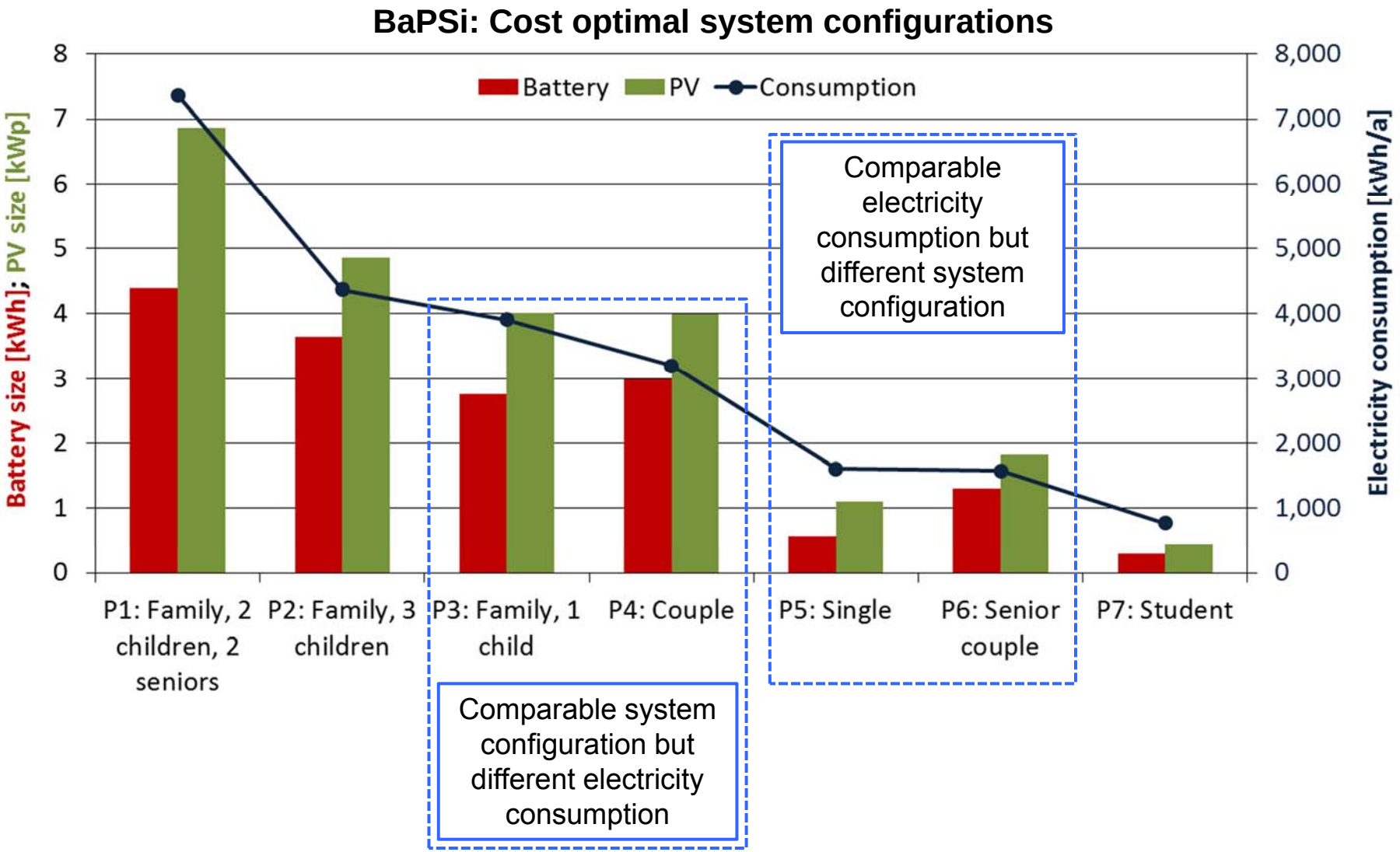
Source: Load Profile Generator - TU Chemnitz, 2014

Scenario 2: Results



- Increasing optimal battery and PV size with increasing electricity consumption
- Approximation for cost optimal system configuration (linearization):
  - PV size = 1 kWp / (MWh/a)
  - Battery size = 0.7 kWh / (MWh/a)

Scenario 2: Results



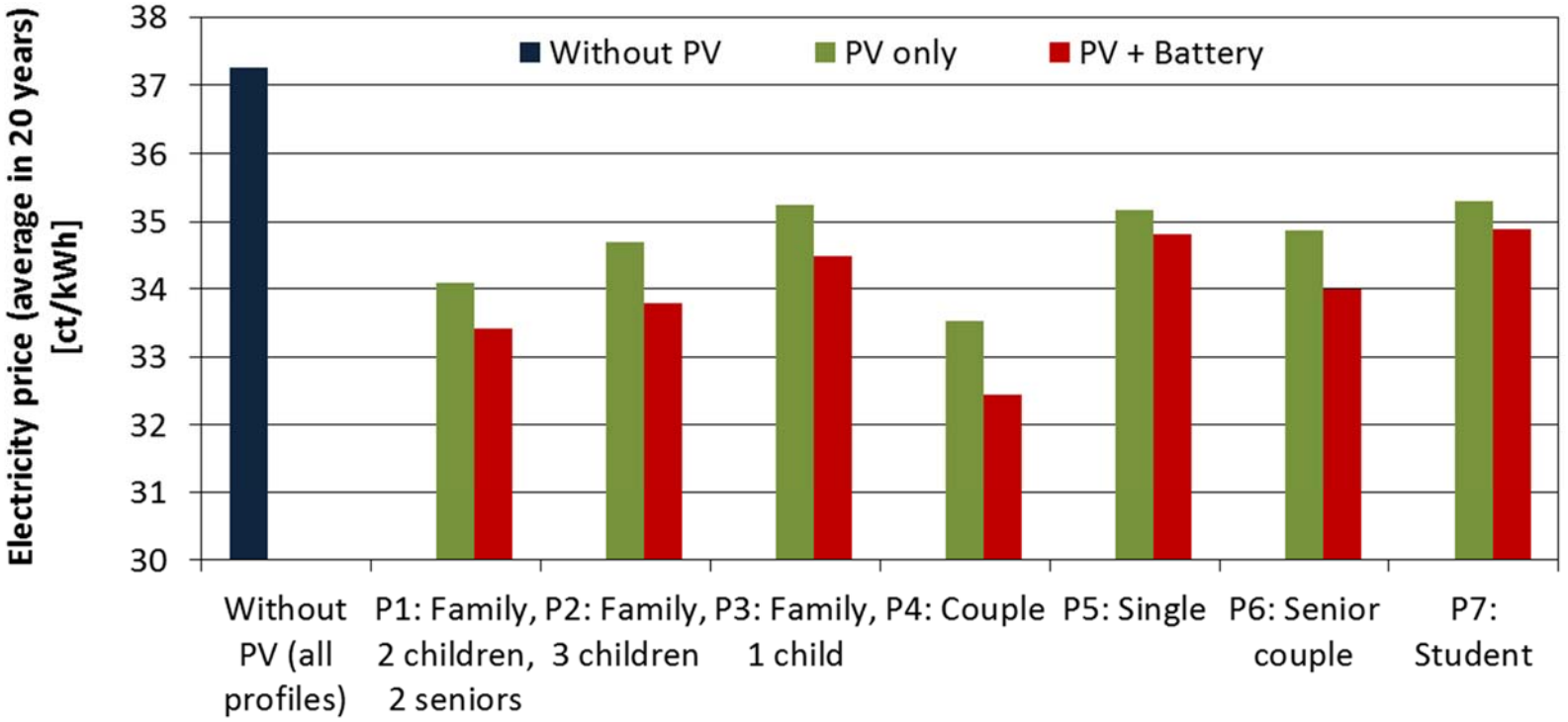
➡ **Impact of different load profiles (consumer behaviour)**

Summary and conclusion

- Considerable impact of load profile on the modeling results regarding total costs and cost optimal system configuration (PV + battery size)
- Direct PV self-consumption is the major impact factor on total costs and depends largely on the relation between base and peak load (demand side)
- Different battery solutions (regarding capacity and type) deployed in cost optimal system configurations
- Impact of different load profiles on battery charge and discharge characteristics (e.g. C-rate, SOC distribution) not essential for battery operation
- Realisitc load profiles are recommanded as basis for modelling, system design and battery selection (Standard load profile not applicable)

Additional slides

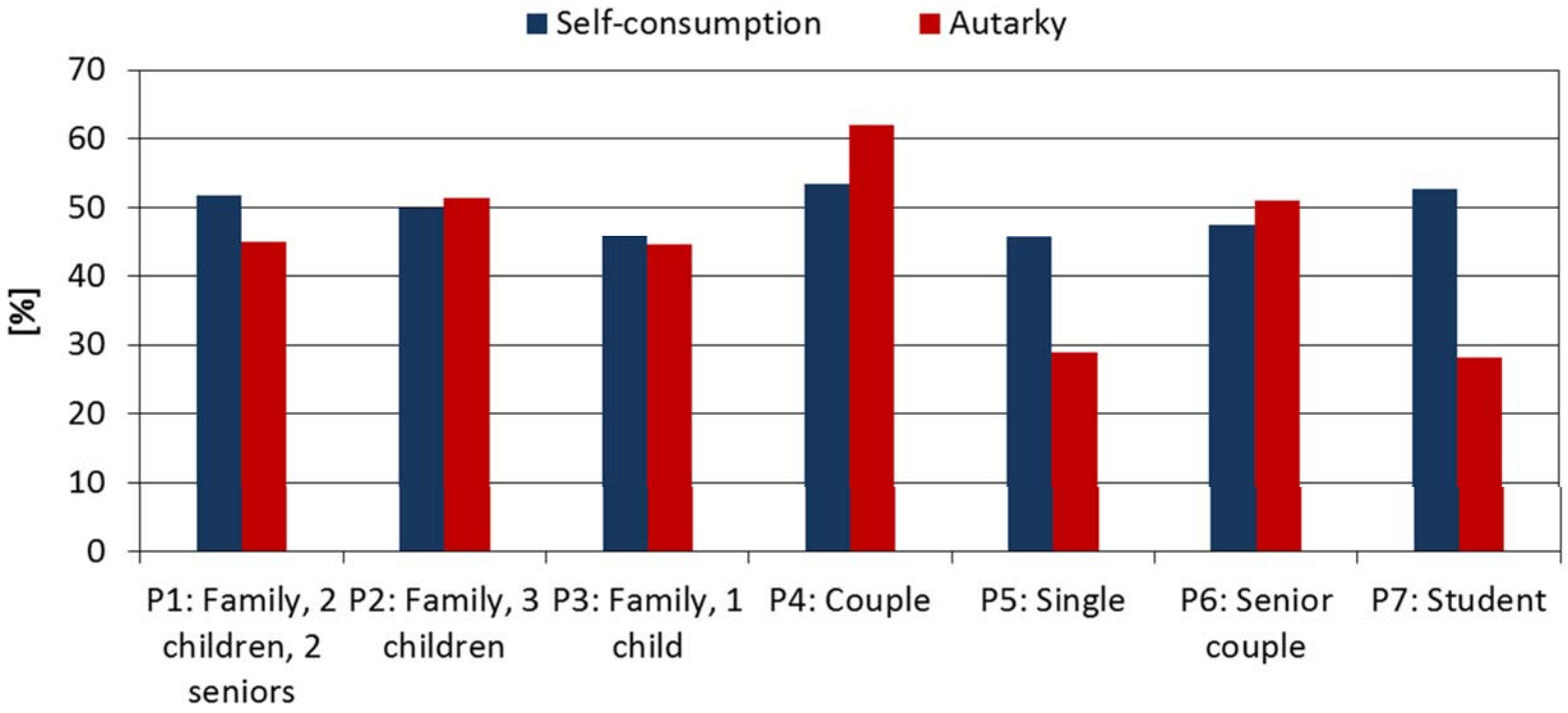
Average electricity price for different load profiles and cost optimal system configurations



Battery size:	4.4 kWh	3.6 kWh	2.8 kWh	3.0 kWh	0.6 kWh	1.3 kWh	0.3 kWh
PV size:	6.9 kWp	4.9 kWp	4.1 kWp	4.0 kWp	1.1 kWp	1.8 kWp	0.4 kWp

Additional slides

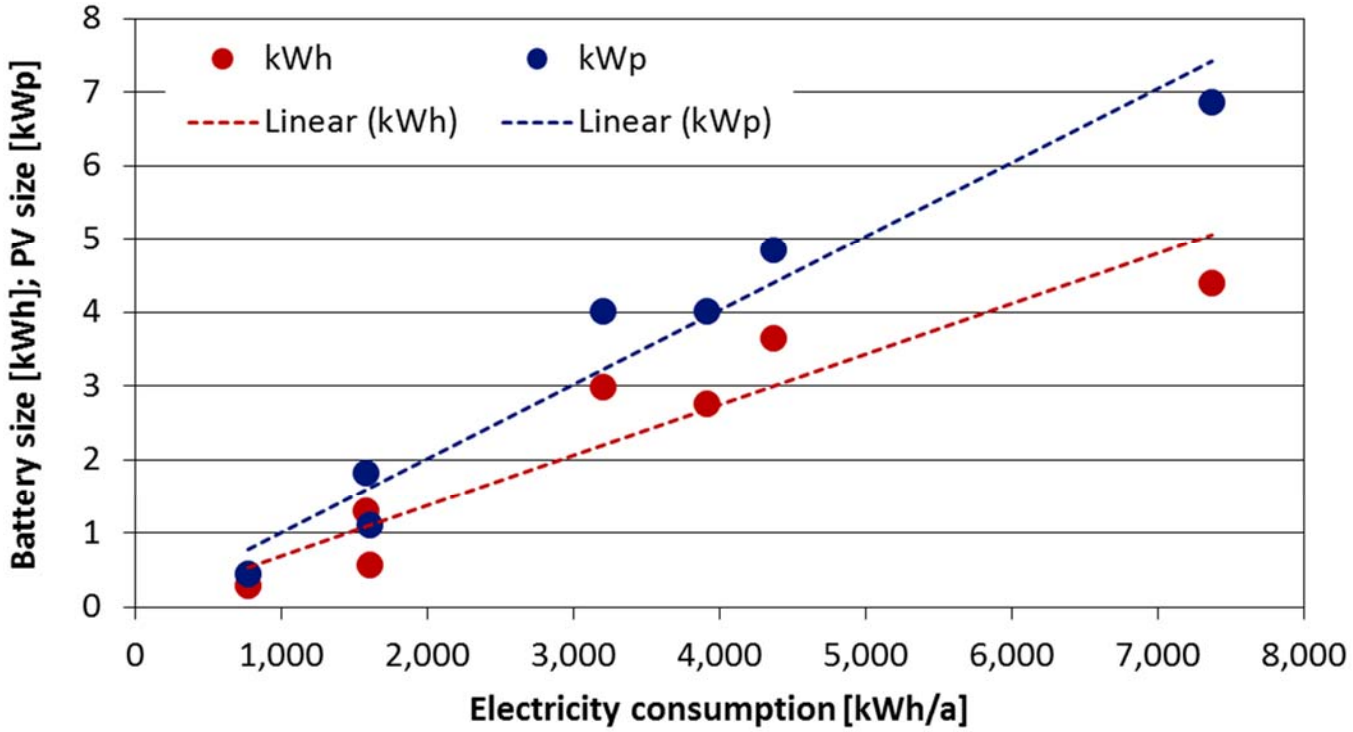
Self-consumption and autarky for different load profiles and cost optimal system configurations



Battery size:	4.4 kWh	3.6 kWh	2.8 kWh	3.0 kWh	0.6 kWh	1.3 kWh	0.3 kWh
PV size:	6.9 kWp	4.9 kWp	4.1 kWp	4.0 kWp	1.1 kWp	1.8 kWp	0.4 kWp

Additional slides

Scenario 2: Results
BaPSi: Cost optimal system configurations



- Approximation for cost optimal system configuration (linearization):
  - PV size = 1 kWp / (MWh/a)
  - Battery size = 0.7 kWh / (MWh/a)